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A Symmetry and Asymmetry Investigation of the Nexus Between Environmental Sustainability, Renewable Energy, Energy Innovation, and Trade: Evidence From Environmental Kuznets Curve Hypothesis in Selected MENA Countries

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The motivation of the study is to gauge the role of renewable energy consumption (REC), energy innovation (EI), and total trade (TR) on environmental sustainability (ES) in selected MENA (Middle East and North Africa) countries for the period 1980–2018 under the assumption of environmental Kuznets curve (EKC). The study implemented several econometrical tools, including structural break unit root test, Bayer–Hanck combined cointegration test, autoregressive distributed lag (ARDL), nonlinear ARDL, and Granger causality test under error correction term. Variables properties test detected that all the variables are stationary after the first difference but neither exposed to stationary after the second difference. The test statistics of the combined cointegration test documented a long-run association between ES, RE, EI, and TR, which is valid for both countries concerned. Regarding EKC concern, study findings with ARDL and nonlinear ARDL validated the EKC hypothesis for Tunisia and Morocco. Finally, the direction causality test documented unidirectional causality between renewable energy and ES, trade and ES, but the feedback hypothesis holds between EI and ES. We can advocate for specific sectoral environmental reforms in Tunisia and Morocco and suggest continuous environmentally friendly technologies by combining study findings. At the same time, subsidies on nonrenewable energy should be reduced, and green trade policies to help advance sustainable development should be implemented.

Keywords: environmental sustainability, renewable energy, energy innovation, trade, EKC, ARDL, NARDL

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INTRODUCTION

The interest in balancing economic growth and environmental degradation stems from the UN conferences in Stockholm, Sweden (1972), and Rio de Janeiro, Brazil (1992), both of which took place before the UN conference on climate change in Montreal, Canada. Many conference participants agreed that the human-perceived environmental issues are both a global problem and a mutual problem requiring international cooperation. Environmental degradation is a result of economically driven development that ignores environmental sustainability (ES) factors. These issues will harm future economic growth because of the finite carrying capacity of natural resources and the environment and the fact that they are being ignored (Nathaniel, 2021a).

The nexus between economic growth and carbon emission has been extensively discussed in the existing literature. Grossman and Krueger (1995) and Grossman and Helpman (1991) were the first to investigate such issues. They reported that economic progress leads to environmental degradation, followed by subsequent environmental improvement, later termed environmental Kuznets curve (EKC) (Panayotou, 1993). The EKC hypothesis considers the association between a deterioration in environmental quality and environmental pollution, especially in recent years. The economic–environmental connection is complicated and multidimensional. According to Everett (2010), economic development has three environmental impacts. First, economic development has a detrimental impact on the environment as increased output and consumption lead to increased environmental deterioration. Second, the transition from agriculture to industries that degrade the environment caused a change in the balance of producing manufactured products toward providing services. Third, the technical effect–technological advancements contribute to changes in the environmental impact of manufacturing, such as increases in energy efficiency.

Furthermore, Panayotou (1993) indicated that economic growth has three distinct effects over carbon emissions/ environmental pollution: scale, technical and structural, and scale effects. The scale effects explain that given a certain level of technology, in order to achieve economic goals, energy consumption leads to higher emissions. The structural effect narrates that structural transformation during economic development affects environmental degradation as higher-polluting industries are replaced by low-polluting industries, reducing carbon emissions during the manufacturing process. Finally, the technical effects explain that despite achieving economic expansion, carbon emissions during manufacturing are reduced mainly due to technological innovation and progress. However, there is a higher focus on investigating the association between greenhouse gas emissions and cleaner energy sources. Bölük and Mert (2015) incorporated an empirical strategy to review the role of renewable energy (RE) while investigating the EKC hypothesis to conclude that environmental degradation has a significant correlation with economic and industrial policies, and clean energy sources are crucial to ensure environmental quality. Recent economic literature has further explored such associations to claim that carbon emissions are significantly lowered after introducing RE into the energy mix (Bashir et al., 2021a).

The novelty of this study lies in the following aspects. First, since its inception, the concept of EKC has been extensively considered and investigated with different macro aspects predominately preferred to carbon emission, energy consumption (Solarin et al., 2017), and environmental quality (Yu et al., 2019). The EKC hypothesis establishes that increasing wealth increases pollution in the early stages of economic growth until the connection between the two variables becomes negative. This phenomenon arises when a nation improves its energy efficiency, RE production, and environmental consciousness, all of which contribute to forming an inverted U-shaped connection between income and pollution. To our best knowledge, this is the first ever study to investigate the EKC hypothesis with ES, RE consumption (REC), total trade (TR), and energy innovation (EI) in Morocco and Tunisia.

Second, according to existing literature, a growing number of researchers have invested time and efforts in exposing the key detriments for achieving ES by lowing carbon emission in the ecosystem with the integration of clean energy (Nathaniel, 2021b; Meo, 2021). Green energy inclusion in terms of energy reliance transition from fossil fuel to renewable sources has established the prime measures in mitigating adversity in environmental degradation. This study contributed to the existing literature by offering fresh insight regarding the role of RE, EI, and TR in achieving the focused goal of ES. Even though all those factors have been separately utilized in different studies, we incorporated all three factors in a single equation for the first time.

Third, we investigated the EKC hypothesis by applying symmetric and asymmetric frameworks following Pesaran et al. (2001) and Shin et al. (2014). In recent literature, the asymmetric assessment has gained apex attention in every aspect of macro fundamental assessment, even in the case of environmental assessment. The motivation for including asymmetric investigation is to document the possible nonlinear association over the conventional perception of the linear relationship. In reality, because of macro fundamental behavior and the effects of globalization in economic and finance, the existing belief is under tremendous pressure. Therefore, in empirical assessment, thorough nonlinear framework has received particular attention due to diversity in empirical findings. We, in the study, assess the role of RE, EI, and TR on ES with EKC under the nonlinear framework and firmly believe that the innovation of empirical findings opens an alternative thinking process for formulating environmental policies and reshapes the existing literature macro policies implementation. Our study findings validated the EKC in Morocco and Tunisia with symmetric and asymmetric assessment. Regarding variable elasticity to ES, the study suggested that RE and environmental innovation mitigate environmental degradation by reducing carbon emissions.

The current study investigates the EKC hypothesis for Morocco and Tunisia. Because of the shift from central planning toward free-market economic reforms, they are among the fastest-growing economies in the Middle East and North Africa (MENA) region. In recent decades, both Tunisia and Morocco have accelerated structural reforms to restructure and liberalize economic and financial sectors to achieve economic goals through Structural Adjustment Programs (Bashir et al., 2020). The opening of the domestic economy was also accelerated as the European Union (EU) became a major trading partner for both countries through multiple accords (73.18% and 72% for Tunisia and Morocco, respectively). Furthermore, both countries have become the preferred destination of foreign direct investment (FDI) in the MENA region. As a result, both countries compete to become the most attractive environment for foreign investors through a qualified workforce, developed infrastructure, stable economic policies, and better political stability than the rest of the MENA countries (Hussain and Dogan, 2021). Other channels might also be explored to examine the interrelation between Morocco and Tunisia's economies, such as imports, FDI flows, and financial linkages.

The aim of the study was to evaluate the role of RE, EI, and trade on ES with the EKC hypothesis for Morocco and Tunisia from 1980 to 2018. The study applied both symmetry and symmetry assessment in the empirical model following Pesaran et al. (2001) and Shin et al. (2014). Study findings found long-run association in an empirical model, according to Bayer and Hanck's (2013) combined cointegration test. The asymmetric long-run association has been established with the cointegration test under nonlinear assessment. Regarding the magnitudes from RE, EI, and TR to ES, the study documented statistically significant adverse effects of RE and TR on ES, implying reduced carbon emission into the ecosystem. At the same time, trade liberalization positively augmented the process of environmental degradation with excessive carbon emission.

The remainder of this article is organized in the following sections: literature review outlines the association between carbon emissions, foreign trade, economic growth, REC, and EI. Section 3 outlines empirical model and econometric strategy; section 4 narrates empirical findings, and section 5 details concluding remarks and conclusion.

LITERATURE REVIEW

Since the industrial revolution, there has been a steady increase in global carbon emissions mainly due to increasingly higher reliance on fossil fuels to achieve economic transformation. Consequently, global emission levels have reached more than 36 billion tons, 1.6 times higher than that in 1990. Furthermore, this has also contributed to the rise of global average temperature in recent decades (Karl et al., 2015; Bashir et al., 2021b), adversely affecting humans and other species alike. Consequently, there is greater awareness to investigate the association between carbon emissions and global climate change. Academic researchers and policymakers have paid significant attention to assessing how carbon emissions affect climate change in different economic demographics. In order to achieve economic goals, the global energy supply has reached 13.7 billion tons of oil equivalent, and fossil fuels contributed to more than 80% of total energy consumption. In comparison, despite having low carbon emissions and recent environmental reforms, the share of RE sources is still less than 20%, which is even significantly lower in developing economies and is an effective alternative to reduce environmental degradation from carbon emissions (Talbi et al., 2020).

Current economic literature has extensively discussed the linkage between trade, RE, economic growth, innovation in environmental technologies, and carbon emission. A portion of research projects has investigated the inner relationship among CO_2 emissions as a measure of ES and the variables above. Mhenni (2005) empirically explored the EKC hypothesis using generalized method of moments methodology from 1980 to 1997; the researcher examined carbon emissions, vehicles, and fertilizer concentration to conclude that the EKC hypothesis is not proven for environmental pollutants. Chebbi et al. (2011) relied on a concentration empiricalapproach to examine how trade openness, per-capita CO_2 emissions, and economic growth influence each other. The empirical findings specified that carbon emissions, trade openness, and economic growth Granger cause one another; further analysis forecasted short-run causal association among trade openness and carbon emissions. In an earlier study, Belloumi (2009) researched how economic growth is influenced by energy consumption through the Johansen cointegration approach to indicate the bidirectional causal association between economic growth and energy consumption in the long run. Fodha and Zaghdoud (2010) also used the causality analysis approach to analyze how economic policies and carbon emissions influence the environmental deterioration in developing economies. The application of Vector Error Correction Model (VECM) and Johansen causality analysis indicated unidirectional causal association from economic growth to carbon emissions in short- and long-run empirical findings. Taking into account the empirical nexus, we reported the literature findings with three subgroups.

First, the pursuit of more remarkable economic development is inextricably linked to energy security and environmental degradation. Energy is a necessary input for economic activity; nevertheless, excessive energy use puts more strain on the environment, via either by-product pollutants or the depletion of natural resources. Economic growth should be accomplished in sustainability while efforts are made to protect the environment to preserve its usefulness for future generations. The EKC hypothesizes that economic growth, rather than being detrimental to the environment, improves environmental indicators, ultimately leading to sustainable development. Khan et al. (2020) assess the role of RE on trade and environment quality in Nordic counties from 2001 to 2018 by applying cross-sectional dependency, panel unit root tests, and dynamic CCE. Study findings reveal positive influence running from REC to trade liberalization and environmental quality. As far as policy intention is concerned, the study advocated that RE integration in the economy offers economic sustainability through domestic trade expansion, environmental quality improvement, and an eco-friendly ecosystem. Busu and Nedelcu (2021) investigate the role of clean energy on the ES

TABLE 1 | Summary of literature survey: nexus between RE and environment.

