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# Clean energy development in the United States amidst augmented socioeconomic aspects and country-specific policies

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A B S T R A C T

The drive toward the attainment of sustainable environment globally through clean energy development or energy efficiency is not more desirable than in the 21st century, thus the existential policy moderations of economic, trade and security mechanisms. On this premise, and foremost in the literature, the current study examined the country-specific (for the United States) and the driving impacts of economic policy uncertainty, trade policy and national security on the development of cleaner energy sources by using quarterly frequency time series data for period 1990:Q1-2018:Q2. By employing economic expansion as additional factor, the study implemented the Autoregressive Distributed Lag Bounds Testing approach to reveal interesting results: (1) there is a significant evidence that economic expansion, economic policy uncertainty (EU), trade policy (TP), and national security (NS) exhibits long term properties in common, (2) the increase in economic expansion and NS effectiveness significantly yields more cleaner energy development, and (3) a more tightened TP and high EU are statistically significant and detrimental to the development of clean energy. The Granger causality evidence substantiates the role economic expansion, TP, EU and national security in renewable energy development. Generally, the study posits cleaner and energy efficiency policy directive for policymakers in the United States and other countries of interest from the framework of climate action and sustainable development.



## 1. Introduction

Renewable energy sources on the other hand, if well developed, executed and managed has the tendency and capacity to meet many countries environmental expectation from the perspective of consumption and production with little or no amount of environmental pollutions/hazards. While the concern about global energy mix especially from the perspective of production (supply) and consumption (demand) has continued to generate debate among the scholars, governments, intergovernmental agencies, and policymakers, the fact remains that clean energy sources are more environmental friendly. Hence, it is paramount to note that, most of these primary energy sources are temporary (Center for Sustainable Systems, 2019). In many countries across the globe, energy-mix policy alone as reported in energy literature appears not to be efficient in curbing and curtailing associated environmental hazards. The reason for this result is associated with increasing consumption of non-renewable (fossil fuels) energy, which among others includes; radioactive waste, severe air pollution, acidic rain, global warming/climate changes, freshwater consumption (CSS, 2019) and bush burning as experienced in Australia and California [1]. Going by statistics of the CSS (2019) report, about 80% of the United States energy consumption are sourced from non-renewable energy sources (fossil fuels), 11% is sourced from renewables, while 8.3% is from nuclear energy sources (CSS, 2019). This trend purely indicate that the United States is yet saddled with the enormous task of improving the country's energy portfolio. However, with the projection of an increase in renewable energy sources consumption between 2020 and 2050 (see Fig. 1) at an average yearly rate of 1.8%, this growth is huge when compared with the overall annual growth rate of energy consumption of 0.2% (Center for Climate and Energy Solution, 2020).

The categorization of the determinants of cleaner energy development as suggested in extant studies is one of the many

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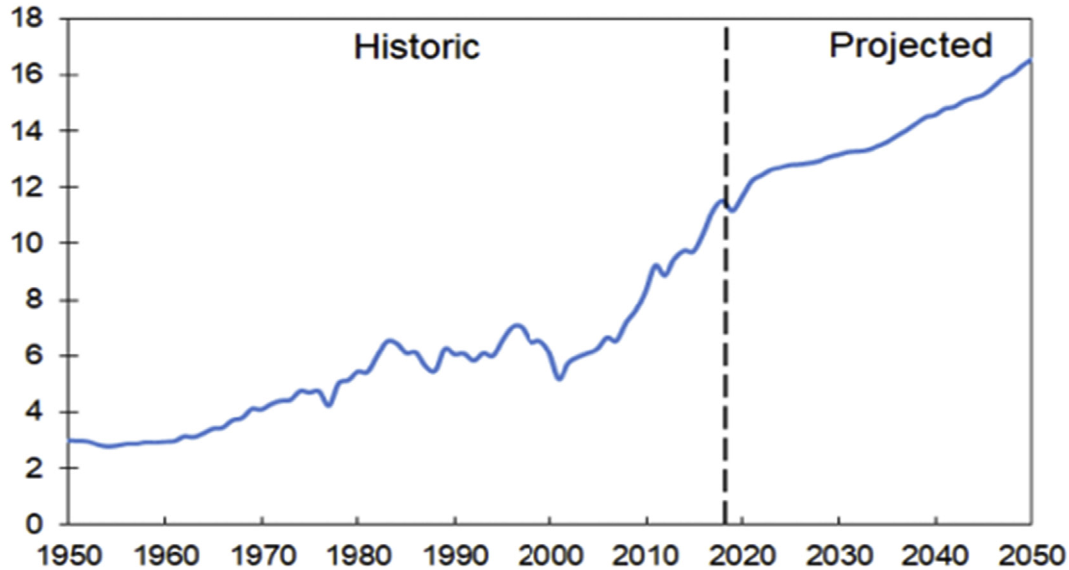


**Fig. 1.** Renewable energy consumption (quads) United States renewable energy consumption: Historic and projected. Source: EIA annual energy outlook, 2019.

climate action mechanisms [2–5]. Examining trade policy impact in energy-trade-environment-growth relationship is crucial in energy literature. Trade policies have also been used as fiscal policy tool to protect infant renewable and cleaner energy industries, to be precise, the manufacturing industries/sector [6]. These policies could be country-specific, depending on the financial commitment as specified by respective nations, and the dimension of implementation of such policy at a particular point in time (International Energy Agency (IEA)). Similarly, the expectation that economic policy uncertainties drive energy sources is well documented in energy literature (see Refs. [2,7–10]. We expect that economic policy uncertainty will inversely affect the development of alternative energy sources. The focus on national security in this case is widen the scope of the relevance of national beyond security to life and property, but to include the nexus between the country's foreign policy and the global energy market [11,12]. Increase in national security effectiveness generates the safety of work force that would work in the line of chain of the development of renewable energy sources, energy-saving and efficient technologies. The expectation that real income drive renewable energy sources development is well documented in energy literature (see Refs. [1,2,13–17]. We expect that real income will positively influence development of renewable energy sources.

