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Analyzing the Role of Renewable Energy and Energy Intensity in the Ecological Footprint of the United Arab Emirates

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Abstract: Even though a great number of researchers have explored the determinants of environmental pollution, the majority have used carbon emissions as an indicator while only recent studies have employed the ecological footprint which is a broader and more reliable indicator for the environment. The present study contributes to the literature by exploring for the first time in the literature the role of real output, energy intensity (technology), and renewable energy in the ecological footprint under the STIRPAT framework for a Gulf Cooperation Council (GCC) country—the United Arab Emirates. By applying the novel bounds testing with dynamic simulations on the data from 1992–2017, the findings of this paper reveal that energy intensity and renewable energy have a negative and significant influence on the ecological footprint but real output has a positive and significant impact on it. In other words, the empirical results indicate that a rise in the real income increases environmental pollution while increases in renewable energy and advances in technology mitigate the level of emissions. The findings also suggest that the government should establish new programs, investment opportunities, and incentives in favor of energy intensity-related technology and renewable energy for the sake of environmental sustainability. The outcomes from this research analysis are useful for policymakers, industrial partners, and project designers in the United Arab Emirates.

Keywords: ecological footprint; renewable energy; sustainability; technology; energy intensity

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1. Introduction

Environmental pollution is a critical issue in the world. Several factors are responsible for worsening of the environmental quality. Among these, human-related factors, such as energy consumption, transportation, and the international import and export trade are primarily responsible for environmental degradation [1–3]. The natural environment is adversely affected by the use of many natural resources in agriculture, industrialization, deforestation, and mining [4]. Recently, there has been significant support for the United Nations Sustainable Development Goals (SDGs), as gradually, more and more nations around the globe are implementing policies to meet the SDG objectives for 2030. Consequently, countries have started redesigning their environmental and energy policies, creating a basis to address the SDG objectives to control environmental degradation by employing the ecological footprint [5]. Renewable energy sources are promoted as the primary option to lessen carbon dioxide emissions and other pollutants that cause global warming [6]. However, the high cost of transitioning to renewable energy technologies is the principal obstacle facing political interventions, and the cost-effective diffusion of renewable power generation is unavoidable. In addition to the energy from renewable sources, energy intensity considered as technology in the sector plays an essential role in fighting against the environmental degradation [7,8].

Over the last decade, global energy prices have risen and the income from oil and gas exports from Gulf Cooperation Council (GCC) countries has touched record levels [9]. Energy demand in non-OECD countries (including the GCC countries) were higher than compared to OECD countries [10]. Also, the continual growth of the GCC countries can be observed by their increasing rates of economic growth, population and energy consumption [9]. On the other hand, Flamos et al. [11] and Hendrix [12] state that the GCC countries' dependence on oil and gas revenues has declined due to the diversification of their economies. As this economic diversification process increases, regions will become more interested in investing in and developing the industries and capacities of the future using renewable energy. The countries of the Middle East have massive potential for the generation and utilization of renewable energy. In the GCC countries; especially, the potential for solar power generation is high due to the temperature/climate and available land area [10]. Additionally, many governments of countries in the Middle East have introduced policies and incentives to encourage and support the development of renewable energy facilities. The GCC countries have shown great interest in engaging in sustainable development by deploying renewable energy [13]. Policymakers in the GCC countries have turned to use renewable energy to desalinate sea and brackish water into potable water [10]. Especially, the United Arab Emirates (United Arab Emirates) has started developing one of the world's most sustainable cities globally. Masdar City, in Abu Dhabi, occupies approximately 6 km2 and has developed global clean technology. "The second project is the Noor Energy One solar power plant, generating 950 MW; 250 MW photovoltaic and 750 MW concentrated solar power, based in the south of Dubai city". The third solar project is Noor One based in Al Ain city and several others [6,14]. Also, Saudi Arabia has already constructed several renewable projects and green energy production areas, particularly in Arabian GCC and Red Sea coastal areas [15]. The NEOM city development in Saudi Arabia cannot be ignored; it will rely on wind and other renewable energy sources to contribute positively to the natural environment [16].The consumption of natural resources generate pollution and carbon dioxide (CO_2) emissions being the most highlighted pollutant [17]. The emissions are released into the atmosphere through human or production activities. In addition, natural gas is one of the key contributors in fossil fuel consumption and sources of energy for commercial and domestic scales and fuel for electricity generation [18].