Authors	Sample and period	Methodology	Remarks		EKC	Causality
			Positive	Negative		
Liu (Liu, 2021)	During 1965–2016; China	ARDL bounding test; ADF; Phillips–Perron (PP); and VECM Granger causality		√ (CO_2)	√	→
Khan, Weili (Khan, 2021)	During 1985–2018 Developed and developing countries	OLS; GMM; FMOLS, and DOL		√ (CO_2)		
Ben Jebli, Ben Youssef (Ben Jebli et al., 2016)	During 1980–2010; 25 OECD	FMOLS and DOLS		√ (CO_2)	√	
Paramati, Mo (Paramati et al., 2017)	G20 countries; during 1991–2012	Cross-sectional augmented panel unit root (CIPS) test; FMOLS		√ (CO_2)		
Dong, Sun (Dong et al., 2017)	During 1985–2016; BRICS countries	VECM Granger causality; AMG estimator		√ (CO_2)	√	← →
Shafiei and Salim (Shafiei and Salim, 2014)	During 1980–2011; for 29 OECD countries	ADF, PP, LLC, and IPS; STIRPAT statistical method		√ (CO_2)	√	←
Danish, Zhang (DanishZhang et al., 2017)	During 1970–2012; Pakistan	ARDL; FMOLS and DOLS; ADF and PP test		√ (CO_2)	√	← →
Dong, Sun (Dong et al., 2018)	During 1993–2016; for China	ARDL; FMOLS, DOLS, and CCR regressions; VECM Granger causality		√ (CO_2)	√	
Dogan and Seker (Dogan and Seker, 2016a)	During 1980–2012; for EU-15 countries	ordinary least squares		√ (CO_2)	√	← →
Bhattacharya, Awaworyi Churchill (Bhattacharya et al., 2017)	During 1991–2012; for 85 countries	GMM; FMOLS		√ (CO_2)		
Sinha and Shahbaz (Sinha and Shahbaz, 2018)	During 1971–2015; for India	ARDL		√ (CO_2)	√	
Nguyen and Kakinaka (Nguyen and Kakinaka, 2019)	During 1990–2013; for 107 countries	FMOLS and DOLS	√ (CO_2) in case of low-income countries	√ (CO_2) in case of high-income countries	√	
Bilgili, Koçak (Bilgili et al., 2016)	During 1977–2010; for 17 OECD countries	FMOLS and DOLS; LLC, IPS and ADF-Fisher unit root tests		√ (CO_2)	√	→
Dogan and Seker (Dogan and Seker, 2016b)	During 1985–2011; for top countries listed in Renewable Energy Country Attractiveness Index	CADF and the CIPS unit root tests; FMOLS and DOLS.		√ (CO_2)	√	
Zoundi (Zoundi, 2017)	During 1980–2012; for 25 African countries	ARDL; GMM; DOLS, and FMOLS.		√ (CO_2)	√	
Bekun, Alola (Bekun et al., 2019)	During 1996–2014; for 16 EU countries	PMG-ARDL		√ (CO_2)		
Danish, Ulucak (Danish et al., 2020)	During 1992–2016; for BRICS	FMOLS and DOLS	√ (env. Quality)		√	
Dogan and Ozturk (Dogan and Ozturk, 2017)	During 1980–2014; for the United States	ARDL		√ (CO_2)	√	
Destek, Ulucak (Destek et al., 2018)	During 1980–2013; for 15 EU countries	FMOLS and DOLS		√ (CO_2)	√	
Khattak, Ahmad (Khattak et al., 2020)	During 1980–2016; for BRICS countries	CCEMG technique		√ (CO_2)	√	
Zandi, Haseeb (Zandi et al., 2019)	During 1990–2017, 105 developed and developing countries	FMOLS and DOLS		√ (CO_2)		←→

of EU countries. Study findings documented a negative, statistically significant association in empirical nexus, suggesting that clean energy integration through biofuel and RE is directly connected with reducing CO_2 level in another study. Shafiei and Salim (2014) documented a positive role between non-RE and carbon emission and negative association between RE and CO_2. Ben Jebli et al. (2016) investigated the EKC hypothesis by taking into account the role of renewable and non-REC on the environment of 25 Organisation for Economic Cooperation and Development (OECD) countries for the period 1980–2018. Empirical estimation with FMOLS validated the EKC hypothesis and established a positive association between non-REC and environmental degradation. The summary of the literature survey focusing on RE and the environment is displayed in **Table 1**.

Second, environmental degradation is a significant problem in economics and has garnered substantial attention from various academics and economists over the last few decades. Countries are confronted with severe global warming issues as a result of the continued rise in carbon emissions. Numerous causes that contribute to the environmental deterioration have been discovered lately, and governments are attempting to address these issues that affect environmental quality. Environmental deterioration has been a significant concern for nations globally in recent years as carbon emissions have increased. Environmental sustainability is a critical issue for nations; yet, the discussion about the role of innovation and institutions in achieving ES is still insufficient. There is a dearth of knowledge about how countries may accomplish both economic development and environmental protection. Innovation is seen as a successful strategy as it improves energy efficiency and produces greener products, thus lowering carbon emissions. Mongo et al. (2021) investigated the impact of environmental innovation on environmental degradation by taking a panel of 15 EU nations over 23 years by using autoregressive distributed lag (ARDL) in panel form. The study established a positive impact in reducing carbon emission in the long run, but rebound effects were revealed in the short run.

Third, according to economic theory, trade liberalization between nations with varying levels of environmental protection can lead to pollution-intensive industries concentrating in countries with lower environmental regulations. This impact is known as the pollution haven effect, and it is the most contentious area of discussion when it comes to TL and the environment. In the economic literature, there is no consensus on whether the pollution haven effect exists. Suppose one country internalizes the social cost of the environment and does not include the environment in international commerce. In that case, the last country has a comparative advantage in items with high environmental costs (Copeland and Taylor, 1994). The linking between trade openness and environmental quality has been extensively studied via the EKC paradigm by examining the relationship between per-capita income and inequality (Grossman and Krueger, 1995). According to the EKC theory, transitional nations may achieve sustainable economic development after reaching a certain level of per-capita income.

In addition, trade openness is a key element in assisting transitional countries to simultaneously reduce carbon dioxide emissions and increase economic development via a combination of size, composition, and method impacts. Moreover, trade openness can be viewed as a critical element affecting environmental quality and regulatory compliance. Numerous studies have been conducted to determine the effect of trade openness on CO_2 emissions. According to Antweiler et al. (2001), trade openness can impact environmental quality via scale, composition, and technique effects. The influence of trade openness on environmental quality may be classified into three categories: size, composition, and method (Grossman and Helpman, 1991). Economic development resulting from trade results in a rise in pollutant emissions due to increased energy consumption and cross-border transportation services. The composition effect is brought about by a company's decision to specialize in a particular industry to gain a competitive edge. This impact varies by competitive advantage source. Because of trade liberalization, the technique's impact results from technology flowing into less-developed nations (Copeland and Taylor, 2001).

In the existing literature, two lines of evidence have suggested regarding the role of trade openness and environmental degradation. First, a growing number of researchers advocated the positive role of trade openness on environmental degradation (Managi et al., 2009), Ahmar and del Val (2020; Yu et al., 2019; and Park et al. (2018). In a study, Ling et al. (2015) postulated that trade openness offering technological efficiency positively correlated with environmental quality by lower carbon emission in the ecosystem. It is due to trade openness-led innovation increasing technical effects and reducing scale effects in aggregate output. The second line of empirical studies established an adverse association between trade and environmental degradation (Nasir and Ur Rehman [2011], Shahbaz et al. [2017]; and Zameer et al [2020]). In a study, Dean (2002) pustulated that trade harms pollution emissions, resulting in environmental deterioration. However, it also lowers pollution emission growth via the income effect, resulting in a beneficial impact on the environment. The summary of literature survey is displayed in **Table 2**.

Conceptual Model and Proposed Hypothesis of the Study

Current economic literature has extensively discussed the linkage between trade, RE, economic growth, innovation in environmental technologies, and carbon emission. A portion of research projects has investigated the inner relationship among CO_2 emissions and the variables mentioned previously. Mhenni (2005) empirically explored the EKC hypothesis using GMM methodology from 1980 to 1997; the researcher examined carbon emissions, vehicles, and fertilizer concentration to conclude that the EKC hypothesis is not proven for environmental pollutants. Chebbi et al. (2011) relied on a concentration empirical approach to examine how trade openness, per-capita CO_2 emissions, and economic growth influence each other. The empirical findings specified that carbon emissions, trade openness, and economic growth Granger cause one another; further analysis forecasted short-run causal association among trade openness and carbon emissions. In an earlier study, Belloumi (2009) researched how economic growth is influenced by energy consumption through the Johansen cointegration approach to indicate the bidirectional causal association between economic growth and energy consumption in the long run. Fodha and Zaghdoud (2010) also used the causality analysis approach to analyze how economic policies and carbon emissions influence the environmental deterioration in developing economies. The application of VECM and Johansen causality analysis indicated unidirectional causal association from economic growth to carbon emissions in short- and long-run empirical findings. The present study does not concentrate on detecting ES factors in Tunisia and Morocco but instead on evaluating the effects of REC, EI, and TR on ES.

Figure 1 exhibits the conceptual framework and the possible causal hypothesis of the study, which is to be tested in the empirical investigation:

TABLE 2 | Summary of literature survey: nexus between trade and environment

Authors	Sample and period	Methodology	Remarks		EKC	Causality
			Positive	Negative		
Khan and Gupta Khan and Gupta. (2020)	India (1985–2018)	OLS	√		√	
Ali, Yusop Ali et al. (2021)	OIC countries (1991–2018)	DCCE		√	√	
Rahman, Ghazali Rahman et al. (2020)	Lithuania (1989–2018)	ARDL	√		NOT	→
Yu, Nataliia Yu et al. (2019)	CIS (2000–2013)	IV	√			
Rana and Sharma Rana and Sharma (2019)	India (1982–2013)	ARDL			√	→
Shahzad, Naifar Shahzad et al. (2017)	1971–2011(Pakistan)	ARDL	√			←→
Destek, Balli Destek et al. (2016)	10 CEECs (1991–2011)	FMOLS		√	√	→
Oktavilia and Firmansyah Oktavilia and Firmansyah, 2016)	Indonesia (1976–2014)	OLS	√		√	
Ling, Ahmed Ling et al. (2015)	Malaysia (1970QI-2011QIV)	ARDL		√	√	
Alam, Rehman Alam et al. (2011)	During 1971–2008; Pakistan	Johansen maximum likelihood cointegration test; ADF test		√		
Umer, Khoso Umer et al. (2014)	12 Asian countries; during 1995–2012	POLS, RE, FE		√		
Zamil, Furqan Zamil et al. (2019)	OMAN; during 1972–2014	ARDL model	√			
Khan and Gupta Khan and Gupta (2020)	India; during 1985–2018	ARDL	√		√	
Engin Balın, mumcu akan Engin Balın et al. (2018)	During 1974–2013; Turkey	ARDL	√		√	
Noreen, Hina Noreen (2020)	During 1980–2018; Pakistan	ARDL		√	√	
Fotros and Maaboudi Fotros and Maaboudi, 1971-2005)	During 1971–2005; Iran	GMM	√			
Anwar and Elfaki Anwar and Elfaki (2021)	Indonesia; during 1965–2018	ARDL; FMOLS; DOLD; CCC	√			
Tran, Gan Tran et al. (2019)	Vietnam; during 1985–2013	ARDL	√			
Mahrinasari, Haseeb Mahrinasari et al. (2019)	From 1980 to 2017 Singapore, Malaysia, Thailand, Indonesia, and the Philippines	FMOLS and DOLS estimations	√			←→
Yi, Li Yi et al. (2021)	27 provinces in China; during 1998–2018	OLS model		√	√	
Salam, Sattar Salam et al. (2015)	*During 1980–2010; Pakistan*	*Granger causality test*	√			←→
Fotros and Maaboudi Fotros and Maaboudi (2011)	Iran; during 1971–2006	GMM	√			→
Sannassee and Seetanah (Sannassee et al. (2016)	During 1976–2013 Mauritius	ARDL.	√			
Mehrara and ali Rezaei Mehrara and ali Rezaei (2013)	*During 1960–2012 for BRICS*	*PGM*	√		√	
Zandi, Haseeb Zandi et al. (2019)	During 1990–2017, 105 developed and developing countries	FMOLS and DOLS	√			→
Shahbaz, Nasreen Shahbaz et al. (2017)	During 1980–2014 105 countries	FMOLS; VECM	√		√	←→
Le, Chang Le et al. (2016)	During 1990–2013; for 98 countries	GLS		√	√	← →
Dogan and Seker Dogan and Seker (2016b)	During 1985–2011; for top countries listed in Renewable Energy Country Attractiveness Index	FMOLS and DOLS		√	√	
Ahmed, Rehman Ahmed et al. (2017)	During 1971–2013; for 5 Asian countries	FMOLS	√		√	→
Sherafatian-Jahromi and Othman Sherafatian-Jahromi and Othman (2020)	During 1960–2016; for Australia	ARDL; FMOLS and DOLS	√			
Al-Mulali, Ozturk Al-Mulali et al. (2015)	During 1990–2013; for 23 EU countries	VECM; FMOLS.		√		
Chang Chang, 2015)	During 1997–2007; for 51 countries	ADF, KPSS, PP tests; GMM	√ (in high corrupted countries)	√ (in low corrupted countries)		
Ali, Law Ali et al. (2016)	During 1971–2011; for Nigeria	ARDL		√		
Zhang, Liu Zhang et al. (2017)	During 1971–2013; for ten newly industrialized countries	OLS, FMOLS, and DOLS; VECM Granger causality test		√	√	
Destek, Ulucak Destek et al. (2018)	During 1980–2013; for 15 EU countries	FMOLS, and DOLS		√	√	

(Continued on following page)

TABLE 2 | (*Continued*) Summary of literature survey: nexus between trade and environment

Authors	Sample and period	Methodology	Remarks		EKC	Causality
			Positive	Negative		
Afridi, Kehelwalatenna Afridi et al. (2019)	During 1980–2016; for SAARC countries	OLS; LLC, and IPS unit root tests		√	√	→
Jabeen Jabeen (2015)	During 1980–2013; Pakistan	The Johansen-Juselius (JJ) Method; ADF test; VECM	√		√	
Shahbaz, Kumar Tiwari Shahbaz et al. (2013)	During 1965–2008; South Africa	ARDL bounds test	√		√	
Charfeddine and Ben Khediri Charfeddine and Ben Khediri (2016)	During 1975–2011; for UAE	VECM Granger causality	√		√	→
Hakimi and Hamdi Hakimi and Hamdi (2016)	During 1971–2013 Tunisia and Morocco	VECM; F-ADF and PP test		√ (environment)		
Rafindadi Rafindadi (2016)	During 1971–2011; for Nigeria	ARDL; VECM model	√			

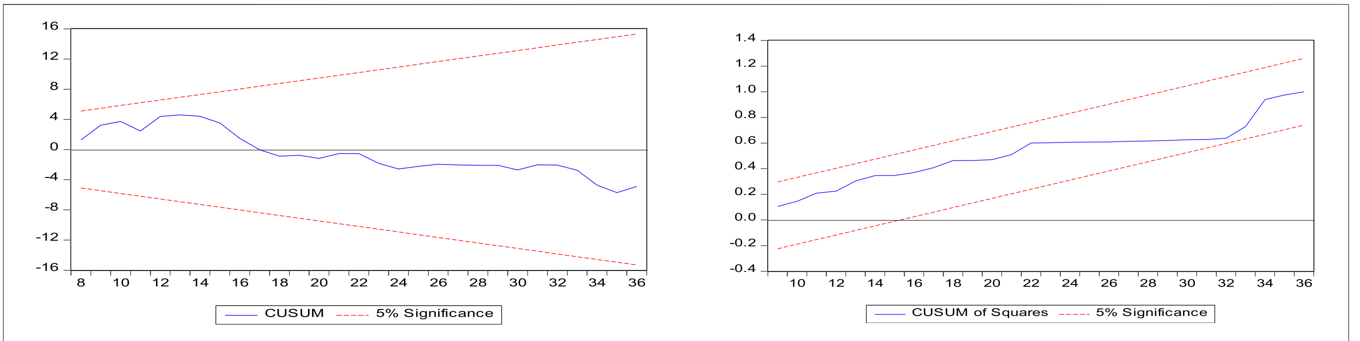

FIGURE 1 | Linear ARDL CUSUM and CUSUMSQ graphs (Morocco).

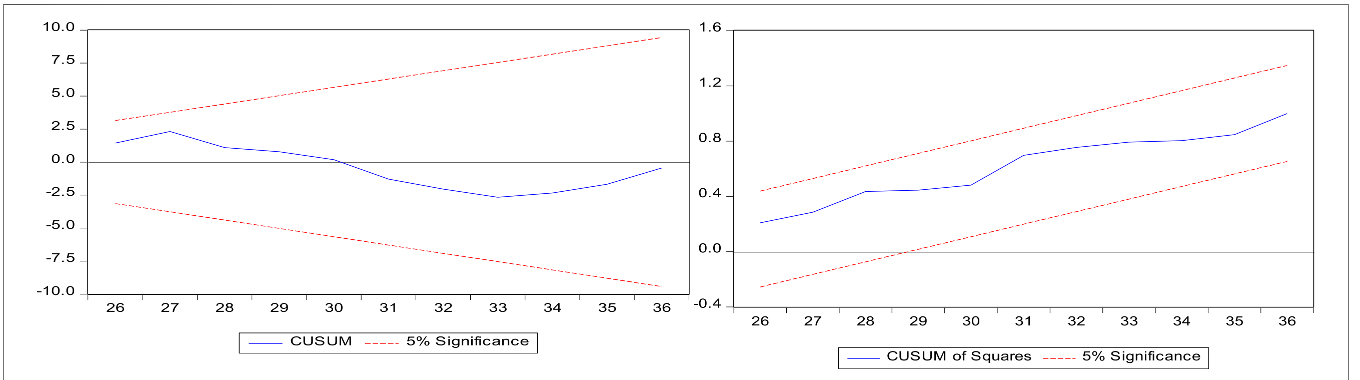

FIGURE 2 | Linear ARDL CUSUM and CUSUMSQ graphs (Tunisia). Asymmetric long- and short-run coefficients.

H_1: EI Granger causes ES and *vice versa*

H_2: TR Granger causes ES and *vice versa*

H_3: REC Granger causes environmental sustainability and *vice versa*

H_4: EI Granger causes REC and *vice versa*

H_5: TR Granger causes REC and *vice versa*

H_6: EI Granger causes TR and *vice versa*

DATA AND MODEL

Descriptive Statistics and Model Specification

The current study utilized time-series data from 1980 to 2018 for Tunisia and Morocco. As a dependent variable, ES is measured by carbon emission per capital extracted from British Petroleum. As

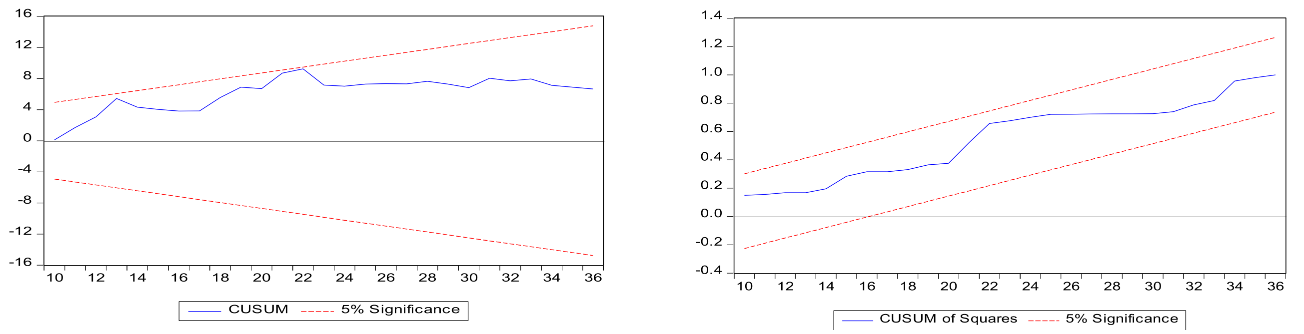

FIGURE 3 | NARDL CUSUM and CUSUMSQ graphs (Morocco).

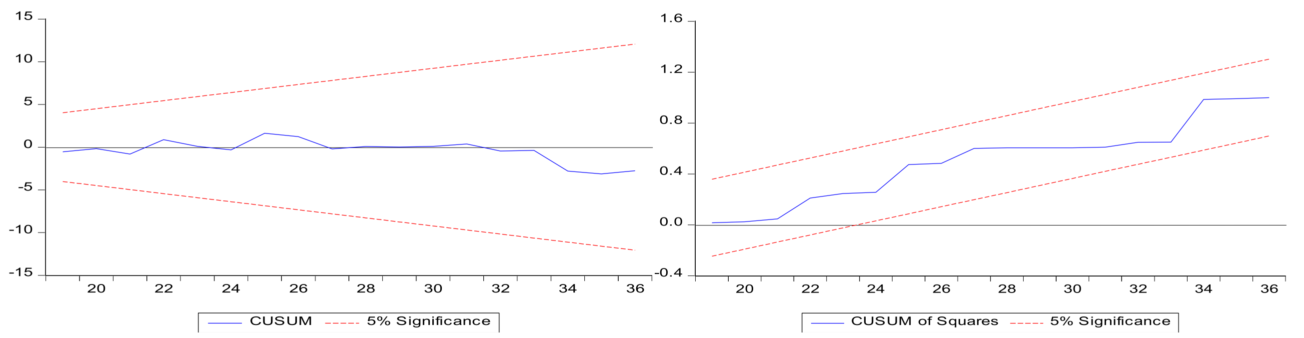

FIGURE 4 | NARDL CUSUM and CUSUMSQ graphs (Tunisia).

TABLE 3 | Descriptive statistics of reserch variales.