Importantly, given the perspective of economic policy uncertainty (EPU) in the concept of energy, specifically, oil price volatility and dynamics has been well established in the literature [7,8,10]. According to Ref. [8]; decrease in the US EPU enhances innovations in the oil production. A shock in the US EPU is expected to have significant impact of its energy sector. In the same context, it is expected that an improvement in national security is geared at yielding a decrease in economic uncertainty and/or volatility vis-à-vis reducing EPU, thus promoting economic growth and stability. Similarly, sound trade policy adjustment is expected to enhance development of alternative energy sources, most especially in the advanced economies such as the United States, both in the immediate and future generation. An insightful analysis on the interactions among the aforementioned factors are examined in this study from the perspective of how the factors influence and drive renewable energy sources development.

In the current case, this study empirically augment trade policy index, EPU index and national security index as country-specific socioeconomic and political factors that drive renewable energy development in the United States over the period 1990:Q1 to 2018:Q2. In order to empirically substantiate the impact of these variables, this study advance the renewable energy development framework of [2] in addition to Ref. [9] by using the Autoregressive Distributed Lag Bounds Testing approach. Billed to significantly contribute to the literature, the current study is designed to explore the novelty associated with economic policy uncertainty and national security in the concept of renewable energy sources development. Importantly, the consideration of EPU in this context is due to the vulnerability of the global economy to shocks resulting from economic and financial crisis (such as the Global Financial Crisis (GFC), global health emergency (such as the 2019 coronavirus pandemic), and other natural and unforeseen events. Evidently, the 2008–2010 GFC that originated in the United States and the September 11, 2001 terrorist attack have not only shown the vulnerability of the United States economic sectors to unforeseen events, it specifically depict the vulnerability of the country's energy sources development. Thus, the advancement of related studies [2,9] in the current context substantiate the role of socioeconomic and political factors vis-à-vis trade policy, economic policy uncertainty, and national security in renewable energy development.

Interestingly, the current study found that trade policy has a direct relationship with renewable energy development. In line with the result and economic expectation, this study revealed that trade policies supports clean energy thus stimulating renewable energy development, and vice versa depending on the design of such trade policies. This is in accordance with the study of [6]. In addition, EPU exhibited an inverse relationship with renewable energy development. By implication, an increase in economic policy uncertainty would harm or delay renewable energy development, thus affirming the study of [8]. Lastly, national security and real income show positive and significant relationship with renewable energy development. An increase in the real income and national security effectiveness is expected to compensate for high cost of renewable energy-saving technologies against the moderate price but severe consequences of the non-renewable energy utilization.

The next parts of the study are as follow: Section 3 is on data description and empirical methods adopted. Section 4 discusses empirical results, while section 5 concludes the study with attendant policy recommendations and suggestions.

**Table 1**
Unit root test and Common statistics.

| Factors | Average | Median | Maximum | Minimum | Skewness | Kurtosis | Jarque-Bera |
|---|---|---|---|---|---|---|---|
| *Rene* | 530.684 | 529.678 | 640.215 | 430.609 | 0.197 | 2.193 | 3.832 |
| *Rgdp* | 13850.59 | 14275.34 | 18514.60 | 9269.367 | −0.209 | 1.822 | 7.419** |
| *Tp* | 162.249 | 114.009 | 1094.156 | 25.95176 | 2.880 | 13.691 | 700.535* |
| *Eu* | 101.296 | 93.363 | 271.832 | 45.527 | 1.200 | 5.143 | 49.162* |
| *Ns* | 102.388 | 77.152 | 758.263 | 26.123 | 4.434 | 31.834 | 4322.742* |

| Stationarity Evidence | | Level | | First difference | |
|---|---|---|---|---|---|
| **ADF** | *with c* | *c and t* | *with c* | *c and t* | *Conclusion__* |
| Rene | −1.061 | −2.345 | −3.510* | −3.442** | I (1) |
| Rgdp | −3.348 | −1.445 | −4.704* | −6.954* | I (1) |
| Tp | −3.365** | −3.684** | −15.347* | −15.291* | I (0) |
| Eu | −3.848* | −5.349* | −1.047* | 0085 | I (0) |
| Ns | −1.652 | −4.778* | −9.541* | −6.385* | I (0) |
| **KPSS** | | | | | |
| Rene | −1.0613 | −2.3451 | 0.118 | 0.110 | I (1) |
| Rgdp | −3.3475 | −1.4445 | 0.089 | 0 .096 | I (1) |
| Tp | 0.311 | 0.195** | 0.071 | 0.05 | I (0) |
| Eu | −1.047* | 0085 | 0101 | 0091 | I (0) |
| Ns | 0.904* | 0.102 | 0.375 | 0.0857 | I (0) |

Note: c, t, and Level respectively indicates intercept, trend and the level. The * and ** are statistical significance at ≤ 0.01 and ≤0.05 level with 81 number of observations. Additionally, *NS, EU, TP* and *Rgdp* are respectively the National Security, Economic Policy, Trade Policy, and the Real Gross Domestic Product (representing the economic growth).

