Journal of Environmental Management 293 (2021) 112890

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Mirroring risk to investment within the EKC hypothesis in the United States

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ARTICLE INFO

Keywords:
Investment risk
Risk to investment led-EKC
Environmental sustainability
United States

ABSTRACT

In reality, economic expansion cannot be paced-up enough. This account for a potential trade-off between income and environmental degradation that is expectedly feasible at a maximum level of income. On this note, the current study looked at the validity of income-environmental degradation (Environmental Kuznets Curve, EKC) hypothesis especially amidst risk to investment in the United States over the period 1984–2017. Considering that the burning of fossil fuels constitutes the largest source of Greenhouse gas (GHG) in the United States, this study employed energy carbon emissions as a proxy for environmental quality and as a dependent variable. While the study employed renewable energy production as additional explanatory variable, it implemented the Autoregressive Distributed Lag (ARDL) technique in addition to a set of cointegration techniques. Importantly, the study found that the EKC hypothesis is valid for the case of the United States but not without a non-significant trade-off of risk to investment. Additionally, renewable energy production exhibits a statistically significant and desirable impact on environmental quality in both the short and long-run. In general, the study posited that while environmental sustainability is achievable at maximum level of income, it is likely attainable at the detriment of risk to investment. Hence, this observation should trigger a potential policy mechanism that minimizes risk to investment in light of the attainment of the country's sustainable development goals (SDGs).

1. Introduction

The pace of economic expansion across the globe cannot be more desirable. With the varying levels of global uncertainties, the desirability of attaining economic expansion and especially a doubled level of expansion is not without the social, economic, and even environmental challenges. Considering the slow growth and increasing uncertainties across the globe, the policymakers' long term objectives and priorities of an improved income arising from economic expansion should be void of elements of distortion (Organisation for Economic Co-operation and Development, OECD, 2020a). This is because the 21st century evidence has consistently shown that environmental factors remained one of the drivers of the world economy. For instance, the OECD noted that the gains of economic growth and achieving a long term sustainable growth are significantly dependent on the global climate actions. This is in respect to the assertion that there is always an environmental consequence of economic growth especially at the beginning of output (Stern, 2004). Stern (2004) further maintained that at a certain level ('a hazardous peak'), in some cases, such observation is immediately followed by a desirable environmental impact especially in the long term, thus suggesting an Environmental Kuznets Curve (EKC). Specifically, the increase in output is responsible for the increasing depletion of the natural resources and more emissions. However, faster growth could trigger more sustainable environment, thus suggesting a trade-off between growth in the short-term and environmental sustainability in the longer-term (Stern, 2004; OECD, 2020b).

In the case of the United States, the country has not only remained the largest economy by GDP, it has continued to be the largest emitter of carbon dioxide (CO_2) emissions after China (Environmental Protection Agency, 2019). For instance, the United States Environmental Protection Agency (EPA) further reported that the total gross of the United States' Greenhouse gas (GHG) has increase to 6, 677.8 million metric tons of carbon dioxide equivalents (MMT CO2 Equivalent) in 2018 since 1990, an increase of 3.7 percent. After a decline in the country's GHG emissions in 2017, United States has since 2018 experienced a spike in GHG emissions rising from increased fossil fuels consumption and other

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https://doi.org/10.1016/j.jenvman.2021.112890
Received 12 February 2021; Received in revised form 21 May 2021; Accepted 23 May 2021
Available online 1 June 2021
0301-4797/

human activities. Specifically, the country's main economic sectors: transport, industry, electricity, and others both has continued to be the main source of GHG emissions and as the economy's powerhouse. This reality for the case of the United States suggests that environmental sustainability and green growth approach is a dire policy essential. Hence, achieving a faster growth is not only challenging, attaining environmental sustainability amidst faster growth especially for the developed economies such as the United States remained a herculean goal. Although, population, affluence, and technological innovation are generally known to have environmental effects (Pham et al., 2020), the literature has increasing shown that carbon emissions is on one hand associated with forecasting and country risk forecasting (Chaudhry et al., 2020; Nguyen et al., 2021), and similarly with financial development (Nasir et al., 2019).

The aforementioned motivations, especially regarding the case of the United States presents a hint for this study's objective. Importantly, the current study offers an insight into investment risk-induced EKC hypothesis for the United States. Besides, the study observed the possible impact of risk associated with investment, the cleaner energy production, and economic expansion on energy carbon emissions over the period of 1984–2017. The investment profile index of the Political Risk Services (PRS) is used as the proxy for the associated risk on investment (https://www.prsgroup.com/explore-our-products/international-country-risk-guide/). By achieving the study's objective, this study presents a novel approach with a capacity of contributing and improving the existing literature through these outline paths. To the best of authors' knowledge, the current study is the first in the literature to examine the validity of the risk to investment-led EKC and especially for the United States. In addition, this study employed energy carbon emissions as a proxy for environmental quality in lieu of the carbon dioxide (CO_2) emissions, thus suggesting a novel approach with the motive of understanding the specificity of the country's energy sector emissions. Moreover, this study primarily employed renewable energy production to further understand the role of renewables as a share of energy sources to the country's environmental sustainability.