	ES	RE	EI	TR	*Y*
Panel A: for Morocco					
Mean	13.30576	3.602237	10.37888	53.6197	6574.143
Maximum	26.89927	4.038096	15.59	110.5771	15974.64
Minimum	9.605895	3.227796	2.37	26.2567	1330.757
Standard deviation	5.516448	0.189496	2.193905	12.79785	4422.016
Skewness	1.92979	0.075355	−1.29837	2.295341	0.659634
Kurtosis	4.97076	2.896117	7.324	12.46061	2.124046
Jarque–Bera	28.17038	0.050257	38.16009	165.8664	3.761641
Panel B: for Tunisia					
Mean	1.029635	48.32269	7.134816	32.28183	864.388
Maximum	1.799825	58.65286	11.24	55.79372	2100.751
Minimum	0.543977	36.02122	2.8	12.21927	296.4352
Standard deviation	0.372336	6.101245	2.412017	14.13899	607.5317
Skewness	0.658441	−0.42325	0.12998	0.136875	0.74026
Kurtosis	2.178882	2.498295	1.803859	1.652436	2.023826
Jarque–Bera	13.61262	21.45241	22.2475	12.8363	4.717281

independent variables, the study considered REC, EI, TR, and economic growth (Y) and all the data were extracted from world development indications published by World Bank (2021). We convert selected variables into natural logarithm form to normalize the data and arrive at reliable and consistent estimates (Nathaniel, 2020).

The present research used the log model to examine the EKC hypothesis and the impact of RE, EI, and international commerce in promoting ES in Tunisia and Morocco. The following empirical model is to be implemented.

$$lnES_{2t} = \vartheta_0 + \vartheta_1 lnGDP_t + \vartheta_2 lnGDP_t^2 + \vartheta_3 lnRE_t + \vartheta_4 lnEI_t + \vartheta_5 lnTR_t + \epsilon_t \quad (1)$$

In the equation mentioned previously, $lnES_2$ is taken as a proxy for ES; $lnGDP$ is the level of economic growth; and $lnGDP^2$ is the nonlinear term to investigate the EKC hypothesis. $lnRE$ represents REC, $lnEI$ represents the level of environmental innovation in the environmental industry, $lnTR$ refers to volumes of international trade, and ϵ accounts for the error term.

The pursuit of economic progress has put extra pressure on energy consumption and infrastructure development, which has led to significant environmental challenges in CO_2 emissions. In addition, we include GDP^2 as it is a major contributor in alleviating ecological problems (Qamruzzaman, 2021). As previously mentioned in the introduction and literature review, We included REC and EI in our empirical analysis because these factors not only alleviate ecological pressure but also reduce the reliance on fossil fuels in the energy mix, thereby sustaining the impact of environmental reforms, particularly in developing economies (Qamruzzaman, 2021; Zhang et al., 2021). Finally, we have included the total volume of international trade as it is a better instrument to measure the impact of industrial and economic activities on environmental degradation (Liddle, 2014). Domestic trade expansion through trade liberalization exacerbates ecological issues through increasing energy consumption, industrial and public infrastructure growth, and continued reliance on fossil fuels as a source of energy. On the other hand, trade openness can mitigate environmental externalities via energy efficiency, creative technology, and economies of scale (Liu et al., 2017). Thus, the inclusion of TR effects in empirical assessment with EKC might reveal a new hope of rethinking the policies in environmental improvement.

The descriptive statistics of research variables is displayed in **Table 3**. Elementary assessment reveals that the mean value of ES measured by carbon emission in Morocco (Tunisia) is 13.3057 (1.0296) falls between 26.8992 and 9.6058 (1.7998 and 0.5439); the variable for RE measured by REC as a percent of total consumption that exposed the mean value is 3.602237 (48.32269) falls between 4.038096 and 3.227796 (58.65286 and 36.02122). EI proxied by green patent application reveals the mean value of 10.37888 (7.134816), which falls between 15.59 and 2.37 (11.24 and 2.8). The sum of export and import was used for measuring the effects of TR with the mean value of 53.6197 (32.28183), which falls between 110.5771 and 26.2567 (55.79372 and 12.21927), and the mean value of economic growth is 6574.143 (864.388), which falls between 15974.64 and 1330.757 (2100.751 and 296.4352).

ESTIMATION STRATEGY

Unit Root Test

Time-series databases' empirical model assessments persistently seek to detect the research units' order of integration for appropriate econometric model selection (Jia, 2021). Following the existing literature trend of variables properties evaluation, the study performed several unit root tests to establish the order of integration in research units, such as the ADF: augmented dickey fuller test P-P: phillips perron test GS-ADF: KPSS: Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests. Furthermore, the study implements unit root test with unknown structural break test following Zivot and Andrews (Zivot and Andrews, 2002).

Bayer and Hanck Cointegration Test

In recent period detecting the long-run association among variables, research has been extensively applying the newly introduced cointegration test commonly known as combine cointegration, familiarized by Bayer and Hanck (2013) over conventional cointegration tests such as those of Engle and Granger (1987), Johansen (1991), and Banerjee et al. (1998). Bayer and Hanck (2013) offered a cointegration test with a combination existing cointegration test with joint test statistics. The advantage of the combined cointegration test is consistency and reliability in estimating the tested coefficient, implying that aggregation of several cointegration tests eliminates the inherent limitation in conventional testing procedures that are short and limited. Following Bayer and Hanck (2013), the combination of the computed significance level (p value) of the individual cointegration test in this article is in Fisher's formula as follows:

$$\mathrm{EG-JOH} = -2\left[\mathrm{In}\left(P_{EG}\right) + \left(P_{JOH}\right)\right] \quad (2)$$

$$\mathrm{EG-JOH-BO-BDM} = -2\left[\mathrm{In}\left(P_{EG}\right) + \left(P_{BO}\right) + \left(P_{BDM}\right)\right] \quad (3)$$

The possible p values of several individual cointegration tests to be extracted from Engle and Granger (1987), Johansen (1995), Peter Boswijk (1994), and Banerjee et al. (1998) P_{EG}, P_{JOH}, P_{BO}, and P_{BDM}, respectively. To get evidence regarding the long-run association, the calculated F statistics has to be greater than the critical value proposed by Bayer and Hanck (2013) and is the rejection of the null hypothesis "no cointegration."

Symmetry and Asymmetry ARDL

We performed extensive unit root analysis to begin the econometric analysis as it is a prerequisite for cointegration and causality analysis. After confirming the variables' integration order of the ARDL and nonlinear autoregressive distributed lag (NARDL) methodologies, that is, data series is stationary at level or first difference, we applied nonlinear and linear cointegration analyses.

We have selected asymmetric (nonlinear) and symmetric (linear) ARDL approaches for the principal empirical analysis. The primary reason for selecting these methodologies is that ARDL and NARDL are flexible and can be used where variables are integrated at level or first difference and suitable for small samples. ARDL requires appropriate lag selection as it can be used to eliminate the issue of endogeneity. Furthermore, a suitable lag length can address the occurrence of multicollinearity in the asymmetric ARDL (Shin et al., 2014).

TABLE 4 | Results of conventional unit root test.

	ADF	GF-DLS	PP	KPSS		ADF	GF-DLS	PP	KPSS
	At level					After first difference			
Panel A: for Morocco									
ES	−0.64	−2.075	−1.239	0.7660	ES	−4.15	−4.774	−3.25	0.1320
RE	−1.777	−0.11	−2.772	0.9200	RE	−5.247	−3.749	−4.487	0.1500
EI	−0.388	−2.283	−2.232	0.8540	EI	−5.94	−3.457	−5.081	0.1510
TR	−1.414	−0.676	−1.701	0.8730	TR	−7.331	−3.685	−3.539	0.1140
Y	−2.975	−0.972	−0.282	0.7870	*Y*	−7.512	−3.478	−3.453	0.1520
Panel B: for Tunisia									
ES	−5.419	−4.008	−4.154	0.1000	ES	−4.651	−3.818	−5.241	0.1090
RE	−6	−2.186	−4.998	0.1260	RE	−7.657	−2.825	−4.756	0.1060
EI	−6.651	−3.172	−5.602	0.1470	EI	−4.552	−4.289	−5.14	0.0750
TR	−5.674	−4.673	−3.696	0.0770	TR	−7.173	−4.087	−5.019	0.1730
Y	−7.145	−4.398	−5.926	0.0760	*Y*	−7.077	−2.446	−4.868	0.1120

The application of ARDL provides us with long- and short-run empirical results, all together, and the lagged ECT provides information about long-run equilibrium's convergence. Bearing this in mind, we transform Eq. 1 into the following ARDL model:

$$\begin{aligned}\Delta(lnCO_2)_t = \sigma_0 &+ \Sigma_{k=1}^{p}\beta_{\alpha k}(lnCO_2)_{t-k} + \Sigma_{k=0}^{p}\beta_{bk}\Delta(lnGDP)_{t-k}\\ &+ \Sigma_{k=0}^{p}\beta_{ck}\Delta\left(lnGDP^2\right)_{t-k} + \Sigma_{k=0}^{p}\beta_{dk}\Delta(RE)_{t-k}\\ &+ \Sigma_{k=0}^{p}\beta_{ek}\Delta(EI)_{t-k} + \Sigma_{k=0}^{p}\beta_{fk}\Delta(TR)_{t-k}\\ &+ \beta_1(CO_2)_{t-1} + \beta_2(lnGDP)_{t-1} + \beta_3\left(lnGDP^2\right)_{t-1}\\ &+ \beta_4(RE)_{t-1} + \beta_5(EI)_{t-1} + \beta_6(TR)_{t-1} + \mu_t\end{aligned} \tag{4}$$

where $\beta_{\alpha,b,c,d,e,f}$, $\beta_{1,2,3,4,5,6}$, Δ, and μ_t. They are used to explain short-run coefficients, long-run coefficients, first difference operator, and the error term, respectively. Before applying the ARDL approach, we used AIC (Akaike information criteria) to select the appropriate lag length.

Any of the following three statistics can test the occurrence of long-run relations. First, the modified F test advanced by Pesaran et al. (2001) tests the joint null hypothesis of no cointegration. The null hypothesis of H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$ articulates the absence of cointegration in the empirical analysis, whereas H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$ is used to indicate cointegration among the variables. Our selection of the bounds tests produce F statistics, which is compared against the critical values to decide the presence of cointegration. Second is a Wald test (WPSS), which also tests the above joint null; and third, a t test (t_{BDM}) proposed by Banerjee et al. (1998) tests the null of no cointegration [$\beta_1 = 0$; $\gamma_1 = 0$; $\mu_1 = 0$] against [$\beta_1 \neq 0$; $\gamma_1 \neq 0$; $\mu_1 \neq 0$]. The testing procedure uses two critical bounds: upper and lower. The null hypothesis of no cointegration can be rejected at conventional significance levels by either the F test, W test, or t_{BDM} test statistic, or both.