## 2. Variable estimate and methods

### 2.1. Data estimate

This study used the independent variables; real gross domestic product (*rgdp*), trade policy (*tp*), economic uncertainty (*eu*), and the national security (*ns*) to examine the determinants of renewable energy development (*rene*) in the United States for the experimented quarterly frequency period (i.e 2nd quarter of 1990 to 2nd quarter of 2018). The indices from the US policy categories were employed as proxies for the examined variables except for the *rdgp*. Specifically, the trade policy, economic uncertainty (*eu*), and the national security are the respective proxies of trade policy index, economic policy uncertainty index, and the national security index and such that comprises of the sub-indexes that were extracted from the news data. Additional information of the variables employed is given as follows:

- The indexes for trade policy (*tp*), economic policy (*eu*), and national security (*ns*) are respectively employed for the United States' trade policy, the country's degree of uncertainty in its economic policy, and the measure of the country's national security.
- Renewable energy usage (*rene* is measured in Btu) proxy the renewable energy development (from the US Energy Information Administration, 2018).
- The Federal Reserve Bank of ST. Louis (2018) is the real Gross Domestic Product (*rgdp).*

In the current study, the variable *rgdp* is incorporated to account for other unobserved such that the estimation model is less affected with an omitted variable bias. Moreover, the statistical inference and the evidence of correlation among the estimated variables are implied in Table 1 and Table 2.

**Table 2**
Correlation matrix.

| Variables | RENE | RGDP | NS | EPU | TP |
|---|---|---|---|---|---|
| RENE | 1.000 | | | | |
| RGDP | 0.527* | 1.000 | | | |
| NS | −0.296* | −0.595* | 1.000 | | |
| EPU | −0.489* | −0.634* | 0.821* | 1.000 | |
| TP | −0.348* | −0.150 | 0.065 | 0.223** | 1.000 |

**Note**: **Note**: The *NS, EU, TP* and *Rgdp* are respectively the National Security, Economic Policy, Trade Policy, and the Real Gross Domestic Product (representing the economic growth). The * and ** are statistical significance at ≤ 0.01 and ≤0.05.

### 2.2. Empirical methods

In the extant literature, especially for the country-specific cases, different factors have been linked with the development of alternative and low-carbon energy portfolio [2,9,18–20]. In measuring the development of renewable energy, handful of determinants has been considered in the aforementioned studies and other related studies. However, considering the decomposition of renewable energy growth into political factors, socioeconomic factors, and the country-specific factors by Ref. [2]; the current study further incorporates trade policy, economic uncertainty, and national security in the renewable energy model of [9]. For the case of the current study. The empirical model is presented as:

$$rene_{\ t} = f\,(rgdp_t,\ ns_t,\ eu_t,\ \mathrm{e}) \tag{1}$$

such that a logarithmic transformation of the above expression become

$$\mathrm{ln}rene_t = \beta_0 + \beta_1 \mathrm{ln}rgdp_t + \beta_2 ns_t + \beta_3 eu_t + \varepsilon_t \beta_1 \beta_2 \beta_3 \tag{2}$$

where t = 1990Q1,1990Q2 …, 2018Q2, and ε = error term that is is iiid ~ $N$ (μ, $\sigma^2$). Also, the $\beta s$ (i.e $\beta_1$, $\beta_2$, and $\beta_3$) are respectively the response rate of the explanatory variables (*rdgp*, *ns*, and *eu*) where $\beta_0$ is the constant.

#### 2.2.1. Preliminary tests

A few priori tests are performed before applying the ARDL estimation technique to investigate the long- and short-run

**Table 3**
Johansen, FMOLS, DOLS and CCR results.

| Trace | | | | |
|---|---|---|---|---|
| No. of CE(s) | Trace 0.05 Eigen value | Statistic | Critical Value | Prob.** |
| None * | 0.260 | 79.389 | 47.856 | 0.000 |
| ≤1* | 0.210 | 45.898 | 29.797 | 0.000 |
| ≤2 * | 0.144 | 19.700 | 15.495 | 0.011 |
| ≤3 | 0.022 | 2.486 | 3.841 | 0.115 |
| Maximum Eigenvalue | | | | |
| No. of CE(s) | Max-Eigen Eigen value | 0.05 Statistic | Critical Value | Prob.** |
| None * | 0.260 | 33.491 | 27.584 | 0.008 |
| ≤1 * | 0.210 | 26.198 | 21.132 | 0.009 |
| ≤2 * | 0.144 | 17.214 | 14.265 | 0.017 |
| ≤3 | 0.0221 | 2.486 | 3.841 | 0.115 |

| | NS | lnRENE | EU | Constant |
|---|---|---|---|---|
| FMOLS | 0.001** | 0.146** | −0.002* | 5.021* |
| DOLS | 0.001*** | 0.141*** | −0.002* | 5.085* |
| CCR | 0.001** | 0.148** | −0.002* | 5.003* |

Note: The *NS, EU, TP* and *Rgdp* are respectively the National Security, Economic Policy, Trade Policy, and the Real Gross Domestic Product (representing the economic growth). The * and ** are statistical significance at ≤ 0.01 and ≤0.05.