The emissions cover the atmosphere to block gases from escaping, which causes heat [19] and a rising temperature driving climate change [20]. Moreover, the current expansion of the petroleum industry causes unfavorable environmental assessments of fossil fuels and oil waste water treatment which are closely associated to human survival [21]. There are several sources that contribute to the environmental degradation and rising CO_2 emissions such as: waste tire pyrolysis oil [22], high-sulfur coal [23] and coal-fired resources (boiler) [24].

Several studies have found that excessive level of emissions can be mitigated by introducing renewable energy sources [1,25–27]. The ecological footprint (EF), on the other hand, measures the productive land and ocean area to back human demand for natural resources and separates the waste produced from human actions [28]. The ecological asset demands of humans have already exceeded their productivity (biocapacity) which means that the use of natural resources is higher than nature can produce. According to [29], the regeneration of natural resources takes one and a half years compared to what is consumed in one year. To sum up, EF proposed by [28] is a more comprehensive and reliable measure of the environmental pollution and carbon emissions through carbon footprint.

The fundamental contribution of this study to existing literature is that this research for the first time in the literature analyzes the impacts of energy intensity and renewable energy on the ecological footprint in the United Arab Emirates—a member of the GCC countries. This research builds on the STIRPAT theoretical framework in which population and real output are used as control variables in addition to focal variables-energy intensity and renewable energy-and employs the novel dynamic autoregressive simulation method developed by [30] alongside a conventional ARDL developed by [31]. The empirical results show the adverse effects of renewable energy and technology (energy intensity) on environmental pollution measured by the ecological footprint for the case of the United Arab Emirates.

The literature review follows in Section 2. In Section 3, the model and data are presented. In Section 4, methodology is presented. Empirical results and discussions are reported in Section 5. In Section 6, the conclusions and policy implications are discussed.

2. Literature Review

The issues of global warming and climate change are threats to human health and the environment, and have emerged as key focal points and fundamental priorities for humanity [32]. Destek et al. [33] speculated that few nations have so far experienced toxic environmental hazards resulting from global warming, which are primarily caused by environmental degradation and rise in carbon dioxide emissions. The primary sources of carbon dioxide emissions and the consumption of natural resources are; agriculture, industrialization, deforestation, mining [4] and transportation [34,35].

Besides, there has been a significant shift in the world's population, as nowadays, more than half of the world's population lives in urban areas [36]. According to Leeson [36] and United Nations [37], almost 66% of the world's population is expected to be urbanized by 2050, which amounts to nearly 2.5 billion more people living in urban areas. As urbanization rises, the demand for transportation, industrialization, and other factors increases, thereby growing fossil fuel consumption and extending the ecological footprint [17]. Also, Zhang et al. [17] said that urbanization generates income for people.

The ecological footprint helps to highlight the direct and indirect impacts of production and consumption activities on the environment by using the Environmental Kuznets Curve model [38]. Therefore, the ecological footprint has been extensively praised as an effective heuristic and pedagogic device for presenting total current resource consumption in a way that can be communicated easily to everyone [39]. In addition, the ecological footprint is a broad measure [40] that many studies have applied as an environmental degradation indicator [33,41,42]. Table 1 summarizes research studies which are relevant to this research context.

Table 1. Summary of literature review.

