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The Environmental Kuznets Curve and Renewable Energy Consumption: A Review

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ABSTRACT

Renewable energy consumption (REC) would reduce pollution and a large pool of literature has probed the Environmental Kuznets Curve (EKC) including REC in a panel or a country-specific model. The present study reviewed 69 empirical studies and found that 57 out of 69 studies validated the EKC but 12 studies did not confirm the EKC. Out of these, 64 studies found that REC reduced emissions. In the country-specific analyses, 18 out of 25 studies validated the EKC and 24 out of 25 studies substantiated that REC reduced emissions. In the panel studies, 39 out of 44 studies validated the EKC and 40 out of 44 studies found that REC reduced emissions. Comparatively, panel studies reported more evidence of the EKC compared to country-specific studies. However, country-specific studies reported more evidence of the positive environmental effect of REC. The results of logistic regression show that the chance of the validity of the EKC is 4.82 times more in the studies if REC reduced emissions in a model. Thus, future studies on EKC testing should include REC in the model. In comparison, panel studies carry more chance of confirmation of the EKC than country-specific studies.

Keywords: Renewable Energy Consumption, The Environmental Kuznets Curve, The Panel Studies, Country-Specific Studies
JEL Classifications: O44, P18, Q20

1. INTRODUCTION

The issue of pollution emissions and global warming is hot in the present environmental and energy economic literature. Renewable energy consumption (REC) would reduce emissions from economic activities and increase carbon productivity. But, the generation of renewable sources of energy and technologies needs a lot of Research and Development (R&D) activities and investment, which may be supported by public finance. Moreover, the economic growth of any country may demand and generate the renewable energy market (Apergis and Payne, 2010). Here, we cannot ignore the discussions of the Environmental Kuznets Curve (EKC). Fossil fuel would be used more during the 1st phase of economic growth, which would damage the environment (Grossman and Kreuger, 1991). Thus, the government of a country may impose pollution taxes to avoid such damages. Here, government regulators are policy suppliers.

Later, the communities require a clean atmosphere after a threshold point of growth, and the community is a policy demander for a clean environment. This demand forces the government of a country to make tight environmental regulations and to support the R&D activities to generate renewable energy projects (Komen et al., 1997). Thus, a technique effect may emerge at this stage to support the REC in the economy and REC would help in tracing the 2nd phase of the EKC. The initial cost of installation of renewable energy projects might be high. Thus, the government might support renewable energy projects by providing tax incentives and subsidies. Moreover, the increasing REC may also increase the competitiveness of a country in the international market (Jordan-Korte, 2011). Thus, producers might shift to REC to reduce social costs (Owen, 2006), to get tax-incentive, and to avoid pollution tax on their production.

From the policy perspective to promote REC, green certificate policies can be used to promote renewable portfolio standards. This policy motivates power suppliers to buy Renewable Energy (RE) plants (Wang et al., 2020). Further, subsidies and renewable energy certificates can be provided for RE investment (Ozge et al., 2020; Ge et al., 2019). Thus, investment in renewable technology would increase RE generation (Genus and Iskandarova, 2020). Moreover, an optimum pricing policy should be designed by providing subsidized to have long-run stable returns from the RE producers (Wang et al., 2016). Overall, the market mechanism is very important to accelerate REC at a large scale (Yu et al., 2019). However, RE production may cause congestion to the power system and an optimum RE production plan should be provided to reduce the congestion (Reza et al., 2017). Moreover, administrative problems and market obstacles would slow down the process of RE transition (Liu et al., 2018), which should be resolved.

R&D and innovations in new technologies of RE are essential for Renewable Energy Transition (RET) in an economy to replace the old energy technologies. However, RET also needs time to diffuse in the industry and the whole economy. Moreover, social and market acceptance are required to diffuse the new technologies (Wüstenhagen et al., 2007). The adoption of new energy needs an educational program to diffuse (Negro et al., 2012) and academic research should support the innovation process to be generalized. The process of development of new energies is started with academic research and the government of any country would play a significant role to accelerate the innovation for cleaner technologies. Afterward, knowledge transfer is required to diffuse technologies among all stakeholders (Gallagher et al., 2012). Nevertheless, a lack of energy infrastructure and political reasons may become a hurdle in the way of RET (Tsoutsos and Stamboulis, 2005). However, economies of scale may foster the process of adaptation to new technologies. Moreover, entrepreneurs would implement new technologies and may support technology diffusion. In addition, the financial market would also finance new green technology projects (Tamazian et al., 2009).