relationship between the series. In this case, the unit test techniques[1] are employed at levels and after first difference in order to verify the behaviour of the series over the experimental period. The unit root result favours the use of the bounds testing to examine the statistical evidence of cointegration. The cointegration test employed presented unrestricted cointegration Rank Test for the Trace and Maximum Eigenvalue [21,22]. Although, this approach is not presented step-wise here because of space constraint, the result displayed in Table 3 shows a statistical significant evidence of two (2) cointegration equation. Moreover, the FMOLS (Fully-modified Ordinary Least Square), the DOLS (Dynamic Least Square), and Canonical Cointegrating Regression (CCR) are all implemented to specifically advance the evidence of long-run nexus of the explanatory factors and the dependent factor. In Table 3, the results of the Johansen cointegration in addition with the long-run estimation of the FMOLS, DOLS, and CCR are illustrated. While the coefficient estimate for FMOLS is estimated from

$$\widehat{\beta}_{FMOLS} = \left\{ \sum \sum_{t=1}^{T} (\mathrm{xt} - \overline{x})(\mathrm{xt} - \overline{x}) \right\}^{-1} * \left\{ \sum \sum_{t=1}^{T} (\mathrm{xt} - \overline{x})(\overline{RENE} - T\Delta\varepsilon\mu) \right\} \tag{3}$$

By implementing equation (2), equation (3) is further modified to examine the coefficient estimate for DOLS and CCR as implemented in the studies of [23–25]. Implicatively, the results from the aforementioned techniques strongly supports statistical evidence of long-run cointegration as displayed in the lower part of Table 3.

### 2.2.2. ARDL approach for long- and short-run

Considering that the series are of mixed order $I(0)$ and/or $I(1)$ (see the result in Table 1) and exhibits long-run nexus (see Table 3), the result paved way for the suitability of the ARDL. Following this evidence, the ARDL bounds testing method of [26] is employed. The ARDL test approach is also suitable because it presents evidence of long-run and short-run relationship. Given the aforementioned advantages in addition to the suitability of the ARDL technique for a small sample size dataset, we proceed to apply the ARDL approach to achieve the underlying objectives.

For this reason, the ARDL bound test approach is implemented from equation (2) such that

$$\begin{aligned} \Delta rene_t = {} & \beta_1 + \beta_{rene} rene_{t-1} + \beta_{rgdp} rgdp_{t-1} + \beta_{eu} eu_{t-1} + \beta_{ns} ns_{t-1} \\ & + \sum_{i=1}^{p} \beta_i \Delta rgdp_{t-i} + + \sum_{j=0}^{q} \beta_j eu_{t-j} + \sum_{k=0}^{r} \beta_k ns_{t-k} + \varepsilon_t \\ & + \sum_{i=1}^{p} \beta_i \Delta rgdp_{t-i} + + \sum_{j=0}^{q} \beta_j eu_{t-j} + \sum_{k=0}^{r} \beta_k ns_{t-k} + \varepsilon_t \end{aligned} \tag{4}$$

where $\varepsilon_t$ is the stochastic terms, while the respective long-run ($\beta_{rene}\beta_{rgdp}$, $\beta_{eu}$and $\beta_{ns}$) and short-run impact ($\beta_i$,$\beta_j$and$\beta_k$) are coefficients are estimated from the below underpinning hypotheses

$$\begin{aligned} & H_0 = \beta_{rene} = \beta_{rgdp} = \beta_{ns} = \beta_{eu} = 0 \\ & H_1 \neq \beta_{rene} \neq \beta_{rgdp} \neq \beta_{ns} \neq \beta_{eu} = 0 \end{aligned} \tag{5}$$

Indicatively, the result of the long-run and short-run estimates in addition to the Wald test diagnostic and other residual diagnostic tests are presented in Table 4.

### 2.2.3. Robustness test

In an attempt to further examine or validate the evidence of long and short term nexus, the equation (4) is re-estimated by using the steps by incorporating addition explanatory variable (trade policy, tp). The result of the new estimate is provided in Table 4 as a robustness check. In addition, the result of short-run nexus between the concern variables is re-examined by using the Vector Error Correction Method (VECM) Granger causality test of [27]. The method presents a pairwise relationship among renewable energy development, the economic growth (real GDP), the trade policy, economic uncertainty, and national security. The VECM method is considered more appropriate to examine the Granger causality between the series since the variables are integrated at 1 (1) [28].

[1] The augmented Dickey & Fuller (1979) (henceforth regarded here as ADF) and Kwiatkowski, Phillips, Schmidt & Shin (1992) (henceforth regarded here as KPSS).

**Table 4**
Long and Short-run ARDL Bound Test estimate.

| Long-run | | | | | |
|---|---|---|---|---|---|
| | *NS* | ln*RGDP* | *EU* | *TP* | *ECT (-1)* |
| $\beta$ | 0.352 | 0.008 | −1.012 | | |
| *p-val.* | *0.021*** | *0.034*** | *0.003** | | |
| Short-run | | | | | |
| $\beta$ | 0.171 | 0.004 | −0.237 | | −0.524 |
| *p-val.* | *0.016*** | *0.041*** | *0.211* | | *0.000** |
| **With Tpolicy (Robustness Check)** | | | | | |
| Long-run | | | | | |
| $\beta$ | 0.305 | 0.008 | −0.902 | −0.041 | |
| *p-val.* | *0.038*** | *0.030*** | *0.008** | *0.331* | |
| Short-run | | | | | |
| $\beta$ | 0.160 | 0.004 | −0.262 | −0.022 | −0.524 |
| *p-val.* | *0.026*** | *0.036*** | *0.214* | *0.360* | *0.000** |
| Wald test estimate | | | | | |
| F-statistic | 5153* | | | | |
| $\chi^2$ | 30,917* | | | | |

| Residual diagnostics | | |
|---|---|---|
| | Serial Correlation LM test | Heteroscedasticity test |
| Chi-square (*p-value*) | 0.784 | 0.591 |
| Normalty test | 2.705 (p-value = 0.259) | |
| Skewness | −0.315 | |
| Kurtosis | 2.571 | |

Note: The model employed are ARDL (2, 0, 0, 1) with *Tpolicy* and ARDL (2, 0, 0, 0, 1) without *Tpolicy*. Additionally, *NS, EU, TP* and *Rgdp* are respectively the National Security, Economic Policy, Trade Policy, and the Real Gross Domestic Product (representing the economic growth).