No	Studies	Country	Year	Independent Variable	Dependent Variable	Methods	Long-Run and Causality
1	[43]	OECD countries	1980–2014	RE, NRE, RI and (TO)	EF	ADF, MG, FMOLS-MG and DOLS-MG tests Second generation panel data methods	RE (−) EF, while NRE + EF, TO (−) EF; RI (−) EF association has been found to be U-shaped
2	[44]	European Union	1997–2014	RGDP, NRE, RE, TO, FR	EF	Panel Pool Mean Group Autoregressive distributive lag (PMG ARDL) model and Im, Pesaran Shin.	RGDP + NRE, NRE (−) EQ; GDP − EQ; FR + insignificant EF; RE and TO with EQ granger causality.
3	[5]	Turkey	1965–2017	GDP, RE, NRE	EF	Quantile Autoregressive Lagged (QARDL) approach	GDP + EF; U-Shaped relationship GDP and GDP2 on EF (EKC); RE (−) EF; NRE + EF.
4	[45]	BRICS-T (Brazil, Russia, India, China, South Africa, and Turkey)	1990–2018	AVA, FA, NRE and RE, and FD	EF	Augmented Dickey-Fuller (CADF) and Cross-sectionally Augmented Im Pesaran and Shin (CIPS), MG, AMG, CCEMG, and FMOLS	FA (−) EF; AVA + EF; NRE + EF; RE (−) EF; FD + EF
5	[46]	(South Asian) India, Pakistan, and Sri Lanka	1990–2014	FD, GDP, TO, PO, NRE and RE	EF	Pesaran Cross-sectional dependency (CSD) test, d Im–Pesaran–Shin (CIPS), GMM (Generalized method of moments)	RE (−) EF; NRE + EF; GDP mixed impact EF; FDI + EF; PO (−) EF,

Table 1. *Cont.*

No	Studies	Country	Year	Independent Variable	Dependent Variable	Methods	Long-Run and Causality
6	[47]	36 developing countries	1990–2016	Re, NRE, NR, HC, and GL, TO, URB, POP	EF	Augmented mean group (AMG), mean group (MG) technique, and common correlated effects mean group (CCEMG), FMOLS and DOLS approach, Dumitrescu and Hurlin causality test	GDP, NRE, NR, and URB + EF; HC, and GL (−) EF.
7	[3]	BRICS countries	1990–2016	GDP, NRE, RE, HC, URB	EF	Common correlated effects mean group (CCEMG), AMG, and PMG estimators	GDP and NR + EF, RE- EF; causality between HC, URB, and EF.
8	[27]	Eight developing countries of South and Southeast Asia	1990–2015	RI, RE, LE, and POP	EF	Cross-sectional augmented autoregressive distributed lag (CS-ARDL)	RE - EF; POP + EF; LE + insig EF; RI and EF are found N-shaped.
9	[48]	BRICS countries	1992–2016	RI, RE, URB, NRR	EF	Fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) long-run estimators	NRR, RE, and URB (−) EF
10	[45]	20 Asian economies	1990–2014	FD, GDP, NRE and RE, TO	EF	Cross-sectional dependency (CSD) tests, augmented mean group (AMG) approach, Dumitrescu and Hurlin (D-H)	EG and NRE + EF; RE (−) EF; TO + EF,
11	[49]	10 countries	(Different date since 1985–2014)	ICT, RE, NRE, FD and EG	EF	ARDL and ADF	NRE - EF; RE, ICT and FD + EF
12	[50]	29 OECD countries	1984–2016	DES and IQ	EF	Cross-sectional augmented distributed lag (CS-DL) estimator	RE, IQ - EF; EG and NRE + EF
13	[51]	128 countires	1995–2019	GTI, RE, GDP, TO, URB, and CG	EF and RD	Driscoll–Kraay (D/K)	RE, URB, and CG (−) EF; GDP, TO + EF; GTI, RE, URB, CG + RD
14	[52]	ASEAN Countries	1990–2018	GDP, RE, and NRE	CO_2	Method of moments quantile regression, (FMOLS, DOLS, FE-OLS	GDP + CO_2; NRE + CO_2; RE (−)CO_2
15	[53]	42 developed countries	2002–2012	RE, NRE, and GDP	CO_2	OLS, GMM, PMG estimator (ARDL) model	NRE (−)CO_2; RE + CO_2
16	[54]	Turkey	1961–2010	RE, NRE and GDP	CO_2	Augmented Dickey–Fuller test ADF, Kwiatkowski-Phillips-Schmidt-Shin KPSS, ARDL	NRE (−)CO_2; RE + CO_2
17	[55]	OECD countries	1980–2010	GDP, RE, NRE and ITR	CO_2	Granger causality tests, FMOLS, DOLS	RE (−)CO_2; ITR and REC (−)CO_2
18	[56]	BRICS countries	1992–2013	REC, NEC, GDP, AVA	CO_2	Generalized method of moments	RE and GDP (−)CO_2; NRE + CO_2.
19	[57]	European Union	1980–2012	RE and NRE, RI and TO	CO_2	Dynamic ordinary least squares estimator	RE and TO (−)CO_2; NRE + CO_2
20	[34]	Japan	1970–2018	RE, GDP, AT, ECI, CR	CO_2	Novel dynamic autoregressive distribution lag (ARDL) model, (dynARDL) and Kernel-based regularized least squares (KRLS)	CR + CO_2; ER (−)CO_2; ECI (−)CO_2,
21	[58]	Turkey	1974–2010	EC, GDP, GDP2 and FDI	CO_2	ADF, Phillipse Perron unit root test PP, Ng-Perron, ARDL, Hatemi-J co-integration, VECM causality	FDI + CO_2; EC + CO_2; GDP, the square of GDP and EC to FDI in the long run
22	[25]	OECD countries	1980–2011	GDP, GDP2, RE, NRE, POP	CO_2	ADF, PP, Breitung, Johansen co-integration, Westerlund co-integration, GMM, VECM causality	RE (−)CO_2; NREC + CO_2
23	[59]	Arctic countries.	1960–2010	RI (Economic growth)	CO_2	Autoregressive distributed lag (ARDL)	RI − CO_2