Asymmetric Autoregressive Distributed Lagged

In recent time, the application of nonlinear framework has gained an apex position in evaluation of the relationship in empirical studies with a motivation to establish possible innovation in explaining the conventional connection (Qamruzzaman, 2021; Qamruzzaman et al., 2021; Zhang et al., 2021; Yang et al., 2021). Following the existing literature, the study has implemented the nonlinear framework to gauge the asymmetric effects of RE, EI, and TR on ES; the study uses a nonlinear framework widely known as NARDL, which was initiated by Shin et al. (2014), and the study generalizes the following asymmetric long-run regression.

$$\begin{aligned}ES_t = &\left(\beta^+RE_{1,t}^+ + \beta^-RE_{1,t}^-\right) + \left(\gamma^+EI_{1,t}^+ + \gamma^-EI_{1,t}^-\right) + \left(\mu^+TR_{1,t}^+\right.\\ &\left.+ \mu^-TR_{1,t}^-\right) + \varepsilon_t\end{aligned} \tag{5}$$

where β^+, β^-, γ^+, γ^-, $\mu^+ and\, \mu_i^-$ are associated with long-run pavements. The coefficient of β^+ *and* β^- specifies the effect of positive and negative shocks in RE, $\gamma^+ and\, \gamma^-$ denote the asymmetric effects of EI, and $\mu^+ and\, \mu^-$ explain the asymmetric effects of TR on ES. The asymmetric shocks that pose negative and positive changes in RE ($lnRE^+$, $lnRE^-$) EI ($lnEI^+$, $lnEI^-$), and trade ($lnTR^+$, $lnTR^-$) have been derived by implementing the following equations:

$$lnRE^+ = \Sigma_{i=1}^{t}lnRE_i^+ + \Sigma_{i=1}^{t}\max(\Delta lnRE_i, 0) \tag{6}$$

$$lnRE^- = \Sigma_{i=1}^{t}lnRE_i^- + \Sigma_{i=1}^{t}\min(\Delta lnRE_i, 0) \tag{7}$$

$$lnEI^+ = \Sigma_{i=1}^{t}lnEI_i^+ + \Sigma_{i=1}^{t}\max(\Delta lnEI_i, 0) \tag{8}$$

$$lnEI^- = \Sigma_{i=1}^{t}lnEI_i^- + \Sigma_{i=1}^{t}\min(\Delta lnEI_i, 0) \tag{9}$$

$$lnTR^+ = \Sigma_{i=1}^{t}lnTR_i^+ + \Sigma_{i=1}^{t}\max(\Delta lnTR_i, 0) \tag{10}$$

$$lnTR^- = \Sigma_{i=1}^{t}lnTR_i^- + \Sigma_{i=1}^{t}\min(\Delta lnTR_i, 0) \tag{11}$$

The generalized form of the nonlinear empirical model is as follows;

TABLE 5 | Unit root test with an unknown structural break.

	At level			First difference		
Panel A: for Morocco						
	Test statistics	**Break year**	**Lag order**	**Test statistics**	**Break year**	**Lag order**
ES	−2.491	2001	1	−4.917	2013	2
RE	−1.976	2004	3	−5.951	2017	3
EI	−2.901	2013	2	−8.733	2015	2
TR	−1.933	2001	2	−5.627	2001	2
Y	−2.372	2015	2	−8.947	2016	2
Panel B: for Tunisia						
ES	−2.169	2014	3	−6.558	2000	2
RE	−2.205	2017	1	−8.135	2015	3
EI	−2.929	2009	3	−7.272	2016	1
TR	−2.515	2017	2	−8.327	2013	1
Y	−2.316	2013	3	−7.856	1997	3

TABLE 6 | Results of combined cointegration test.

	EG-JOH	Critical value	EG-JOH-BO-BDM	Critical value	Remarks
Panel A: for Morocco					
ES|RE, EI, TR, *Y*	14.132	11.229	26.868	21.913	√
RE|ES, EI, TR, *Y*	13.382	10.895	31.227	21.106	√
EI|ES, RE, TR, *Y*	12.033	10.637	27.575	20.486	√
TR|ES, RE, EI, *Y*	12.182	10.576	31.012	20.143	√
Y|ES, RE, EI, TR	15.071	10.419	34.198	19.888	√
Panel B: for Tunisia					
ES|RE, EI, TR, *Y*	21.078	11.229	73.309	21.913	√
RE|ES, EI, TR, *Y*	14.092	10.895	43.314	21.106	√
EI|ES, RE, TR, *Y*	16.601	10.637	71.43	20.486	√
TR|ES, RE, EI, *Y*	15.238	10.576	49.924	20.143	√
Y|ES, RE, EI, TR	14.705	10.419	51.778	19.888	√

TABLE 7 | Symmetry and asymmetry cointegration test.

Panel A: for Morocco					
Model	**Fpass**	**BDM**	**Wpass**	**Lag order**	
ES = Y Y^2, RE, EI, TR	8.225*	−14.6125*	12.614*	[1, 0, 1, 0, 1]	
ES = Y, Y^2, RE^+, RE^-, EI^+, EI^-, TR^+, TR^-	25.614*	−7.2057*	16.845*	[1,1,1,2,1,0,2,0,1]	
Panel B: for Tunisia					
ES = Y Y^2, RE, EI, TR	15.2541*	−8.219-	10.945*	[1,0,2,1,1]	
ES = Y, Y^2, RE^+, RE^-, EI^+, EI^-, TR^+, TR^-	12.241*	−7.9112*	22.614*	[1,1,1,0,1,0,1,1,20]	
	Critical valued (ARDL)			**Critical values (NARDL)**	
	LCB I(0)	**UCB I(I)**		**LCB I(0)**	**UCB I(I)**
10% critical value	2.08	3		2.86	3.96
5% critical value	2.39	3.38		2.55	3.45
1% critical value	3.06	4.15		1.96	2.91

*Note: *, **, and *** represents significance level at 1, 5 and 10%, respectively.*

TABLE 8 | Results of long- and short-run coefficients with symmetry assumption.

	Morocco				Tunisia			
	Coefficient	Standard	t Statistics	p	Coefficient	Standard error	t Statistics	p
Panel A: long-run coefficients								
GDP	0.225525	0.1186	1.901	0.0414	0.3845	0.08799	4.369	0.0414
GDP^2	−0.17417	0.0825	−2.11	0.0092	−0.2271	0.06347	−3.578	0.0001
RE	−0.22162	0.1042	−2.126	0.0034	−0.21619	0.06588	−3.281	0.0004
EI	−0.10739	0.0925	−1.16	0.0905	−0.1176	0.07804	−1.506	0.0905
TR	0.190671	0.0807	2.363	0.0034	0.1834	0.08577	2.138	0.0034
C	−1.65826	0.1233	−13.45	0.0000	−1.58256	0.07926	−19.966	0.0000
Panel B: short-run coefficients								
GDP	0.2547	0.0537	4.74	0.0026	0.24737	0.1071	2.308	0.0526
GDP^2	−0.2845	0.1093	−2.603	0.0093	−0.3845	0.0989	−3.886	0.0003
RE	0.0241	0.0114	2.107	0.0153	0.14153	0.0627	2.255	0.0153
EI	0.0257	0.008	2.958	0.0001	0.1874	0.1098	1.705	0.047
TR	−0.0121	0.009	−1.239	0.0223	−0.0212	0.00783	−2.716	0.0223
ECT (−1)	−0.3308	0.0807	−4.098	0.000	−0.5879	0.07161	−8.209	0
Panel C: Residual diagnostic test								
x^2_{Auto}	0.7581				0.7216			
x^2_{Het}	0.781				0.7647			
x^2_{Nor}	0.7097				0.851			
x^2_{RESET}	0.7859				0.7546			

$$
\begin{aligned}
\Delta lnES_t = \alpha_0 &+ \sum_{i=1}^{n}\mu_1 \Delta lnES_{t-i} + \sum_{i=0}^{m}\mu_2^+ \Delta lnPOS(RE)_{t-i} \\
&+ \sum_{i=0}^{k}\mu_2^- \Delta lnNEG(RE)_{t-i} + \sum_{i=0}^{r}\mu_3^+ \Delta lnPOS(EI)_{t-i} \\
&+ \sum_{i=0}^{j}\mu_3^- \Delta lnNEG(EI)_{t-i} + \sum_{i=0}^{r}\mu_4^+ \Delta lnPOS(TR)_{t-i} \\
&+ \sum_{i=0}^{j}\mu_4^- \Delta lnNEG(TR)_{t-i} + \sum_{i=0}^{r}\mu_5 \Delta lnY_{t-i} + \sum_{i=0}^{j}\mu_6 \Delta lnY^2_{t-i} \\
&+ \gamma_0 lnES_{t-1} + \gamma_1^+ lnPOS(RE)_{t-1} + \gamma_1^- lnNEG(RE)_{t-1} \\
&+ \gamma_2^+ lnPOS(TR)_{t-1} + \gamma_2^- lnNEG(TR)_{t-1} \\
&+ \gamma_3^+ lnPOS(EI)_{t-1} + \gamma_3^- lnNEG(EI)_{t-1} + \gamma_4 lnY_{t-1} \\
&+ \gamma_5^- lnY^2_{t-1} + \omega_t
\end{aligned} \tag{12}
$$

The long-run elasticity can be figured through $R^+ = \frac{-\gamma_1^+}{\gamma_0}$; $R^- = \frac{-\gamma_1^-}{\gamma_0}$; $TO^+ = \frac{-\gamma_2^+}{\gamma_0}$; $TO^- = \frac{-\gamma_2^-}{\gamma_0}$; $EI^+ = \frac{-\gamma_3^+}{\gamma_0}$; $EI^- = \frac{-\gamma_3^-}{\gamma_0}$, similar to the linear ARDL bound testing procedure—by F-pass and W-pass statistics under the joint null hypothesis of no cointegration that is H_0: $\gamma_0 = \gamma_1^+ = \gamma_1^- = \gamma_2^+ = \gamma_2^- = 0$ and the t_{BDM} statistics, which tests the null hypothesis of no cointegration H_0: $\gamma_0 = 0$. When nonlinear cointegration is confirmed, the next step is to investigate long-run symmetry.

$H_0 = (\gamma_1^+ = \gamma_1^-)$; $(\gamma_2^+ = \gamma_2^-)$; $(\gamma_3^+ = \gamma_3^-)$ and short-run symmetry (additive) $H_0 = (\sum_{i=0}^{m-1}\mu_2^+ = \sum_{i=} 0^{k-1}\mu_2^-)$; $((\sum_{i=0}^{r-1}\mu_3^+ = \sum_{i=0}^{j-1}\mu_3^-))$; $(\sum_{i=0}^{r-1}\mu_4^+ = \sum_{i=0}^{j-1}\mu_4^-)$.

The non-ARDL approach primarily relies on the bound test to investigate nonlinear cointegration, whereas the decision criteria for cointegration, alternative, and null hypothesis are similar to the linear ARDL. After investigating cointegration, we devise **Eq. 11** to investigate the asymmetric effects of the variables included on the CO_2.

Furthermore, we applied several diagnostics models to investigate the stability of symmetric and asymmetric models. We also used the Wald test to confirm that both regressors' asymmetric effects are significant.