Accordingly, the followed sections are outlined in this order. Section two is an outline of literature on the drivers of environmental sustainability and EKC especially for the case of the United States. In section three, the data employed and empirical methods are carefully presented. The discussion of the empirical findings and the diagnostic test observation are presented in section four. A concluding remark with policy perspectives is the content of section five.

2. The EKC and environmental quality in United States: a synopsis

Since the study of Grossman and Krueger (1991) and followed by Grossman and Krueger (1995), similar studies have considered the validation of the EKC hypothesis for the different cases across the globe. But, until now few of these studies have focused on examining the EKC hypothesis for the United States (Dogan and Turkekul, 2016; Dogan and Ozturk, 2017; Isik et al., 2019; Ozcan and Ozturk, 2019). For instance, while Isik, Ongan and Özdemir (2019) examined the EKC hypothesis for the ten (10) states in the United States, the study of Dogan and Turkekul (2016) was based on the account of EKC nationally. In their study, Isik et al. (2019) applied the heterogeneously panel estimation method to examine the EKC hypothesis for 10 (California, Florida, Illinois, Indiana, Louisiana, Michigan, New York, Ohio, Pennsylvania, and Texas) Unites States' states over the period 1980-2015. Consequently, the study validated the hypothesis for only Florida, Illinois, Michigan, New York, and Ohio. However, Dogan and Turkekul (2016) considered a national level study and revealed the non-existence of EKC hypothesis because the result showed that income growth actually increases environmental quality in the country.

However, the study of Song et al. (2019) proved otherwise. Additionally, Song et al. (2019) examined both the EKC hypothesis and a decoupling theory for the world's two largest emitters (United States and China). In specific, the study found that the two-dimensional decoupling theory is valid for the United States. Additionally, a $7999.5 and $50980.52 of GDP per person threshold value is estimated for China and the United States respectively. Concerning decoupling, there is a statistical significant evidence of strong decoupling of CO_2 emission from economic expansion in the United States during the periods 2014–2015 and 2015–2016. In a similar study, Farhani and Balsalobre-Lorente (2020) equally established the EKC hypothesis for the United States and India when the role of coal is compared with other energy sources. However, by considering the energy sub-sector component's greenhouse gas emissions for the United States' in a decomposition analysis, Cary (2019) found that the sub-sector level modeling approach does not validate the EKC hypothesis.

Moreover, being one of the climate actions, renewable energy sources has remained an energy efficiency mechanism that presents the capacity to mitigate carbon emissions (Ben Jebli, Ben Youssef & Ozturk, 2015; Al-Mulali et al., 2016; Sharif et al., 2019; Dogan et al., 2020). In the studies of Sawayama et al. (1999) and Ryu (2010), the role of renewable energy production was found to be significant at mitigating GHG emissions. In specific, Ryu (2010) found municipal solid waste (MSW) capable of mitigating GHG emissions especially in South Korea. The study revealed that the production of renewable energy from MSW in South Korea is essential because the country's 57% of household waste and 26% of landfills were being recycled as at early 2000s. In addition, Ryu (2010) posited that energy from waste (EfW) is considered an efficient carbon mitigation alternative since it is a source of direct environmental anthropogenic. Similarly, Sawayama et al. (1999) employed the thermochemical liquefaction for the production of liquid fuel energy from microalgae. Specifically, the study found that the process of thermochemical liquefaction for liquid energy production from Botryococcus braunii exhibit the potential of lowering heating value even as against the renewable sources from Dunaliella tertiolecta.

In general, the validity of EKC for the USA have been extensively examined in the purview of energy portfolio, financial development, trade, tourism, and other related environmental quality determinants in the literature. Although diverse factors have been considered in modelling the validity of EKC for the USA (see Table 1), the risk associated with investment is however considered for the first time in the EKC framework.

3. Methodology and data

3.1. Variable utilization

Considering the outlined objective in this study, a balanced dataset is utilized over the experimental period 1984–2017 for the USA. The energy carbon emission (ECEM) is employed as the environmental variable. Additionally, the real gross domestic product (GDP), the square of real gross domestic product (GDPSQ), renewable energy production (RENP), and the risk to investment vis-à-vis the investment profile (RINVEST) are employed as the explanatory variables. Consequently, data limitation especially for the RINVEST series (giving that the series is available from 1984) is responsible for the short time span or small number of observations. Notwithstanding, the remaining relevant information regarding the variable employed is outlined in Table 2.

Moreover, the correlation among the employed variable is illustrated in the lower part of Table 2. Expectedly, the series demonstrated a correlation especially between the explanatory variables and the dependent variable (ECEM) with a 1% statistical significant level. Furthermore, the common statistics of the series is presented in the upper part of Table 2. The statistics show that the variables employed are distributed normally except for the renewable energy production. Regarding other statistical properties, except for the renewable energy production, the distribution shows that the series are all negatively skewed. Additionally, the difference in the million metric tons of CO_2

Table 1
Highlight of EKC examination in the United States.