Table 1. *Cont.*

No	Studies	Country	Year	Independent Variable	Dependent Variable	Methods	Long-Run and Causality
24	[60]	Pakistan	1970–2018	NRE, RE, EF, URB, TR	CO_2	Ordinary least-squares and dynamic ordinary least-square model, FMOLS and DOLS	NRE, the EF + CO_2; RE (−)CO_2; URB and TR + CO_2
25	[61]	Sweden	1965– 2019	RE, TO, and EG	CO_2	Quantile-on-quantile regression (QQ)	TO (−)CO_2; ER (−)CO_2; EG (−)CO_2
26	[62]	14 European countries	1990–2014	GDP, RE and FF	EF and CO_2	ADF, cross-sectionally augmented Dickey Fuller (CADF) unit root test.	RE (−) CO_2 and EF; FF CO_2 and EF.
27	[63]	OECD countries	1990–2014	GDP, RE, NRE, OP and TO	CO_2	Fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS)	OP and RE (−) CO_2; NRE + CO_2
28	[64]	Pakistan	1971–2014	GDP, EC and GFP	EF	Multivariate NARDL model	EG (−) EF; CAP (+) EF,
29	[65]	Arab world	1980–2014	RI, EC, EBS, RE, NRE, LS	EF	Ordinary least squares (OLS), FMOLS, DOLS	RE (−) EF, NRE + EF,
30	[66]	Nigeria	1990–2014	GDP, EG, NRE, FDI, AVA, EC, POP	EF	ARDL, NARDL	EG + EF; RI and PO (−) EF, NRE + EF
31	[67]	ASEAN countries	1995–2016	GTI, GDP, EC, NR	EF	Driscoll–Kraay panel regression model and Dumitrescu–Hurlin panel	NS and GTI (−) EF; GDP and EC bidirectional effects EF
32	[68]	Uruguay	1971–2014	GDP, FDI, EC, ED	EF	Dickey–Fuller, Dickey–Fuller generalized least squares, and KPSS tests, ARDL	EC + EF; GDP u shaped EF; FDI (−) EF
33	[69]	66 developing countries	1990–2014	EE, RE, NEC, GDP	CO_2	OLS, panel quantile regression (PQR)	EE (−) CO_2; RE (−) CO_2; NEC mixed effects CO_2; GDP mixed effects CO_2
34	[70]	ASEAN countries	1990–2017	GDP, POP, TI, EI, ECI, EX.	CO_2	OLS, panel quantile regression (PQR)	POP and EI + CO_2; TI and ECI (−) CO_2; EX + CO_2
35	[71]	Pakistan	2017–2019	NRE (FF, NEC, Co, OI, NG and PE), RE (SO, WI, GE, HY, TI, WA and BI)	CO_2 and other gas emissions	SWOT analysis	NRE − CO_2 and RE + CO_2.
36	[72]	Malaysia	2020	NRE (BD) and OET	CO_2	Biodiesel production and parametric analysis	NRE (BD) and OET − CO_2