Lastly, we proceeded with the VECM to identify the causal association between variables through the following model:

$$
\begin{bmatrix} InCo_2 \\ InGDP \\ InGDp^2 \\ InRE \\ InEI \\ InTR \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} + \begin{bmatrix} v_{11k} & v_{12k} & v_{13k} & v_{14k} & v_{15k}v_{16k}v_{17k} \\ v_{21k} & v_{22k} & v_{23k} & v_{24k} & v_{25k}v_{26k}v_{27k} \\ v_{31k} & v_{32k} & v_{33k} & v_{34k} & v_{35k}v_{36k}v_{37k} \\ v_{41k} & v_{42k} & v_{43k} & v_{44k} & v_{45k}v_{46k}v_{47k} \\ v_{51k} & v_{52k} & v_{53k} & v_{54k} & v_{55k}v_{56k}v_{57k} \\ v_{61k} & v_{62k} & v_{63k} & v_{64k} & v_{65k}v_{66k}v_{67k} \end{bmatrix} \times \begin{bmatrix} \Delta InCo_2 \\ \Delta InGDP \\ \Delta InGDp^2 \\ \Delta InRE \\ \Delta InEI \\ \Delta InTR \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} (ECT_{t-1}) + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \end{bmatrix} \tag{13}
$$

In **Eq. 11**, ε and Δ illustrate the error term and the first difference operator. The lagged error correction term has been denoted by ECT_{t-1}. The presence of long-run causal association

TABLE 9 | Long- and short-run coefficient with asymmetric estimation.

	Morocco				Tunisia			
Panel—A: long- and short-run symmetry test								
W_{LR}^{RE}	11.378*				15.302*			
W_{SR}^{RE}	9.113*				9.343*			
W_{LR}^{EI}	14.872*				12.562*			
W_{SR}^{EI}	9.612*				15.347*			
W_{LR}^{TR}	13.699*				9.471*			
W_{SR}^{TR}	13.978*				8.887*			
Panel B: long-run asymmetric coefficients								
	Coefficient	**Standard error**	***t* Statistics**	***p***	**Coefficient**	**Standard error**	***t* Statistics**	***p***
GDP	0.2193	0.0503	4.3598	0.0015	0.1841	0.0079	23.303	0.015
GDP^2	–0.2503	0.0834	–3.0012	0.0016	–0.1406	0.0595	–2.3630	0.0016
RE^+	0.2618	0.0602	4.3488	0.0007	0.1793	0.0577	3.1074	0.007
RE^-	0.1759	0.0801	2.196	0.089	0.1938	0.0703	2.7567	0.009
EI^+	0.2815	0.0291	9.6735	0.0008	–0.1442	0.0046	–31.347	0.000
EI^-	0.2789	0.0744	3.7487	0.001	0.1237	0.0504	2.454	0.0001
TR^+	0.1297	0.0272	4.7661	0.000	0.1099	0.0716	2.791	0.0001
TR^-	–0.1615	0.0805	–2.0062	0.002	–0.1786	0.0336	–5.315	0.000
C	0.181	0.0692	2.6156	0.005	0.2101	0.0845	2.486	0.0001
Panel C: short-run asymmetric coefficients								
GDP	0.0674	0.0301	2.348	0.005	0.0965	0.057	1.692	0.225
GDP^2	0.0623	0.0341	1.827	0.022	0.0755	0.0118	6.398	0.000
RE^+	0.082	0.0843	0.9727	0.646	0.0675	0.0207	3.260	0.000
RE^-	0.0818	0.066	1.2394	0.118	0.1216	0.0559	2.175	0.018
EI^+	0.0964	0.0806	1.196	0.225	0.0648	0.0625	1.036	0.025
EI^-	0.0883	0.0403	2.1911	0.448	0.0841	0.0859	0.979	0.448
TR^+	0.076	0.0069	11.014	0.922	0.1317	0.0642	2.051	0.000
TR^-	0.0839	0.0038	22.079	0.553	0.0734	0.0754	0.973	0.553
ECT (–1)	–0.0958	0.0429	–2.2331	0.004	–0.1082	0.0292	–3.7059	0.001
Panel D: residual diagnostic test								
x_{Auto}^2	0.6817				0.8362			
x_{Het}^2	0.7886				0.7049			
x_{Nor}^2	0.7571				0.7502			
x_{RESET}^2	0.8211				0.7707			
CUSUM	Stable				Stable			
CUSUMSQ	Stable				Stable			

depends on a significant *ECT* with a negative sign. Lastly, we investigate short-run causality through the Wald statistics.

ESTIMATION AND INTERPRETATION

The results of variables' propriety detection are displayed in **Table 4**. It is apparent from the stationary test statistics that all the variables are stationary after the first difference I(1). However, neither variable is exposed to stationary properties after the second difference I(2). The established variables' properties are valid for both country estimations.

The study evaluated the stationary properties with unknown structural breaks by applying the framework proposed by Zivot and Andrews (2002), and test statistics are reported in **Table 5** with panel A for Morocco and panel B for Tunisia. The study reveals that all the variables are stationary after the first difference with a break year; precisely, for the variables, ES reveals break year (large order) for Morocco 2013 (2) and for Tunisia 2000 (2), RE exposed stationary with break year (lag) for Morocco 2017 (3) and Tunisia 2015 (3), EI for Morocco 2015 (2) and Tunisia 2016 (1), for TR in Morocco 2001 (2) and in Tunisia 2013 (1), and finally economic growth in Morocco 2016 (2) and Tunisia 1997 (3), respectively.

Before implementing the prime target model for detecting long- and short-run coefficients, the long-run association was evaluated through the cointegration framework introduced by Bayer and Hanck (2013) with the hull hypothesis on cointegration among research units. From the test statistics of combined cointegration test reports shown in **Table 6**, it is evident that all the test statistics derived with Fisher's effect are higher than the critical value at a 5% level, suggesting that the rejection of null hypothesis alternatively confirmed the long-run association between ES, RE, EI, TR, and Y, which is valid for both economies.

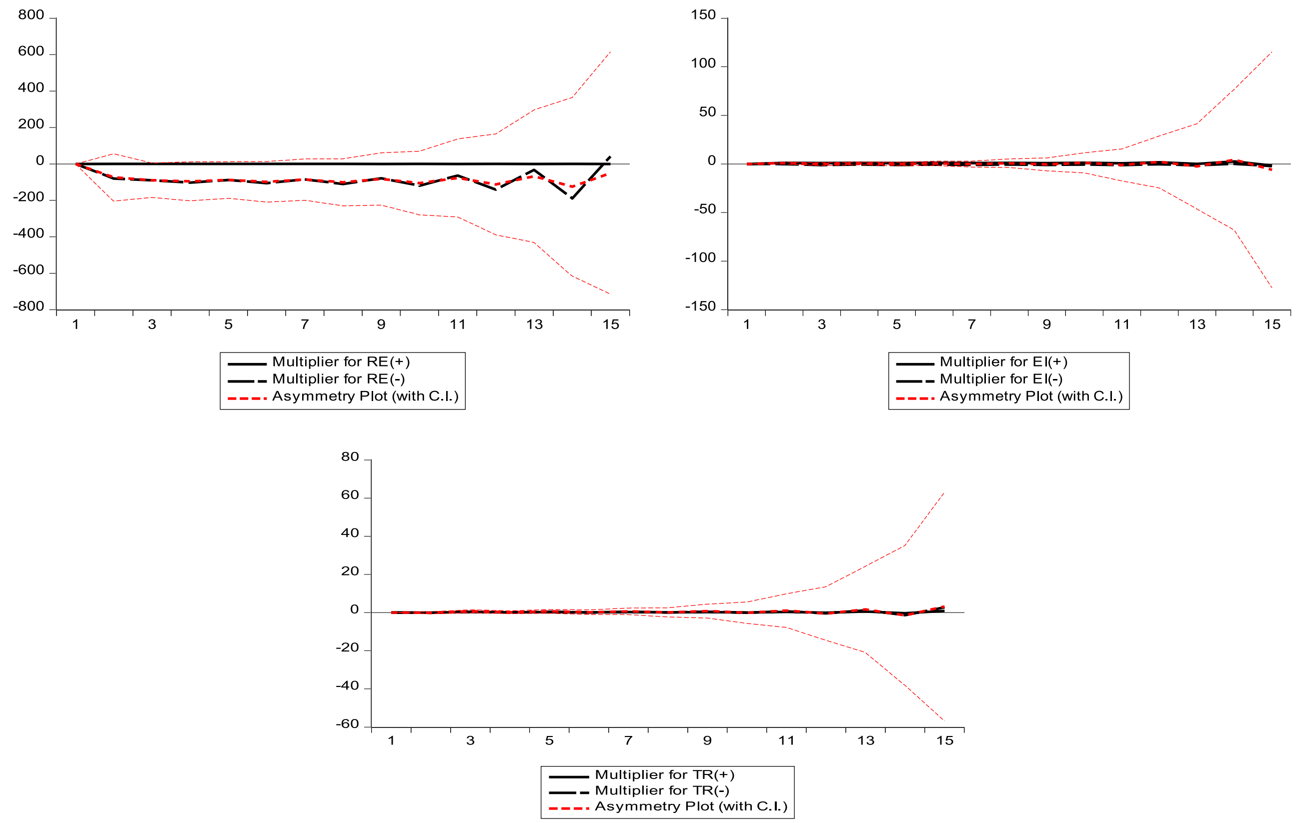

FIGURE 5 | Nonlinear ARDL dynamic multiplier effect graphs (Morocco).

Symmetry and Asymmetry Cointegration

The study used the symmetry and asymmetry cointegration tests by implementing three statistics: Fpass for bound testing, Wpass for joint probability test, and t_{BDM} test. The results of the long-run cointegration test with three test statistics are displayed in **Table 7** with panel A for Morocco and panel B for Tunisia. Referring to test statistics, it is apparent that all the test statistics regardless of estimation assumption that is symmetry or asymmetry are statistically significant at a 1% level, suggesting the long-run association between ES, RE, EI, TR, and Y with the integration of EKC hypothesis in the empirical assessment.

Long- and Short-Run Assessments

Table 8 displays the long- and short-run coefficients under a symmetry environment for Morocco (Tunisia). Regarding the coefficient of economic growth on environment sustainability measured by carbon emission, it is statistically significantly positive at a 1% level with a coefficient of 0.225525 (0.3845). A study suggests that economic activity growth increases carbon emission, thus incurring additional costs of reducing environmental degradation to achieve ES in both Morocco and Tunisia. The nonlinear coefficient of economic growth (Y^2) exposed negative statistical significance at a 1% level for Morocco (Tunisia) with a coefficient of −0.17417 (−0.2271). Study findings suggest that sustainable economic growth with specific periods plays an inductive role in integrating technological and energy efficiency. The positive coefficients for gross domestic product (GDP) and negative coefficient values for GDP^2 validate the EKC hypothesis for Tunisia and Morocco. Our findings confirm that environmental quality initially deteriorates in both countries due to industrial activities but ultimately decreases after certain economic growth levels have been achieved.

The significant impact from RE is evident in environmental quality in Morocco (Tunisia), suggesting a negative statistically significant linkage. More precisely, a 10% growth in RE integration in aggregate energy consumption increases ES by reducing the degree of carbon injected into the ecosystem by 2.216% (2.162%). Study findings suggest that establishing ecological balance in Morocco and Tunisia makes it imperative to initiate policy strategies for transition from fossil fuel dependency to RE integration and increase REC to avoid climate change and higher carbon emissions in the coming decades.

The coefficient value of EI is statistically significantly negative for environmental quality improvement through carbon emission reduction in Morocco (Tunisia) with a coefficient of −0.10739 (−0.1176). In particular, a 10% innovation in energy efficiency can decrease carbon emissions and accelerate ES by 1.073% (1.1176%). Environment innovation in RE technology innovation restricts the flows of carbon emission and augments the process of ecosystem improvement, eventually establishing ES (Wang and Zhu, 2020).