As such, the VECM Granger causality method performed as performed on equation (2) is specified as

$$(1-L)\begin{bmatrix}\text{lnren}_t\\ \text{lnrgdp}_t\\ \text{lneu}_t\\ \text{lnns}_t\end{bmatrix}=\begin{bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\end{bmatrix}+\sum_{i=1}^{p}(1-L)\begin{bmatrix}z_{11i}&z_{12i}&z_{13i}&z_{14i}\\ z_{21i}&z_{22i}&z_{23i}&z_{24i}\\ z_{31i}&z_{32i}&z_{33i}&z_{34i}\\ z_{41i}&z_{42i}&z_{43i}&z_{44i}\end{bmatrix}\times\begin{bmatrix}\text{lnren}_{t-1}\\ \text{lnrgdp}_{t-1}\\ \text{lneu}_{t-1}\\ \text{lnns}_{t-1}\end{bmatrix}+\begin{bmatrix}\omega\\ \gamma\\ \theta\\ \rho\end{bmatrix}ECT_{t-1}+\begin{bmatrix}\psi_{1t}\\ \psi_{2t}\\ \psi_{3t}\\ \psi_{4t}\end{bmatrix} \tag{6}$$

where the lagged residual value given as $ECT_{t-1}$ is from the long-run nexus. Additionally, the difference operator and the random terms are respectively$(1-L)$ and ($\psi_{1t}$, $\psi_{2t}$, $\psi_{3t}$, and $\psi_{4t}$). Also, while the statistical evidence of the estimated coefficients$\omega$, $\gamma$, $\theta$, and $\rho$ (of the $ECT_{t-1}$) demonstrates the long-run causal nexus estimates, the short-run causal nexus is identified from the significance of F-statistics by using the Wald test. For instance, $z_{14i}\neq 0\forall_i$ means that national security (*ns*) predicts the renewable energy development (*ren*), while $z_{41i}\neq 0\forall_i$means that the renewable energy development (*ren*) predicts the national security (*ns*). Hence, aforementioned estimates are presented in Table 5.

**Table 5**
The granger causality evidence.

| Null Hypothesis: | F-Statistic | Prob. |
|---|---|---|
| RGDP does not Granger Cause RENE | 3.71391 | 0.0276** |
| RENE does not Granger Cause RGDP | 1.99404 | 0.1412 |
| TP does not Granger Cause RENE | 0.17258 | 0.8417 |
| RENE does not Granger Cause TP | 3.22541 | 0.0436** |
| NS does not Granger Cause RENE | 3.38028 | 0.0377** |
| RENE does not Granger Cause NS | 3.45382 | 0.0352** |

Note: The RENE, *NS, EU, TP* and *Rgdp* are respectively the renewable energy consumption, National Security, Economic Policy, Trade Policy, and the Real Gross Domestic Product (representing the economic growth). Also, ** is the statistical significance at 5% level.

### 2.2.4. Additional robustness and diagnostics tests

In addition to the VECM Granger causality expressed above, the dynamic and static forecasting of the renewable energy consumption is further examined as a robustness check to the result of the ARDL estimation. Furthermore, the cumulative sum (CUSUM) and the CUSUM of squares (See Fig. 2) of [29] both implied a residual diagnostic and stability test. In this case, the residual diagnostic test offered that the estimated model (of equation (1)) and especially the long-run estimated coefficients are stable since the 'bluish' trend is sandwiched by the two 'red-sloppy' lines of Fig. 2 (i.e all variables are within the critical limits of 5%). Moreover, the estimated ARDL model is tested to ascertain the possible presence of serial correlation and heteroskedasticity. Given the results of the serial correlation and heteroskedasticity in Table 4, statistical evidence showed that both null hypotheses (of 'no serial correlation' and homoscedasticity) are rejected i.e p-values for serial correlation and heteroskedasticity tests are respectively 0.784 and 0.591. Desirably, the forecasting of renewable energy consumption within the framework of economic policy uncertainty, trade and national security is also provided in Fig. 3

## 3. Empirical observations

### 3.1. Common statistic

The common statistics presented in Table 1 posits an interesting statistical inference of the variables being investigated. Indicatively, the mean, maximum and minimum values of the renewable energy consumption (*rene*) implies that there seems to be small variance in the quantity of *rene* over during the investigated period. While the *rene* is observed to have a slightly long right tail (positively skewed) relative to the left tail, the trade policy (*tp*), economic uncertainty (*eu*), and the national security (*ns*) are all also right-tailed. However, the real GDP is observed to be more skewed to the left against the