Renewable energy (RE), Non-Renewable energy (NRE), Real income (RI), Trade openness (TO), Real Growth domestic growth (RGDP), Fertility rate (FR), Growth domestic product (GDP), Agriculture value-added (AVA), Financial development (FD), International trade (ITR),Urbanization (URB), Natural resource rent (NRR), Economic complexity index (ECI), Coal rent (CR), Coal (CO), Foreign direct investment (FDI), Population (POP), Human capital (HC), Globalization (GL), Global tourism index (GTI), Cultural globalization (CG),Transportation (TR), Information and communication technologies (ICT), Disaggregated energy sources (DES), Institutional quality (IQ), Carbon dioxide (CO_2), Ecological Footprint (EF), Environmental quality (EQ), Forest area (FA), Politics (PO), Air transport (AT), Energy Consumption (EC), Life expectancy (LE), Economic growth (EG), Resource depletion (RD), Cultural globalization (CG), Oil Price (OP), Oil (OI), Fossil Fuel (FF) Energy consumption (EC), Energy by sources (EBS), Livestock (LS), Natural resources (NR), Natural Gas (NG), Environmental degradation (ED), Energy efficiency (EE), Nuclear energy consumption (NEC), Technological innovation (TI), Energy intensity (EI), Eco-innovation (ECI), Export (EX), Peat (PE), Gross fixed capital (GFP), Solar (SO), Wind (WI), Geothermal (GE), Hydral (HY), Tidal (TI), Wave (WA), Biomass (BI), Biodiesel (BD), Oil extraction technologies (OET).

Table 1 summarizes 36 studies; all of the papers indicate that renewable energy has an inverse relationship with ecological footprint and carbon emissions. Only a very small percent of studies employ employs novel ARDL techniques on the nexus of different variables, ecological footprints and carbon dioxide emissions.

3. Model and Data

This study analyzes the mediating effects of real output, renewable energy and energy intensity on ecological footprint for United Arab Emirates by using data from 1992–2017. The data on renewable energy are not available before and after the above-mentioned dates; thus, this research utilizes the maximum period of the dataset. Chertow [73] states that the IPAT identity is a framework to describe what determines environmental patterns. The model explains how population, affluence and technology are the major contributors of environmental changes (usually measured in emissions, either air pollutions or ecological footprint).

$$I = P \times A \times T \tag{1}$$

where I is proxy for environmental degradation (emissions), P is population growth, A is societal affluence (usually measured in GDP) and T is proxy for technology. The IPAT model was criticized for its simplicity and the assumption that the elasticities of all parameters are each equal to one [74]. Dietz and Rosa [75] improved the initial IPAT by proposing the STIRPAT model:

$$I_t = \alpha P_t^b A_t^c T_t^d e_t \tag{2}$$

where a represents the constant term, P, A and T are the same as before, b, c and d represent the elasticities of environmental impacts with respect to P, A and T respectively, et is the error term and the subscript t denotes the year. The below model is tested building on the well-established and applied population, affluence, and technology-STIRPAT-theoretical framework:

$$EF_t = \beta_1 + \beta_2 GDP_t + \beta_3 ENI_t + \beta_4 REN_t + \beta_5 POP_t + \mu \tag{3}$$

where "EF is ecological footprint as an environmental indicator; GDP is real gross domestic product in constant US$ 2010; ENI is the energy intensity as a technology indicator showing how efficiently the population uses energy (MMBtu/person); REN is the share of renewable energy in total energy consumption; POP is the share of urban population to total population". The descriptive statistics are reported in Table 2. A table reports the summary statistics showing the mean, median, standard deviation, maximum and minimum of the variables. Table 2 shows that ecological footprint, the real gross domestic product, renewable energy and population exhibit positive average except energy intensity (ENI) over the considered period. The ecological footprint has highest mean value 17.803 with minimum of 17.096 and maximum of 18.300 over the sample period. In terms of mean average, renewable energy and the real GDP are close to each other at 6.337 and 5.942, respectively. Where population average mean is 4.407. But the energy intensity found has a negative mean value of −2.546.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
lnEF	26	17.803	17.775	0.419	17.096	18.300
lnGDP	26	5.942	6.004	0.348	5.344	6.434
lnENI	26	−2.546	−2.641	0.438	−3.158	−1.473
lnREN	26	6.337	6.382	0.169	6.054	6.662
lnPOP	26	4.407	4.408	0.033	4.361	4.457

4. Methodology

The ARDL bounds testing approached developed by Pesaran et al. [31] analyzes the long-run relationship among variables with a mixed order of integration of I(0) or I(1) or without pre-specification of the variables that are either I(0) or I(1) [76]. However, it cannot be applied to I(2) variables [77]. The ARDL approach is single dynamic model equation and unrestricted error correction model that reparametrizes and analyze the short-run and long-run relationships of the endogenous and exogenous variables [31,77]. Furthermore, this approach absorbs a sufficient number of lags to obtain the data generating process in general to a specific model [31].

The ARDL model carries a complex specification, for instance, multiple lag structures, first differences, and lagged differences of variables. In short, it is complicated to determine the short-run and long-run influence of regressors on the endogenous variable. Therefore, to mitigate this complexity, Jordan and Philips [30] developed a dynamic ARDL model, which comprises a dynamic error-correlation mechanism [76].

This study further applies the novel dynamic ARDL simulation model developed by Jordan and Philips [30] to examine the one explanatory variable counterfactual response while others remain constant on the explained variable. The empirical process enhances the complicated interpretation of the current ARDL model [77]. The dynamic ARDL simulations algorithm is helpful for testing co-integration, short-run and long-run equilibrium relationships in both differences and levels [8]. Also, this model permits the influences of positive or negative changes in an predictor variable on the dependent variable to be assessed and examined graphically, based on the ceteris paribus principle [76]. Hence, the dynamic ARDL model offers one to one analysis of the relationship between exogenous and endogenous variables. This method applies 5000 simulations of the vector of parameters by utilizing multivariate normal distribution. The equational form of dynamic ARDL approach based on dynamic simulation is presented as:

$$\Delta(y)_t = \alpha_0 + \delta(Y)_{t-1} + \delta_1(x_1)_{t-1} + \cdots + \delta_k(x_k)_{t-1} + \sum_{i=1}^{p}\alpha_i\Delta(y)_{t-1} + \sum_{j=0}^{q_i}\beta_{ij}\Delta(x_1)_{t-j} + \cdots + \sum_{j=0}^{q_k}\beta_{kj}\Delta(x_k)_{t-j} + \epsilon_t \quad (4)$$