Author(s)	Country Specification	Period	Results
Unruh and Moomaw (1998)	The United States and 15 other countries	1950–1992	There is cycling attraction in the (1) 1950s before a sustained growth phase; and (2) a loose attractor established in the 1970s of about 5.8 tonnes, then a decline to slightly lower levels. Is experienced
Isik et al. (2019)	Ten states with highest CO_2 emission in the United States	1980–2015	The EKC hypothesis is valid only in Florida, Illinois, Michigan, New York, and Ohio.
Seppälä, Haukioja and KAIvo-ojA (2001)	Industrialized countries: the USA, Germany, Japan, the Netherlands and Finland	1975–1994	The EKC hypothesis does not hold for aggregate direct material flow in the countries.
Godil et al. (2020)	Examining nexus of transportation services (i.e., passenger and freight) and carbon emissions in the USA	2000M1-2019 M8	The transportation system of the USA helps to reduce CO_2 emissions. The EKC does not hold
Song et al. (2019)	The United States and China	1965–2016	With a threshold value of per capita GDP $50980.52, the validity of EKC is affirmed in the United States·
Iş;ik et al. (2020)	The G-7 economies (the USA inclusive)	1995–2015	The tourism-induced EKC hypothesis is not valid for the United States (only valid for France).
Dogan and Turkekul (2016)	The United States	1960–2010	The EKC hypothesis is not valid with CO_2 emissions.
Pata (2020)	The United States	1980–2016	The EKC hypothesis is valid with both CO_2 emission and Ecological footprint.
Shahbaz et al. (2017)	The United States	1960–2016	The EKC hypothesis and N-shaped relationship between CO_2 emission and growth is valid.
Koirala and Mysami (2015)	The United States	2002 cross-sectional data	The study affirmed ECK hypothesis while illustrating the effect of forest resources on the emission of CO_2.
Aldy (2005)	The State-level and national level for the United States	1960–1999	There is validity of the EKC hypothesis for production- and consumption-based CO_2 emission.
Baek (2016)	The United States	1960–2010	With nuclear and renewable energy utilization, the study validates the EKC hypothesis on in the short run.
Atasoy (2017)	A panel of 50 states in the United States of America.	1960–2010	With income per capita lie between $1292 and $48597, the EKC hypothesis holds in 30 of the 50 states.
Farhani and Balsalobre-Lorente (2020)	China, the United States and India.	1965–2017	The United States and India exhibits the EKC hypothesis amidst coal, gas and oil energy utilization.
Khan and Hou (2021)	The United States.	1980–2015	The study supports the EKC hypothesis.
Roach (2013)	State-level of the United States of America	1980–2010	By accounting for stochastic trends, the EKC hypothesis is valid.
Yang and Qiu (2016)	State-level of the United States of America	1960–2011	The EKC hypothesis is validated in 13 states, N-shaped in 18 states, 6 states indicate increasing linear relationship, 6 states show a decreasing linear relationship, and no cointegration is displayed in the remaining (7) states.
Plassmann and Khanna (2006)	The United States.	1990 cross-sectional data	The EKC hypothesis is valid for coarse particulate matter, but a non-monotonic relationship for carbon monoxide and ground-level ozone.
Anastacio (2017)	North America (Canada, United States and Mexico)	1980–2008	The EKC hypothesis is valid for panel.
Cary (2020)	The United States' sector-level analysis	1990–2011	The EKC hypothesis is almost non-existing.

Table 2
Variables, Unit of measurement and Correlation Matrix.

Variable Name	Code	Unit of measurement	Source
Energy carbon emissions	ECEM	Million Metric Tons of CO_2	EIA
Renewable energy production	RENP	Trillion BTU	EIA
Real gross domestic product	GDP	USD annual rate of 2012	FRED
Investment profile	RINVEST	Score of 12 = low risk, 0 = high risk	PRS

Correlation Matrix

Variables	ECEM	RINVEST	RENP	GDP	GDPSQ
ECEM	1				
RINVEST	0.423*	1			
RENP	0.008	0.523*	1		
GDP	0.67*	0.743*	0.691*	1	
GDPSQ	0.663*	0.747*	0.696*	0.999*	1

Note: BTU, FRED, EIA, and PRS are respectively the British Thermal Units Federal Reserve Bank, the US Energy Information Administration, and the Political Risk Service while CO_2 is carbon dioxide. Also, ecem, renp, rinest, gdp, and gdpsq are the energy carbon emissions, renewable energy production, risk to investment, the real gross domestic product, and square of the gross domestic prooduct respectively. The * indicate the 1% statistical significance level.

from energy sources, the renewable energy production (in trillion Btu), and the real GDP illustrates the significant change in the variable over the period of investigation (1984–2017). The time series plot of the variables in Fig. 1 affirms this observation.