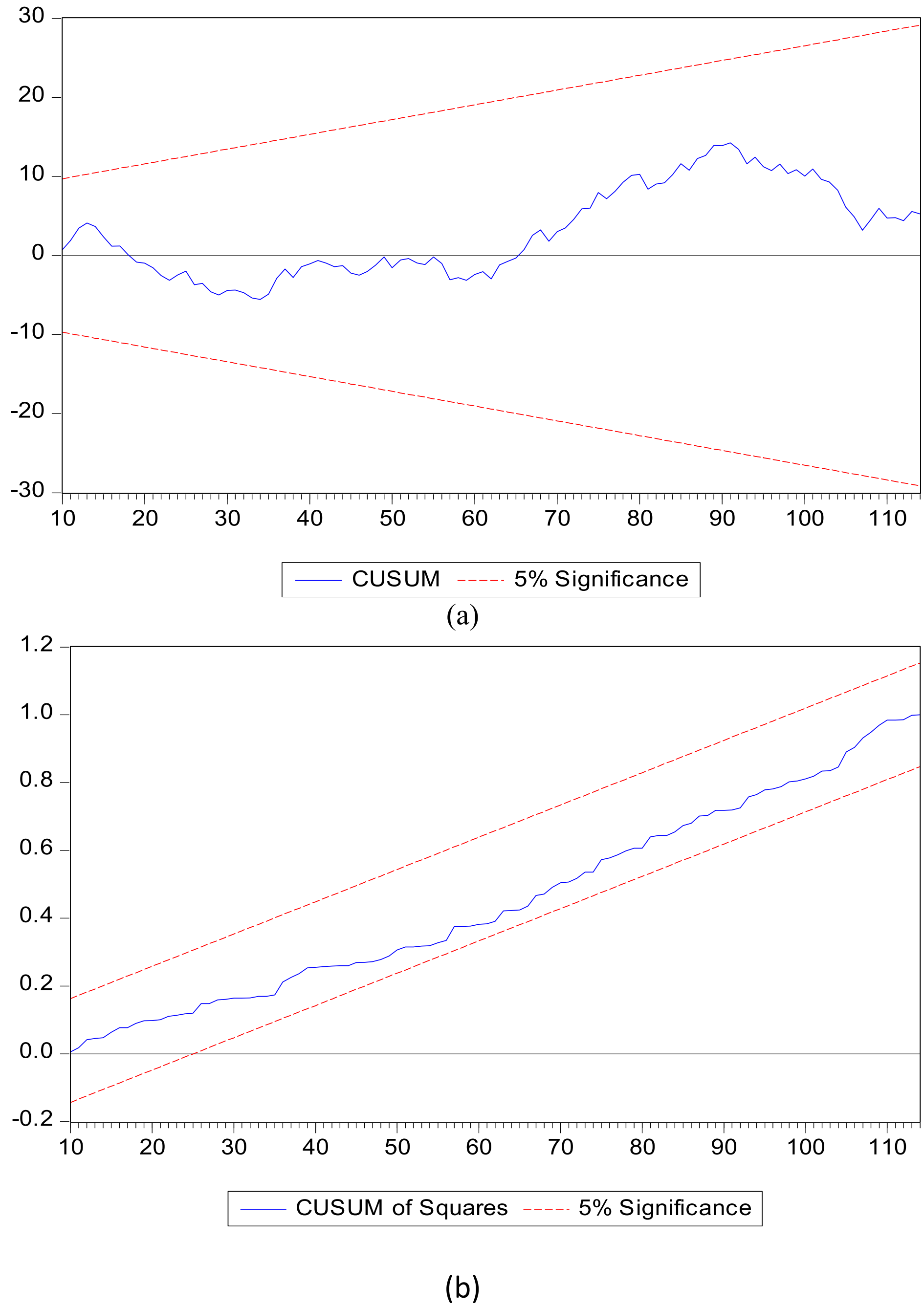


**Fig. 2.** The cumulative sum (a) and cumulative sum of squares (b).

right skewness inference of other variables. Interestingly, given the significant mean deviations of the values of trade policy, economic uncertainty, and the national security, the observation posits a potentially dynamic impact of these concerned variables. Additionally, the concerned variables (trade policy, economic uncertainty, and the national security) are observed to have heavy tails, thus the kurtosis are higher than 3.0. Lastly, the statistical significant evidence of correlation among the variables as also illustrated in Table 2 further presume the essence of studying the cointegration evidence.

### 3.2. *The long and short term inference*

In the estimation of the long-run and short-run relationships via the ARDL model that is presented in Table 3, both the real GDP and the national security are observed to cause a desirable and significant impact on clean energy consumption. It then suggests that 1000USD increase in the *rgdp* accounts for a growth of about 0.008 Btu in *ren* during the investigated period. Similarly, a positive and significant relationship is equally observed between *ren* and the *RGDP* in the short-run. As expected, the positive nexus of *rgdp* and