In Equation (4), y shows the variation in the dependent variable; α_0 is the intercept; $t-1$ is the maximum p-value of the independent variable; q_k is the number of lags; Δ indicates the 1st difference operator; t is the time period and ε is the error term. The null hypothesis of no co-integration (H_0: $\delta_0 + \delta_1 + \cdots + \delta_k = 0$) is checked against the alternative hypothesis (H_1:$\delta_0 + \delta_1 + \cdots + \delta_k \neq 0$). If calculated F-value is greater than the critical value, the null hypothesis of no co-integration is rejected. The final modified model is given in below Equation (5).

$$\begin{aligned}\Delta\ln(EF)_t = {} & \alpha_0\ln(EF)_{t-1} + \beta_1\Delta\ln(GDP)_t + \vartheta_1\Delta\ln(GDP)_{t-1} + \beta_2\Delta\ln(ENI)_t + \vartheta_2\Delta\ln(ENI)_{t-1} + \beta_3\Delta\ln(REN)_t \\ & + \vartheta_3\Delta\ln(REN)_{t-1} + \beta_4\Delta\ln(POP)_t + \vartheta_4\Delta\ln(POP)_{t-1}\end{aligned} \quad (5)$$

5. Empirical Results and Discussions

The study first conducts the unit roots test to check the level of stationarity using the Augmented Dickey Fuller (ADF) and Phillips and Perron tests. The result of these tests is reported in Table 3 which shows that all the variables, ecological footprint (EF), gross domestic product (GDP), energy intensity (ENI), renewable energy (REN) and population (POP), are non-stationary at levels. After taking their first differences, all the variables exhibit stationary property I(1).

Table 3. Results from unit root tests.

	ADF (Augmented Dickey Fuller)		Phillips-Perron	
	Level	First Difference	Level	First Difference
lnEF	−1.62	−3.85 ***	−1.54	−3.87 ***
lnGDP	−1.31	−4.20 ***	−1.35	−4.17 ***
lnENI	−1.87	−5.08 ***	−1.87	−5.15 ***
lnREN	−0.09	−3.29 **	−0.45	−3.16 **
lnPOP	1.28	−2.80 *	0.707	−2.73 *

Note: *, **, *** represent 10%, 5% and 1% level of significance, respectively.

Given that the series are integrated in the order of I(I), a further test; namely, a co-integration test is mandatory for reliable empirical outcomes. Table 4 shows that there is long-run relationship among the variables under consideration by applying the co-integration test of Kripfganz and Schneider [78].

Table 4. Results from the Kripfganz and Schneider [78] co-integration test.

	Calculated Statistics	*p*-Value		10%		5%		1%	
		I(0)	I(1)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)
***t*-test**	−3.71 *	0.013	0.092	−2.522	−3.652	−2.939	−4.158	−3.826	−5.252

Note: * represents 10% level of significance.

Regarding long-run estimations, Table 5 shows the empirical results from the dynamic ARDL simulations and the conventional ARDL methods. First, it shows that gross domestic product (GDP) positively and significantly influences the ecological footprint (EF). More specifically, a 1% increase in economic growth increases environmental pollution by around 1.04%. This result is consistent with the outcome of Anwar et al. [52], Nathaniel et al. [2], and Sahoo and Sethi [47]. In 2009, the Supreme Council of Energy in the United Arab Emirates was established and tasked to ensure that long-term economic growth be driven by a sustainable energy strategy [79]. Furthermore, energy intensity has a negative and statistically significant impact on ecological footprint. In detail, a 1% change in technology adversely changes the environmental degradation by 0.18. A similar result is found by Aydin and Turan [7]. According to Elrahmani et al. [80], Abu Dhabi National Oil aims to enhance its energy efficiency by 10% by 2020 as well as the Emirates National Oil Company of Dubai which has implemented energy and resources management strategies to take operation and saving energy developments over the last 5 years.

Table 5. Results from the long-run estimates from autoregressive distributive lag (ARDL) and dynamic ARDL simulations methods.