3.2. Empirical model

In the literature, early studies have illustrated the determinants of environmental degradation (Dietz and Rosa, 1994; York et al., 2003; Rosa et al., 2004). A continuum of studies have further the scope to accommodate other potential drivers of environmental sustainability such as the information and communication technology (ICT), energy sources, corruption, human development index, total resource rent, fertility, immigration, democracy; political institution policy, globalization, tourism, partisan conflict, among others (Shahbaz et al., 2013; Asongu et al., 2018; Ahmad et al., 2018; Shahbaz et al., 2018; Sarkodie and Adams, 2018; Alola, 2019 a&b Alola and Kirikkaleli, 2019; Bekun et al., 2019; Ozturk et al., 2019; Usman et al., 2019; Udemba, 2019; Adedoyin et al., 2020; Adedoyin et al., 2020a,b; Joshua and Alola, 2020; Kose et al., 2020; Saint Akadiri and Alola, 2020; Usman et al., 2020; Nasir et al., 2021).

A handful of the aforementioned factors have been implemented in the framework of EKC but not with investment risk. Consequently, we proceed by examining the EKC hypothesis as induced by the risk to investment on environmental sustainability is investigated with a carbon function model that is presented as:

$$ECEM = f(renp, gdp, gdpsq, rinvest) \quad (1)$$

Nevertheless, the natural logarithmic transformation is applied in order to attain direct elasticities through an empirical equation in the form of:

$$\ln ECEM_t = \beta_0 + \beta_1 \ln renp_t + \beta_2 \ln gdp_t + \beta_3 \ln gdpsq_t + \beta_4 \ln rinvest_t + \varepsilon_t) \quad (2)$$

where β_0 is the constant (intercept) and β_1 β_2, β_3, and β_4 illustrate the impact of the logarithmic values of *renp*, *GDP*, square of GDP (*GDPSQ*), and investment profile (RINVEST) on the quality of the environmental for each period $t = 1984, 1985, \ldots, 2017$ with constant term (ε) that is expectedly normal and independent and identically distributed.

3.3. Methodology

3.3.1. Priori tests

As a priori test, the unit root test is conducted such that the order of integration of the series is revealed. The Augmented Dickey-Fuller (ADF) by Dickey and Fuller (1979) and the Lee and Strazicich (2003) (LS) unit root tests are employed (see Table 3). The employed LS unit root test compliment the ADF technique by accounting for possible two break dates that might affect the efficiency of the conventional test approaches. In so doing, the result of the LS specifically revealed the break dates for each of the variable (see Table 3). Importantly, both the GDP and ECEM expectedly present evidence of time break that coincides with the period of the global financial crisis (GFC) i.e between 2007 and 2012. But, because of space constraint, it is difficult to provide the step-by-step procedure for the Dickey and Fuller (1979) and the Lee and Strazicich (2003).

In light of the priori investigation, evidence of at least one cointegration equation as shown by the Johansen and Juselius (1990) cointegration test is illustrated in Table 4. Therefore, the study proceeds with further cointegration tests with the Fully-Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), the Canonical Cointegrating Regression (CCR) techniques, and followed by the short and long-run investigation by the ARDL technique.

3.3.2. The FMOLS, DOLS and CCR

Here, the DOLS and the advantages of the FMOLS estimators are employed to provide the first statistical evidence of cointegration (Phillips and Hansen, 1990; Saikkonen, 1992; Stock and Watson, 1993). Because it accounts for a small sample bias by using the leads and lags of first-differenced regressors, the estimators are preferred to the OLS. Hence, the autoregressive form is given as:

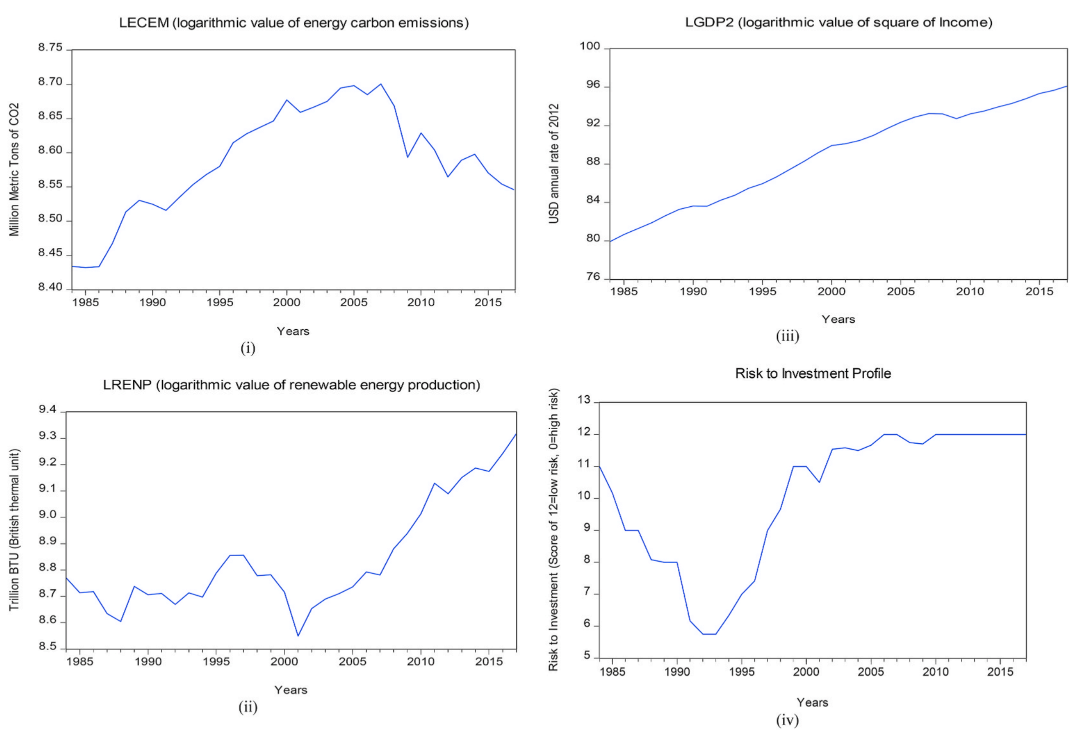

Fig. 1. The variable-specific plots.

Table 3
Statistical properties 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
RENP	7037.826	6465.285	11140.20	5161.724	1561.477	1.187	3.200	8.045[y]
GDP	12824.37	13196.53	18108.08	7632.812	3233.882	−0.058	1.645	2.621
RINVEST	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[x]	I (1)
lRENP	0.641	−1.333	−5.439[x]	−5.897[x]	I (1)
lGDP	−1.440	−1.375	−3.446[y]	−3.679[y]	I (1)
lGDPSQ	−1.300	−1.458	−3.505[y]	−3.667[x]	I (1)
RINVEST	−0.667	−2.618	−3.998[x]	−3.967[x]	I (1)

Lee Strazicich	Level **Test statistic**	**Break date**	First Difference **Test statistic**	**Break date**
lECEM	−6.917[y]	2004, 2007	−8.351	2004, 2008
lRENP	−6.809[x]	1999, 2011	−5.854[z]	1994, 1997
lGDP	−9.740[x]	1996, 2007	−6.240[z]	2003, 2007
lGDPSQ	−9.672[x]	1995, 2007	−6.122[z]	2004, 2007
INVEST	−12.620	2000, 2003	−10.248	1996, 2005

Note: The [x], [y], and [z] are statistical significance at 1%, 5%, and 10% respectively. Also, ecem, renp, rinest, gdp, and gdpsq are the energy carbon emissions, renewable energy production, risk to investment, the real gross domestic product, and square of the gross domestic prooduct respectively while *l* is the logarithmic values.

Table 4
Johansen and Juselius (1990) cointegration test with linear deterministic trend.

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigen value	Trace Statistic	Critical Value	Prob.**
None *	0.665	81.734	69.819	0.004
At most 1**	0.483	46.731	47.856	0.064
At most 2	0.383	25.644	29.797	0.14

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	Critical Value	Prob.**
None *	0.665	35.003	33.877	0.037
At most 1	0.483	21.087	27.584	0.271

Note: * and ** represents the 1% and 5% statistical significance level.

$$x_t = x_{t-1} + \varepsilon_t \quad (3)$$

such that x_t (*rinvest*, *renp*, *gdp*, and *gdpsq*) of parameter vector β for all x_t such that t = 1984, 1984, …, 2017 and ε_t is the error terms.

Thus, the FMOLS model is expressed as:

$$\widehat{\beta}_{FMOLS} = \left\{ \sum \sum_{t=1}^{T} (\mathrm{xt} - \overline{x})(\mathrm{xt} - \overline{x}) \right\}^{-1} * \left\{ \sum \sum_{t=1}^{T} (\mathrm{xt} - \overline{x}) \left(\overline{ECEM} - T\Delta\varepsilon\mu \right) \right\} \quad (4)$$

However, the DOLS estimator augments the cointegrating regression and presented as:

$$ECEM_t = \alpha + \beta x_t \sum_{k=-p1}^{p2} \lambda k \ \ \Delta ECEM\, \mathrm{t-k} + \sum_{k=-q1}^{q2} \gamma k \, \Delta \, \mathrm{x\, t - k} \ + \mu_t \quad (5)$$

with intercept (α), cointegrating vectors (β), and dynamic vectors (γ) of dependent and independent variables are respectively represented as are. Additionally, the CCR estimator is employed such that the results from these aforementioned techniques are illustrated in Table 5.

3.3.3. The ARDL: short and long-run estimate

In complimenting the statistical evidence of cointegration as demonstrated by the aforementioned techniques, the advantage of the Autoregressive Distributed Lag (ARDL) approach is employed to estimate the short-run and long-run relationship. The ARDL is considered appropriate for this case because it is efficient in estimating both a small and large sample size observation. In addition to the FMOLS, DOLS and CCR, the ARDL of Pesaran et al. (2001) estimate presents the short-run and long-run relationships. Although the step-wise illustration of the method is not provided in this text, the result of the ARDL estimate is illustrated in Table 5. Moreover, the test for the EKC hypothesis is inferred from the estimation equation.