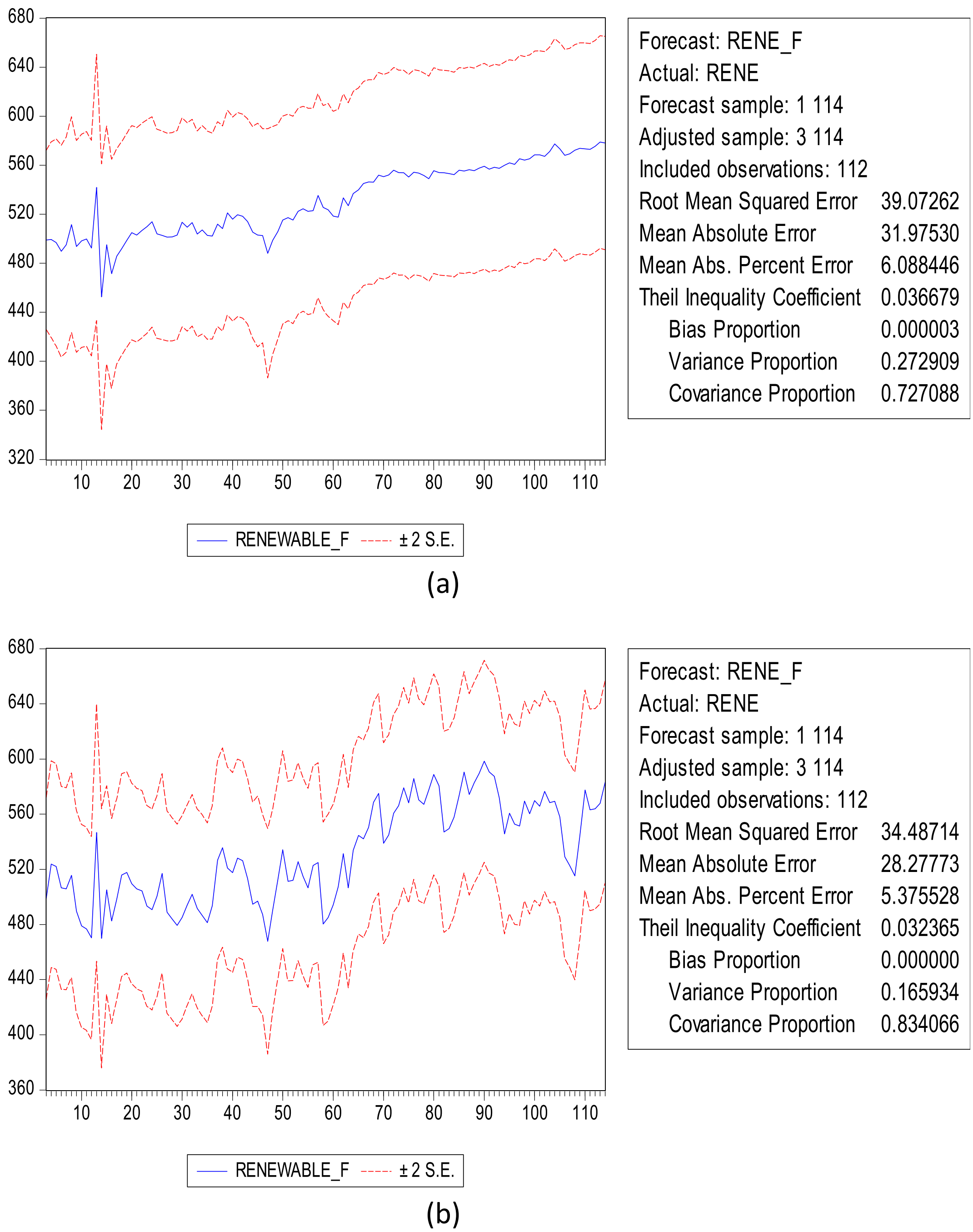


**Fig. 3.** The dynamic (a) and static (b) forecasting of the RENE (renewable energy consumption respectively.

*ren* implies that a better economy vis-à-vis improved income level among other economic indices in the country will ensure improved supply of renewable energy. For instance, the improved income level is expected to compensate for the high price of renewable energy technologies (against the moderate price of fossil fuel), thus there will be more spending on renewable energy. Interestingly, this is a similar position held in the study of [3] especially for the case of Coastline Mediterranean Countries. Additionally, while [30] affirmed a positive nexus of economic expansion and electricity consumption in Japan [31], also adhered that economic growth have a statistical significant impact of biofuel consumption and production among the selected developed and developing countries. Likewise [32], held the same view for the case of China.

Regarding the national security, the long and short-run statistical evidence implies that 1 unit increase in the security index is responsible for the country's growth in the renewables by 0.171 Btu and 0.352 Btu in the immediate term and long term respectively especially during the period 1990 to 2018. This evidence further advance the perspectives of the nexus of national security, foreign policy, and energy market expressed in the studies of [11,12]. In addition [33], inferred that the determinants of renewable energy development are categorized as domestic and international. By deducing that population, wealth are components of domestic factors that determines renewable energy consumption [34], affirmed that there is a significant bi-directional causality from renewable energy to economic growth in France. However, a few studies observed that militarization negatively affect economic growth [3,35]. In such situation when there is a significant economic downturn, the studies opined that the deterioration in the development of renewable energy is inevitable.

Moreover, the nexus of EU and energy especially the oil (fossil fuel) price has been well established in the literature [7,8,10]. Specifically [8], found that a decrease in the United States' Economic Policy Uncertainty is capable of enhancing innovations in the country's oil production. Thus, a shock in the United States' Economic Policy Uncertainty is expected to have significant impact of the country's energy industry. The result of the current study also illustrate similar inference (see Table 4). For the current study, the impact of EPU on renewable is negative, thus informing that a high level of uncertainty in the United States' economic policy will cause detrimental effect in the country's renewable energy development in both the short and long-run. Even when trade policy variable is incorporated in the robustness model, the effect of EPU and other explanatory variables remained unchanged. However, the impact of trade policy on the development of renewable energy is statistically significant but undesirable. This effect is not quite different from the observation form the existing literature [36–38].

## 4. Summary remark with policy suggestion

In recent time, the growing demand arising from increased economic activities and population increase in addition to the drive to mitigate the effects of global warming has led to advances in alternate energy sources. In the advance economies such as the United States, the pressure from both the domestic actors and intergovernmental agencies is largely responsible for the increased development of cleaner energy sources. However, like other nations, the United States is expected to experience challenges in the drive toward increasing the country's share of renewable energy consumption.