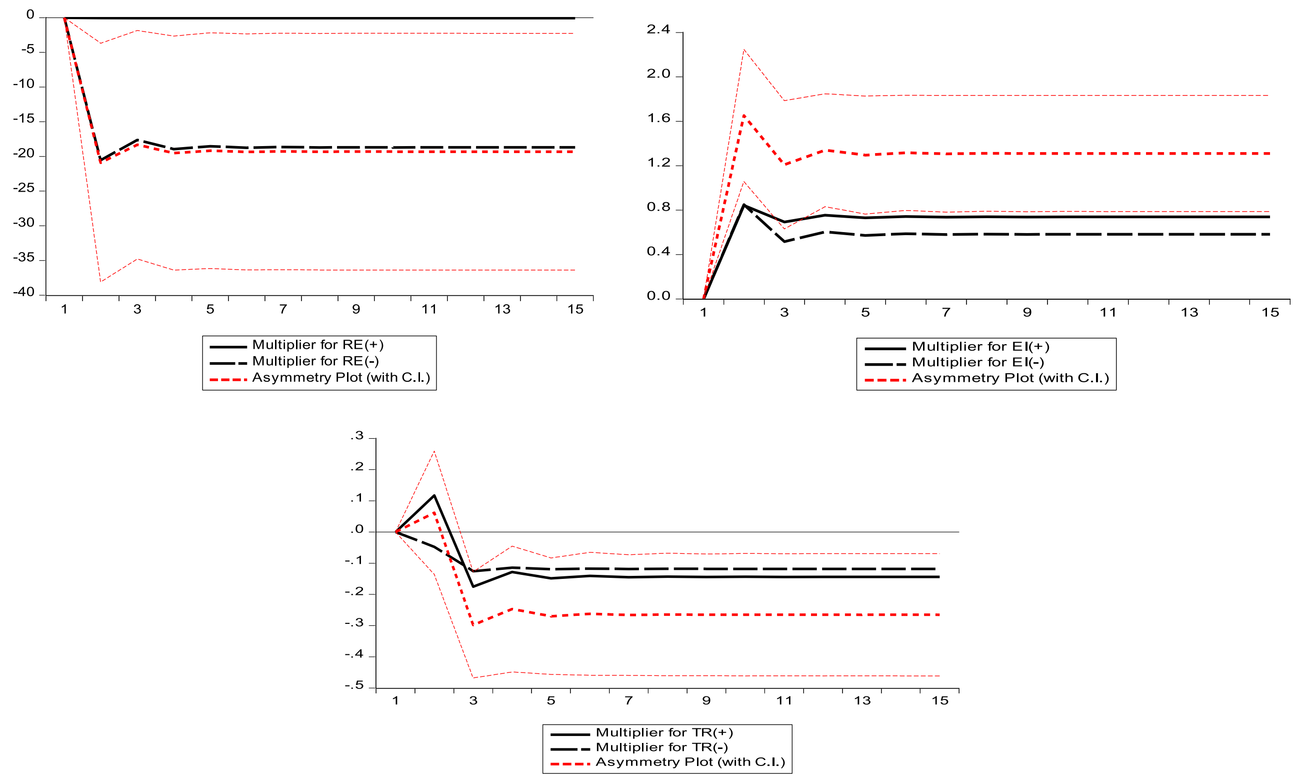

FIGURE 6 | Nonlinear ARDL dynamic multiplier effect graphs (Tunisia).

TABLE 10 | Results of causality test under VECM.

	Short-run						Long-run	Remarks
	ES	**RE**	**EI**	**TR**	**Y**	**Y^2**	**ECT (–1)**	
Panel A: for Morocco								
ES	—	3.652*	10.467*	2.375	4.932*	11.216*	–0.268*	RE→ES; Y←→ES; Y^2←→ES; EI←→RE; ES→EI; Y^2→ES; RE→TR; Y→TR; Y^2 →TR; EI→Y; RE→ Y^2; EI→ Y^2
RE	0.581	—	5.681*	6.360*	0.422	0.427	0.1482	
EI	10.094*	3.321	—	1.147	3.390	6.839*	–0.0648**	
TR	2.990	7.080*	1.581	—	20.823*	12.202*	–0.0566*	
Y	4.101**	2.207	5.262*	1.152	—	1.0240	0.1014	
Y^2	7.4929*	7.821*	6.0707*	2.857	0.818	—	–0.2865**	
Panel B: for Tunisia								
ES	—	7.513*	19.569*	3.566	8.781*	7.776*	–0.0271**	RE←→ES; EI→ES; Y→ES; Y^2→ES; ES→TR; EI→TR; RE→Y
RE	11.719*	—	1.307	1.186	0.378	0.356	–0.0332*	
EI	0.830	1.574	—	3.747	1.595	1.565	0.3559	
TR	11.588*	5.819*	3.328	—	0.553	0.505	–0.0111**	
Y	0.231	5.094*	0.896	0.0358	—	1.132	–0.3272*	
Y^2	0.038	3.874**	0.096	0.0174	0.227	—	0.0381	

*Note: the superscript * and ** specify the level of significance at 1 and 5%, respectively.*

Next, we examined the linkage between TR and ES, and the study documented a statistically significant positive association in Morocco (Tunisia); specifically, a 10% development in TR can significantly decrease ES by 1.096% (1.834%) (TR). The symmetric ARDL illustrates that a 1% increase in COs emissions increases carbon emissions by 0.0041% and 0.0906% for Tunisia and Morocco.

For the short run, the coefficient of error correction terms is negative in sign and statistically significant at a 1% level, implying

TABLE 11 | Results of the empirical model robustness test.

Regressors	FM-OLS			DOLS			CCR		
	Coefficient	**Error**	**Statistic**	**Coefficient**	**Error**	**Statistic**	**Coefficient**	**Error**	**Statistic**
Panel A: for Morocco									
RE	−0.2059	0.0585	−3.519	−0.4954	0.0621	−7.977	−0.3601	0.0333	−10.813
EI	−0.2492	0.0595	−4.188	−0.3825	0.0733	−5.218	−0.3423	0.0727	−4.708
TR	0.3885	0.0334	11.631	0.3743	0.0463	8.084	0.4986	0.0509	9.795
Y	−0.2613	0.0358	−7.298	0.7462	0.0583	12.79	0.4706	0.0562	8.373
Y^2	−0.2825			−0.769	0.0523	−14.703	−0.4545	0.0387	−11.744
R		0.9945		0.9845				0.9871	
Adjusted *R*		0.9802		0.9799				0.9798	
Panel B: for Tunisia									
RE	−0.305	0.0356	−8.567	−0.5211	0.0675	−7.72	−0.6686	0.0557	−12.003
EI	−0.1461	0.041	−3.563	−0.356	0.0701	−5.078	−0.7875	0.0325	−24.237
TR	0.1815	0.0485	3.742	0.5829	0.0384	15.179	0.7361	0.0565	13.028
Y	0.246	0.0458	5.371	0.7023	0.068	10.327	0.7648	0.0368	20.782
Y^2	−0.3417	0.032	−10.67813	−0.5585	0.0426	−13.11033	−0.4989	0.0754	−6.616
R		0.9877		0.9982				0.9925	
R		0.9787		0.9763				0.9799	

that the long-run disequilibrium due to short-run shock in independent variables will reach long-run convergence with a speed of 33.08% in Morocco and 58.79% in Tunisia.

The short-term findings for EI of symmetric ARDL highlight that innovations in the environmental and energy sector in Tunisia (Morocco) have led to lower (higher) carbon emissions in the short run with a coefficient of 0.0257. This is attributed to the allocation of research and development expenditures, significantly higher in Tunisia than in Morocco. Also, the recent focus on environmental and economic reforms means that Tunisia has paid significant attention to the developments in environmental technologies than the rest of the MENA countries, that us, Morocco. Lastly, trade (TR) negatively affects ES in both Tunisia (a coefficient of −0.0121) and Morocco (a coefficient of −0.0212), which is supported by the fact that the integration of globalization and technology transfer contributes to fewer carbon emissions in the short run and positively correlates with energy efficiency.

Moreover, for ensuring model internal consistency and efficiency in estimation, several residual diagnostics tests have been performed (panel C). according to the test statistics, empirical estimations are free from serial correlation, and residuals are normally distributed, with no issue regarding heteroscedasticity. The RESET test confirms stability in model construction. Furthermore, the CUSUM and CUSUM of square test establish coefficient stability and robustness (see, **Figures 1**, **2**).

Asymmetric Long-Run and Short-Run Coefficients

The study moved to gauge the asymmetric effects of positive and negative shocks in RE, EI, and TR on ES. The results are displayed in **Table 9** with three panels of outputs.

Panel A contains the test statistics with the standard Wald test for the long- and short-run with the null hypothesis of "symmetry." The test statistics for the long run (W_{LR}) and short-run (W_{SR}) of each targeted variable in the study revealed statistical significance at a 1% level, suggesting the rejection of the null hypothesis. Thus, the asymmetry association between dependent and independent variables is established in empirical assessment, valid for Morocco and Tunisia. Once the asymmetry was confirmed, the study moved to detect and explain the asymmetric magnitudes of respective variables on ES.

Panel B reports the long-run asymmetric coefficients for Morocco (Tunisia). There is linkage between economic growth and ES, which is statistically significantly positive at a 1% level with a coefficient of 0.2193 (0.1841). The study established that the growth of economic activities increases the level of carbon emission, thus incurring additional costs of reducing environmental degradation to achieve ES in Morocco and Tunisia. The nonlinear coefficient of economic growth (Y^2) exposed negative statistical significance at a 1% level for Morocco (Tunisia) with a coefficient of −0.2503 (−0.1406). Study findings signify that economic growth, in the long run, plays a multivalve role in environmental development with the integration of technological and energy efficiency. The positive coefficients for Y and negative coefficient values for GDP^2 validate the EKC hypothesis for Tunisia and Morocco. Our findings confirm that environmental quality initially deteriorates in both countries due to industrial activities but ultimately decreases after certain economic growth levels have been achieved.

The asymmetric effect of REC, that is, positive and negative shocks, on ES reveals a negative statistically significant linkage in Morocco (Tunisia). Specifically, a 10% positive innovation in RE can increase environmental quality by reducing carbon emission in the ecosystem by 2.618% (1.793%), whereas a 10% adverse shock that decreases the integration of RE suggests reliance on fossil fuel, resulting in increasing carbon emission, hence deteriorating the environmental quality in Morocco

(Tunisia) with a rate of 1.759% (1.938). Study findings postulated that in improving environmental quality to sustainability, the application and integration of RE emerged as critical in this regard. Therefore, effective energy policies focused on energy transition from fossil fuel to green energy to be the best alternative for Morocco and the Tunisian economy.

The analysis of EI's positive and negative shocks presents rather exciting results. Panel B of **Table 9** documents that positive shocks on EI have led to higher carbon emissions in Morocco (a coefficient of 0.2815). In contrast, the opposite is true for Tunisia (a coefficient of –0.1442). On the other hand, adverse shocks in EI hurt environmental quality in Morocco (a coefficient of 0.2789) and Tunisia (a coefficient of 0.1237). Study findings advocate that constant environmental concern induces the economy to invest in technological advancement, eventually improving environmental quality by lessening the ecological effects of excessive carbon emissions.