Table 5
ARDL estimates.

	lRENP	*lGDP*	*lGDPSQ*	*RINVEST*	*ECT (-1)*
Long-run	−0. 2500*	10.9821*	−0.5677*	0. 0002	
Short-run	−0. 0250	6.0180**	−0.2619**	0.0001	−0.5480*
Robustness evidence					
				I0 bound	I1 bound
Bound test	F-statistics = 6.1508*	(k = 4)	5%	3.74	5.06
Wald test	F-statistic	12.3774*		χ^2	61.8871*
Residual diagnostics					
Serial correlation LM test			Heteroscedasticity test		
Chi-square (*p-value*)	0.1623 (0.6870)			4.1030 (0.7679)	
Normal (Jarque-Bera)	0.3503 (0.8393)				
Skewness	0.2495		Kurtosis	2.9234	
Robustness check with FMOLS, DOLS and CCR					
	lRENP	*lGDP*	*lGDPSQ*	*RINVEST*	*C*
FMOLS	−0.02512	6.3190*	−0.2770*	0.0003	−24.3593*
	R-Square: 0.97		Standard Error of Regression: 0.014		
DOLS	−0.0250	6.0180*	−0.2619*	−0.0492*	−23.1755*
	R-Square: 0.97		Standard Error of Regression: 0.014		
CCR	−0.0133	6.5028*	−0.2855*	−0.0508*	−25.0513*
	R-Square: 0.97		Standard Error of Regression: 0.014		

3.3.4. Robustness and diagnostic tests

A set of diagnostic test is employed to validate the results of the estimation. For instance, the coefficient diagnostic with the Wald test is significant. The Wald test show a significant evidence of short-run relationship among the estimated variables. Also, the serial correlation by Breusch-Godfrey serial correlation Lagrange Multiplier test and the heteroskedasticity by Breusch-Pagan-Godfrey heteroskedasticity test were performed and it presented a favourable outcome (see Table 5). This shows that there is statistical evidence that the estimated model is normally distributed without serial correlation and heteroskedastic concern. Additionally, a stability test with the CUSUM (cumulative sum) and CUSUM of squares of Fig. 2 revealed that the estimated model (from equation (2)) is stable. Furthermore, the impulse response especially from the ECEM due to shock from RENP, GDP, and the RINVEST is illustrated in Fig. 3. It implies that the renewable energy production exhibits an environmental friendly characteristic since the response in energy carbon emissions by shocks coming from the renewable energy production is negative. Interestingly, energy carbon emission exhibits an inverted U-shaped response to economic growth (GDP). This because the energy carbon emission initially responds positively to shocks from the GDP but the response is negative in the case of GDPSQ. Moreover, the ARDL estimate in equation (4) is validated for robustness purpose by using only RENP, GDP and RINVEST as the dependent variables. The result presented further show significant evidence of cointegration (see Table 6).

4. Results and discussion

The priori tests presumed cointegration evidence that necessitated the implementation of the FMOLS, DOLS and CCR cointegration approaches. As indicated in Table 5, a follow-up test to examine the short-run and long-run relation further affirmed the relationship between the investigated variables. Specifically, the risk to investment is interpreted by using the rating scale adopted for investment profile (INVEST) in PRS. The investment profile (INVEST) is the risk to investment rating measured by the Political Risk Service (PRS). Thus, the investment profile is ranked such that the highest number of rank points (12)

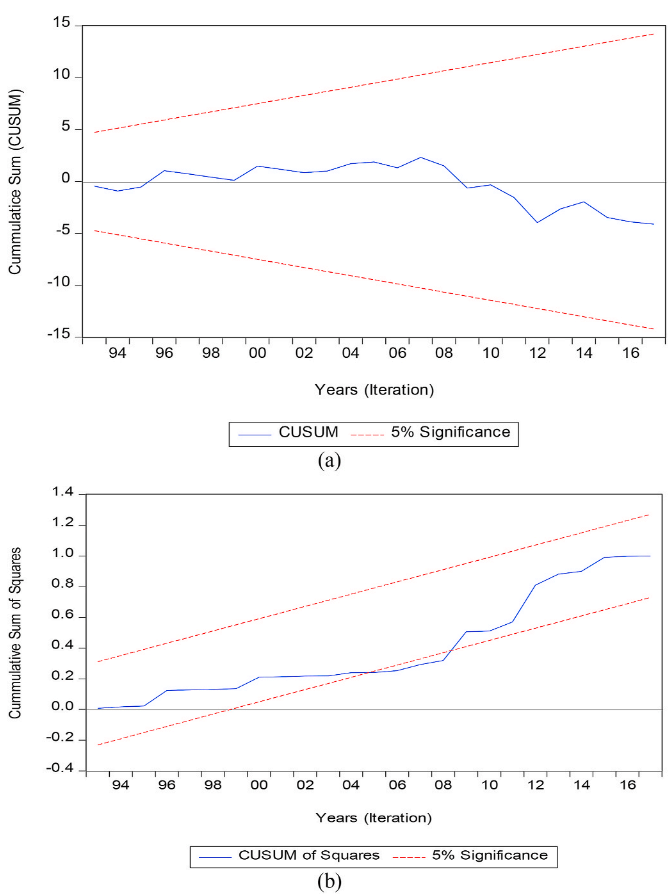

Fig. 2. The cumulative sum (a) and cumulative sum of Squares (b) stability diagnostics.