	Dynamic ARDL Simulations		ARDL	
Regressor	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**
lnGDP	1.047 ***	0.009	1.702 ***	0.001
lnENI	−0.179 **	0.016	−0.160 ***	0.004
lnREN	−0.800 **	0.018	−0.791 ***	0.000
lnPOP	−8.234 **	0.041	−7.527 *	0.078
Constant	48.584 ***	0.005	47.238 ***	0.004
Simulation#	5000			
R^2	0.704		0.696	
F-stat	3.09 **	0.032		
Diagnostic tests			**Statistics (Chi^2)**	**Prob.**
Durbin's test (autocorrelation)			2.36	0.124
Breusch-Pagan (Heteroscedasticity)			0.50	0.48
White's test (Heteroscedasticity)			24.01	0.40
Skewness and Kurtosis (Normality)			0.72	0.69

Note: *, ** and *** represent 10%, 5% and 1% level of significance, respectively.

Renewable energy has a significant and inverse influence on ecological footprint in both the dynamic ARDL simulations and ARDL methods values by –0.800 and –0.791, respectively, and the result is consistent with various studies [43,46,48–50,52,81]. Biodiesel is a biodegradable, energy competitive, and renewable resource to mitigate the ecological footprint and also it has the ability to fulfil the energy demand of the world [72,82,83]. Ayoub et al. [72] states that biodiesel is sort of solution replacing fossil fuels causing environmental degradation and damaging ozone layers. Also, they said that renewable fuel releases less emissions on burning and can be replaced with existing petroleum diesel engines. We cannot ignore biomass as a renewable energy source which mitigates the carbon emissions [71,84].

From a policymakers point of view, the United Arab Emirates, and the states Abu Dhabi and Dubai set a target of 7% by 2020, 25% by 2030, and 75% by 2050 for electricity generation [85]. Furthermore, the population shows significant and negative effects on the dependent variable in both methods with values of −8.234 and −7.527, which is in line with

South Asian results [46]. The explanatory power R square of Dynamic ARDL method 0.704 and ARDL method 0.6936 are adequate to generalize results of the analysis. The United Arab Emirates population and economic growth caused of sharp energy consumption [6] so Dubai government initiated the green building regulations and specifications [86].

Finally, Table 5 exhibits four diagnostic tests, specifically, autocorrelation (Durbin–Watson test), heteroskedasticity (Breusch–Pagan, and White's test), and normality (skewness and kurtosis). The results and related p-values indicate that the model is free of autocorrelation, heteroscedasticity and non-normality.

6. Conclusions and Policy Implications

This study contributes to the existing body of research by, for the first time, investigating the impacts of energy intensity and renewable energy on the ecological footprint in the United Arab Emirates. This research builds on the STIRPAT theoretical framework in which population and real output are used as control variables in addition to the aforementioned focal variables, and employs the novel dynamic autoregressive simulation method developed by Jordan and Philips [30] alongside a conventional ARDL developed by Pesaran et al. [31]. By applying the novel bounds testing with dynamic simulations on the data from 1992–2017, the findings of this paper reveal that energy intensity, urban population, and renewable energy have negative and significant influence on the ecological footprint except gross domestic product. Overall, the explanatory power-R square- of the model is adequate to justify the results.

The empirical results indicate that increases in the real income increase environmental pollution, while increases in renewable energy and advances in technology lower the level of emissions. The findings also suggest that the government should establish new programs, investment opportunities, and incentives in favor of energy intensity-related technology and renewable energy for the sake of environmental sustainability. Furthermore, the United Arab Emirates being a GCC country has already taken great initiatives in terms of deployment of renewable energy and energy-related technologies. The government should prioritize technology implementation in existing infrastructure, metallurgical states, geographical locations and utilizing material abundance. Besides, the United Arab Emirates government should reduce the consumption and dependence on fossil fuels by putting emphasis on energy from renewable sources such that the country has a rich potential on solar photovoltaics. The current and recent stage of renewable energy growth across states provides the benchmark analysis for policymakers, industrial partners and project designers attracted to leverage the potential and improve renewable energy in the United Arab Emirates. For future research, oil wastewater and its treatment can be considered, especially in GCC countries.

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