The findings of the NARDL approach suggest that 1% positive shocks in TR lead to higher carbon emissions in Morocco (a coefficient of 0.1297) and Tunisia (a coefficient of 0.1099). On the other hand, a negative shock in trade liberalization is responsible for higher environmental degradation as it increases carbon emissions into the atmosphere. However, the positive change has a much more profound impact. This is again evidence of the importance of using asymmetric methods in environmental economics.

Moreover, for ensuring model internal consistency and efficiency in estimation, several residual diagnostic tests have been performed (panel D); according to the test statistics, empirical estimations are free from serial correlation; residuals are normally distributed, there is no issue regarding heteroscedasticity, and the RESET test confirms stability in model construction. Furthermore, CUSUM and CUSUM of square test establish coefficients stability and robustness (see **Figures 3**, **4**).

The multipliers for both variables are plotted in **Figures 5**, **6**, which portray adjustment to a new equilibrium after positive and negative shocks. The black dotted line indicates the nonlinear adjustment of CO_2 to adverse shocks, whereas the solid black line portrays the adjustment of CO_2 to a positive shock. The asymmetric pattern indicated by the red dotted line is the difference between both negative and positive shocks.

Next, the study moved in gauging the directional associations between ES, RE, EI, TR, and economic growth by executing a vector error correction model. Granger causality test results under ECM are displayed in **Table 10**, consisting of panel A for Morocco and panel B for Tunisia.

The long-run causalities in empirical estimation was investigated through the lagged error correction term coefficient. For long-run causality, the coefficient of error correction term has to be negative in sign and statistically significant. The study documented that several ECT coefficients are statistically significantly negative, primarily ES treated as the dependent variable, suggesting the long-run causal effects available in the equation.

For the short-run, the study documented that several directional associations in the empirical assessment such as bidirectional causality prevail between economic growth and ES [Y←→ES], EI and REC [EI←→RE] in Morocco, whereas RE and ES [RE←→ES] in Tunisia. Furthermore, the study disclosed several unidirectional linkages between variables, especially to ES, including RE to ES [RE→ES] in Morocco, EI to ES [EI→ES], and economic growth to ES [Y→ES].

To ascertain the long-run impact of REC, EI, and trade on ES in Morocco and Tunisia, the study further implemented fully modified OLS introduced by Phillips and Hansen (1990) and dynamic OLS and canonical cointegrating regression (CCR) familiarized by Stock and Watson (1993). The results of the robustness test are displayed in **Table 11**. Study findings reveal the expected sign for each explanatory variable in explaining the association with ES. More precisely, the magnitudes of RE and EI exposed negative association, and trade augmentation revealed a positive role in carbon emission in Morocco and Tunisia.

DISCUSSION OF RESULTS

The empirical evidence for the existence of the EKC hypothesis through symmetric and asymmetric methodologies is in contrast to Mrabet et al. (2017) and Charfeddine (2017). However, our findings align with Solarin et al. (2017), who investigate a panel of high-income countries. It is evident from empirical estimates that the GDP coefficients are positive, which documents that economic growth takes precedence in Tunisia and Morocco; it drives human demands and is also the primary reason for ecological problems. These outcomes were expected as the recent ecological footprint of Tunisia and Morocco has significantly increased along with its GDP. Also, these countries in recent years have overseen the transformation of the quality of life, and more and more people have access to better sanitation, health, food, and other necessities. However, this massive scale of economic progress has impacted daily lifestyles and has increased demand for natural resources beyond the necessities of basic needs; this, in turn, leads to pressure on environmental quality. The negative coefficient of GDP^2 indicates that the achievement of specific economic goals and prosperity, environmental quality in Tunisia and Morocco can be improved through structural changes in the domestic economy, innovation in environmental technologies, and integration of environmental reform within the economic policies as Ulucak and Bilgili (2018) argued that advanced environmental technologies and stringent regulations minimize the ecological footprint in emerging economies.

The current study also presents interesting empirical outcomes between REC and carbon emissions in Tunisia and Morocco. In recent economic literature, several studies have provided support for REC to reduce environmental degradation. Among these, Bhattacharya et al. (2017) used a panel dataset for 85 developed and developing economies to articulate that growth in RE gas has a significant impact on environmental quality and economic growth especially in developing economies. Likewise, Hu et al. (2018) selected 25 developing economies and used FMOLS and DOLS to indicate that effective implementation of RE leads to lower carbon emissions over the long run. In support of these outcomes, (Dogan et al., 2010) selected SSA countries to explore the association between environmental pollution and RE during the time scale of 1980–2011. They found that higher fossil fuel consumption contributes to environmental pollution, whereas RE hurts environmental degradation. However, Apergis and Payne (2012) contradicted these findings for a panel of 29 developing economies to report that RE positively affects carbon emissions because of inadequate storage technology to deal with supply constraints. For Vietnam, Solarin et al. (2017) highlighted that a lower share of REC means that RE had no significant impact on carbon emissions. Khoshnevis Yazdi and Shakouri (2018) also reported similar outcomes.

Regarding EI and ES, the study documented a positive and statistically significant association, suggesting that clean energy integration in the aggregated productivity expansion boosts economic output and increases ES prospects by lowering carbon emission. Several empirical studies have recently explored the association between EI and carbon emission to capture the effects of RE with patents and R&D expenditure as the primary proxy variable being used. The findings of empirical literature remain inconclusive. In a comprehensive study, Fernández-Amador et al. (2019) investigated the association between carbon emission and innovation in environmental technologies to conclude that environmental technologies effectively reduce carbon emissions over the long and short run. In recent years, Awaworyi Churchill et al. (2019) and Petrović (1968) explored the association between RE, environmental technologies, and carbon emission to report mixed findings for different countries over the different periods and argued that the association between environmental technologies and carbon emissions is significantly dependent on the application of environmental legislation. Several studies such as those of Acemoglu et al. (2012) and Jaffe et al. (2002) have argued that limitation of carbon emissions through environmental technologies is dependent on country-specific characteristics and further explained that these effects rebound over time and negatively affect the accumulation of long-term environmental goals through innovation in green technologies (Braungardt et al., 2016). The energy structure of developing economies is based on the overexploitation of natural and fossil resources. However, in recent decades, this model has been altered by the increase in renewable sources and the implementation of innovations thought to be conducive to a more sustainable model in the energy sector. This new scenario represents an agreement on the need of increasing ES through the deployment of low-carbon technology. The efficacy and application of environmental rules will be critical in the long-term evolution of environmental pollution.

Lastly, we investigate the empirical association between carbon emissions and trade openness. In the last two decades, several studies have explored such association and how it affects economic growth over the long run. Obradović and Lojanica (2017) investigated the association between trade, carbon emissions, and energy consumption for southeastern European countries through the VECM approach to discover the long-run causal association between energy consumption, carbon emissions, and trade openness. However, the authors found no short-term causality between trade and carbon emissions for Bulgaria and Greece. Cherni and Essaber Jouini (2017) furthered the research by using the ARDL approach to examine how trade affects carbon emissions or *vice versa* for Tunisia. The researchers used the Granger causality test to report long- and short-term causal associations and their direction. The empirical analysis revealed the bidirectional causality between trade and carbon emissions and trade and REC; however, it found no causality between REC and carbon emissions. In another study, Kais and Sami (2016) investigated energy consumption and trade effects over carbon emissions for 58 emerging and developed economies from 1990 to 2012. The authors developed three panels, that is, Latin America and Caribbean, north Asian region, and Europe. The empirical analysis indicated that carbon emissions and energy consumption were positive for all three panels. The researchers reported similar trade and carbon emission estimates, and its statistical value was significant for north Asia and Europe. Lastly, the researchers also confirmed the existence of a U-shaped curve for trade and carbon emissions.

CONCLUSION

The current study has attempted to investigate the dynamic association between carbon emissions, trade openness, income, EI, and RE for Tunisia and Morocco. It compares the influence of the variables as mentioned previously in these emerging MENA economies. To analyze this nexus, we applied a series of unit root tests; next, symmetric and asymmetric cointegration was investigated. Afterward, unlike mainstream literature, we used both ARDL and NARDL methodologies to evaluate long-run elasticities comprehensively. We further investigate the impact of positive and negative changes in RE, EI, and trade and how it impacts environmental degradation in Tunisia and Morocco. Finally, we report causal analysis to evaluate the short- and long-run causal association between the variables included in the study.

Our empirical approach allows us to provide useful econometric findings. It is evident from the empirical estimates for asymmetric and symmetric ARDL approaches that GDP and GDP^2 are significant under both empirical approaches. The positive coefficients for GDP and negative coefficient values for GDP^2 validate the EKC hypothesis for Tunisia and Morocco. Initially, environmental quality deteriorates in both countries because of higher industrial activities but ultimately decreases after certain economic growth levels have been achieved. We further disclose that for Tunisia, RE and EI reduce carbon emissions, whereas trade (TR) has a positive association with environmental degradation. However, in the asymmetric ARDL findings, positive (RE^+) and negative (EI^-) contribute to environmental degradation. For Morocco, the empirical estimates (ARDL) for RE, EI, and TR report similar findings as Tunisia. However, the findings for NARDL reveal that adverse changes in trade (TR^-) contribute to environmental degradation.

These findings suggest that policymakers in Tunisia and Morocco must introduce institutional and environmental reforms to achieve higher cohesiveness between domestic and foreign investors. These policies will also allow these emerging economies to take advantage of globalization and higher integration between international trade and FDI. In addition, policy changes aimed at lower tax, and related invectives will allow these investors to promote investments in green energy projects. However, higher taxation and restrictions on outdated technologies will prevent environmental degradation.

We further document that causality runs from GDP and RE toward CO_2 emissions for Tunisia, whereas there is a causal association between EI and trade toward CO_2 emissions for Morocco. This causal association allows us to propose that further environmental policies must promote energy efficiency and energy conservation through better environmental technologies. Furthermore, the share of RE in the energy mix must be increased to minimize the adverse effects on the ecological footprint. In this regard, higher investments in green energy technologies will effectively reduce environmental damage from fossil fuel consumption. In addition, the higher share of fossil fuels in the energy mix must be minimized by adding low pollution natural gas. Lastly, reforms in pricing strategies must be considered a policy mechanism to increase REC in both Tunisia and Morocco.

Finally, although the current study provides a significant contribution to the existing economic literature; however, we have been unable to account for the association between carbon emissions and structural changes in Tunisia and Morocco within the MENA region. These economies rely significantly on informal economies. Further research is required to evaluate the association between industrial competitiveness and microenterprises and how recent economic and environmental policies have affected them. Hence, we encourage future studies to evaluate these policies for MENA regions. Evaluating these policies is a crucial factor in reaching future international climate control agreements in developing economies.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: The World Bank Data Catalog, https://datacatalog.worldbank.org/search/dataset/0037712.

AUTHOR CONTRIBUTIONS

AA: Introduction, methodology, and first draft preparation. MQ: Introduction, methodology, empirical model estimation, and final preparation. All authors contributed to the article and approved the submitted version.

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