indicates the lowest potential risk for that component while the lowest number (0) indicate the highest potential risk to investment. For instance, the short- and long-run ARDL results posit that risk to investment (INVEST) exert a positive and non-significant effect on energy carbon emissions. Importantly, the impact of GDP and GDPSQ on ECEM are both significant in the short- and long-run but respectively positive and negative. The implication is that a 1% increase in the GDP (amidst higher rank point correspond to lower risk) is responsible for a respective 6.0180% and 10.9821% increase in the Million Metric Tons of CO_2 from energy sources in the short-run and long-run. It further meant that more economic expansion in the United States will drive and cause more pollution arising from the emission of CO_2 of energy source. Expectedly, evidence from previous literature have also shown that an increased economic expansion especially in the United States aggravates environmental degradation (Alola, 2019 a&b; Umar et al., 2021).

Similarly, in the presence of high risk to investment, when income (economic expansion) is doubled (i.e GDPSQ), it triggers a statistical significant decline in energy carbon emissions in both the short- and long-run. Specifically, a 1 per cent increase in the GDPSQ yields a 0.2619% and 0.5677% decline in the Million Metric Tons of energy CO_2 emissions. While this result affirms the EKC hypothesis for the case of United States, it posits a desirable outlook for the country's environmental sustainability. Evidently, Isik et al. (2019) similarly found significant evidence that the EKC is established for investigated five of the ten states of the United States. Additionally, the study of Song et al. (2019) revealed that the GDP satisfies the inverted U-shaped property for the United States while the evidence of the U-shaped hypothesis was not significant in the study of Dogan and Turkekul (2016). Meanwhile, as observed in Table 6, and without the influence of a doubled income in the model (i.e without the EKC framework), a low risk to investment is desirable for improving environmental quality in both the short- and long-run.

Regarding the impact of renewable energy production, this investigation found that renewable energy production is responsible for a respective 0. 025% and 0.250% reduction in the energy carbon emissions in the short- and long-run whenever there is a 1 per cent increase in RENP. This statistical evidence translate that a more sustainable environment is achievable by the United States through a paradigm shift in the energy portfolio especially toward the development of renewables. This desirable role of renewable energy production in mitigating the GHG has been expressed in previous studies (Sawayama et al., 1999); Ryu (2010); Chen et al. (2019). Specifically, Sawayama et al. (1999) found that liquid fuel from Botryococcus braunii (a renewable energy source) is capable of causing significant CO_2 mitigation.

5. Conclusion and policy perspective

There is a persistent urgency for the containment and mitigation of climate change effects among the developed economies. For instance, the enormous GHG emissions by the United States remain a concern for the government, policymakers and intergovernmental agencies. Thus, investigating the validity of an investment risk-induced U-shaped hypothesis to ascertain the environmental sustainability status of the country is timely. In the concept of risk to investment, this study found that the impacts of economic growth (GDP), square of the GDP, and risk of investment is statistically significant over the experimental period of 1984–2017. Importantly, the result of the investigation posits that economic growth (GDP) worsens the environmental quality in both the short and long-run while the environmental condition improves as the expansion is doubled (GDPSQ). The implication is that the EKC hypothesis is established amidst investment risk for the United States. Nevertheless, the production and of renewable energy expectedly improves environmental sustainability in the United States, thus inspiring a suitable and robust energy diversification policy for the country. From this point of view, the result of the current study suggests policy lines and recommendation for the climate actors and stakeholders.