The theoretical literature on REC motivates a lot of empirical studies in testing the role of REC in tracing the EKC. Some review studies conducted in the EKC literature on some macroeconomic indicators of pollution (Saini and Sighania, 2019; Liobikienė, 2020; Leal and Marques, 2022; Chang et al., 2017). Isa et al. (2015) reviewed the relationship between growth and energy use. Other studies focused on the scientific aspects of RE i.e., RE trading and generation (Huang and Li, 2022), RE integration in smart grids (Godoy Simões et al., 2019), uncertainty in predicting methods for RE power (Li et al., 2021), the role of RE in generation expansion planning (Dagoumas and Koltsaklis, 2019), sustainable RE supply chain (Fontes and Freires, 2018), Bayesian networks in RE system (Borunda et al., 2016), technology diffusion in RE technology (Rao and Kishore, 2010), optimized methods to renewable energy (Banos et al., 2011), and RE policy mechanisms (Cheng and Yi, 2017). However, a comprehensive review study is missing to present a complete role of REC in emissions and shaping the EKC, which is the main motivation behind this review study.

2. REC AND GLOBAL CO_2 EMISSIONS TRENDS

To capture the snapshot of the REC and emissions relationship, we collect the global data from BP (2022) and Global Carbon Atlas (2022). Figure 1 shows that the REC trend is upward but still the percentage of REC in primary energy consumption (PEC) is meager in Figure 2.

Figure 3 shows the scatterplot of REC and territorial emissions nexus. A positive relationship shows that REC could not help to reduce total territorial emissions. However, Figures 4 and 5 show a minute negative effect of REC on per-person emissions and territorial emissions per unit of gross domestic product (GDP). Thus, REC helped to increase carbon productivity and to reduce per capita emissions.

Figure 6 shows the scatterplot of the positive relationship between REC and consumption-based emissions. Thus, REC is increasing total consumption-based emissions. However, Figures 7 and 8 show a negative impact of REC on per-person emissions and

Figure 1: Primary energy consumption and Renewable Energy Consumption trends

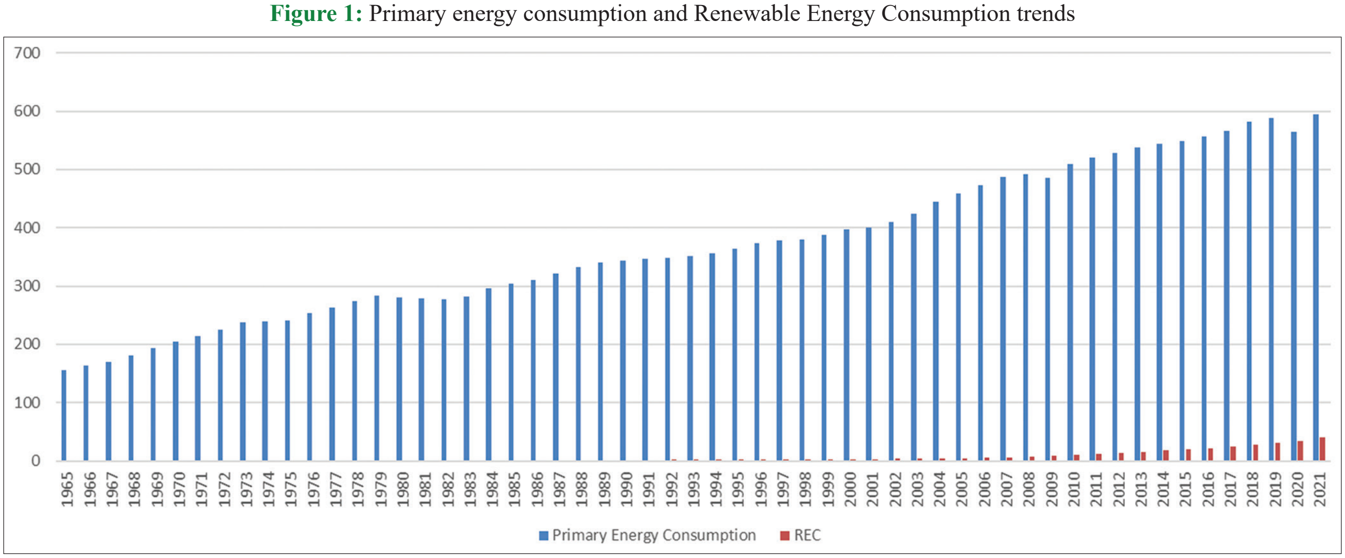


Figure 2: Percentage of renewable energy consumption in primary energy consumption