Considering the advances in renewable energy development in the United States and the associated challenges, the current study examined the impact of national security, economic policy uncertainty, and economic expansion in addition to trade policy on renewable energy consumption. A series of techniques that include the Johansen cointegration approach in addition to the FMOLS the DOLS and CCR were employed as a priori procedure to reveal the nature of the relationship between the aforementioned variables. Importantly, the ARDL bound test cointegration approach further ascertain the statistical evidence of short and long-run relationship. Interestingly, the study found that improved national security, decrease in economic policy uncertainty, increased growth or expansion in the economy, and a less stringent trade policy is statistically significant to the development of renewable energy in the United States in both the immediate time and distance future.

Therefore, the implication of the current result is that the growing need for more re-enforcement of the national security and cleaner energy development cannot be downplayed in the case of United States. The role of national security network in energy development in the United States can be viewed from the perfective of the strong nexus between the country's foreign policy and the global energy market [11]. On the other hand, the provision of effective security is tantamount to human capita development, thus employed as input in both energy sources development and economic expansion. On this term, it clearly suggest the policy dimensions to sustain an enhanced national security as a target toward improving renewable energy development. Hence, the United States government should further advance the policies that primarily target greater achievements of national and state-level drive for renewable energy and clean energy technologies. Revisiting the country's foreign policy especially with the crude oil exporting states such as Russia, Venezuela, and other Organization for Petroleum Exporting Countries (OPEC) could further ease the reliance of the United States on oil importation, thus advancing the country's renewable energy development. In addition, the United States should put in place an intermediary or inter-sectoral think tank mechanism that supposedly synchronize the underlying energy programs and a specified unit of from the country security networks. By so doing, the government will not jeopardize the achievement in the renewable energy development at the detriment of improving national security and vice versa. In addition, the economic policy of the country should be further re-invigorated inclusively such that potential shock on the economy is effectively cushioned without causing a significant level of uncertainty. Consequently, the risk to sustainable development programs such as the renewable and energy efficiency policy of the government is largely minimized.

## CRediT authorship contribution statement

**Andrew Adewale Alola:** Writing - review & editing, Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, and Corresponding. **Seyi Saint Akadiri:** Data curation, Writing - original draft.

## 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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## Appendix

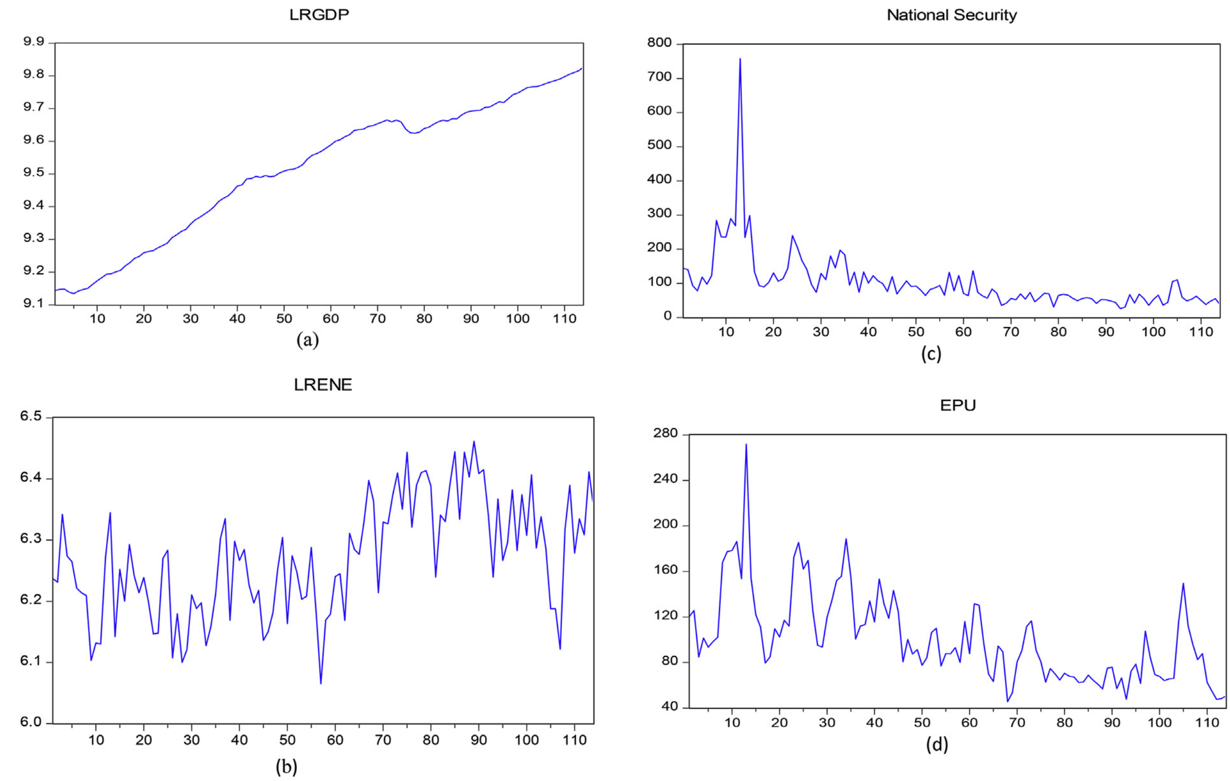


**Fig. A.** Time series plot for a: clean energy source (RENE), b: economic expansion (GDP), c: national security (NS), and d: economic policy uncertainty (EPU).

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