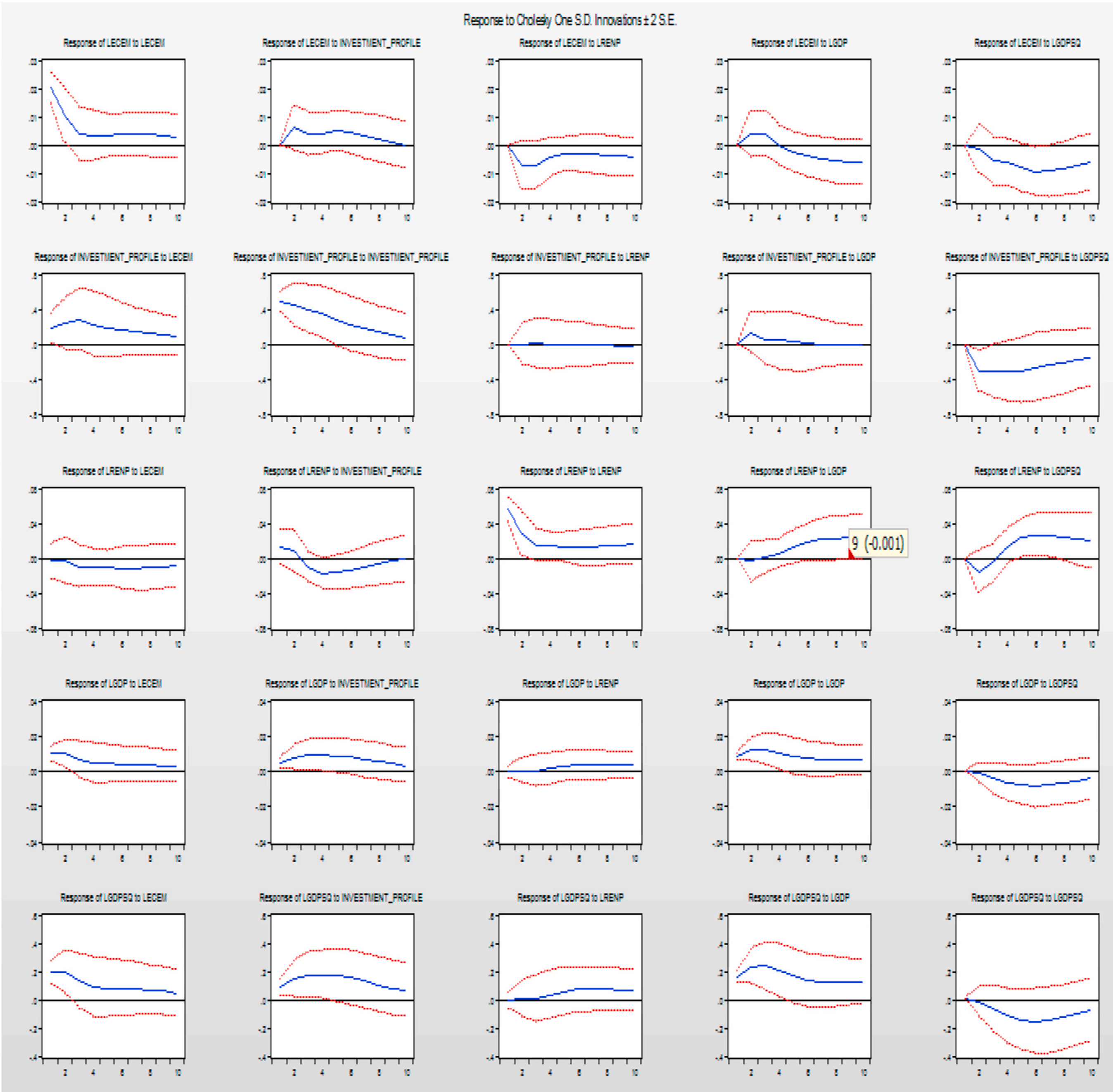

Fig. 3. Impulse Response from each variable to the others.

Table 6
ARDL estimate.

Model A	lRENP	lGDP	RINVEST	ECT (−1)
Long-run	−0.444*	−0.493*	−0.014***	
Short-run	−0. 026	1.270*	−0.004***	−0.307*
Serial correlation LM test			**Heteroscedasticity test**	
Chi-square (p-value)	0.162 (0.687)		0.790 (0.586)	
Jarque-Bera statistics	0.786 (0.675)			
Skewness	−0.188		Kurtosis	3.656

5.1. Policy and recommendations

Going by the result of the impact of income or economic expansion (GDP) on environmental quality in the United States i.e desirable environmental effect of economic expansion, this suggests that an inclusive approach toward economic growth should be fostered and sustained both across state-level and national level. Importantly, the while pursuing economic development, priority should be placed on the low-risk pathway in all economic activities in order to achieve a sustainable development. To further boost the capacity of the country's main sectors, other salient sectors of the economy could be further harnessed in order to attain more than double of the current GDP. While primarily focusing on economic expansion, there should be more coveted effort directed at providing and guiding investors on risk assessment, thus minimizing potentially high risk associated with low-carbon energy investment and market. Although the current share of renewable energy production is good at mitigating environmental hazard, further energy-related and climate action policies such as low tax on energy technologies could further sustain the current achievement(s) on energy efficiency.

Since the current study has not specifically considered the risk associated with energy investment, future research can complement this study by employing the impact of energy investment risk on environmental sustainability. Moreover, by extension, future study could also model the investigation in a non-linear framework. Additionally, future study can focus on investigating the state-level validity of the trend associated with the relationship between environmental quality and economic expansion for the United States.

Authors contributions

Andrew Adewale Alola: Conceptualization, Methodology, Software, Data curation, Writing, Visualization. Ilhan Ozturk: Supervision, Writing, Reviewing and 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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