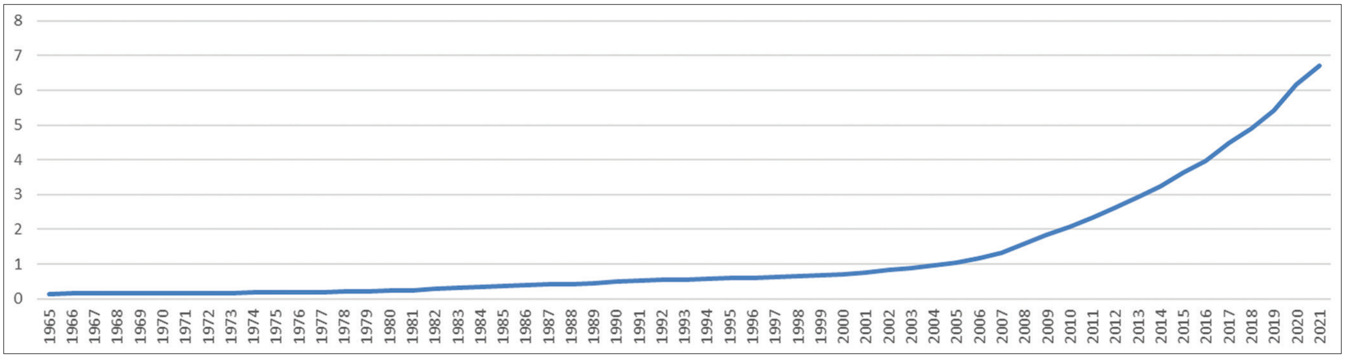


Figure 3: Renewable energy consumption and territorial emissions relationship

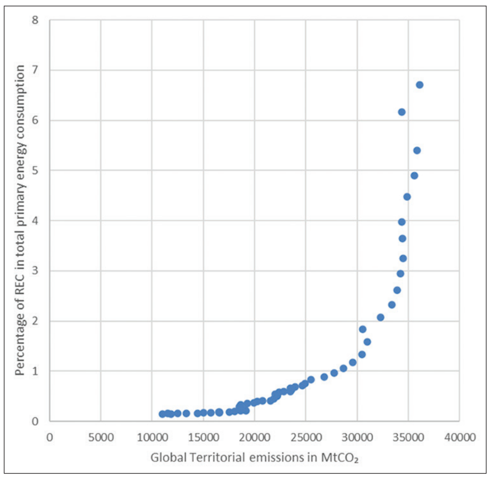


Figure 4: Renewable energy consumption and per person territorial emissions relationship

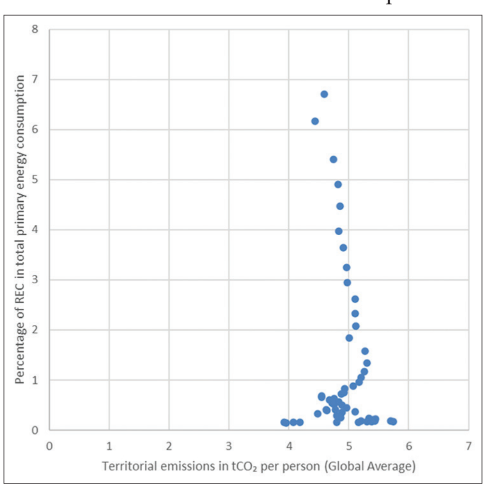


Figure 5: Renewable energy consumption and territorial emissions per gross domestic product unit relationship

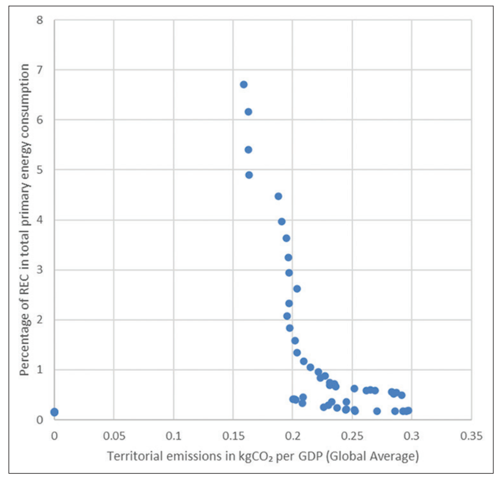
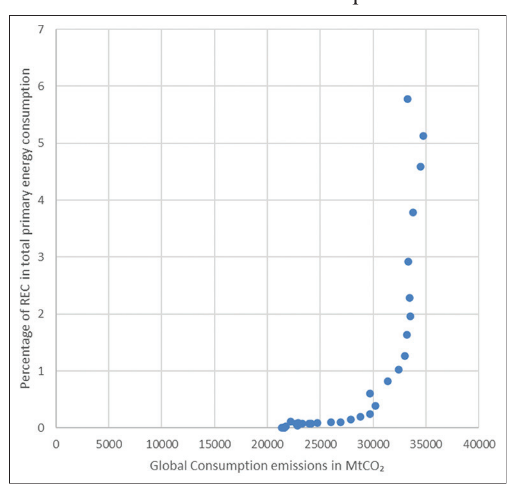


Figure 6: Renewable energy consumption and consumption emissions relationship



consumption-based emissions per unit of GDP. Thus, REC helped to increase carbon productivity in terms of consumption-based emissions and reduced per capita consumption-based emissions as well.

The above figures expose a complex relationship between REC and emissions, which motivates a lot of literature to capture the exact relationship in different regions of the globe. Section 3 presents a comprehensive review of the literature in this regard.

3. LITERATURE REVIEW

3.1. The Testing of the EKC Including REC in Country-Specific Analysis

First, we discuss the studies investigating the EKC in country-specific analyses and Table 1 shows a summary. For instance, Ohler (2015) investigated the US from 1990 to 2008 and found that REC could not decrease CO_2 emissions. Moreover, the EKC was

Figure 7: Renewable energy consumption and per person consumption emissions relationship

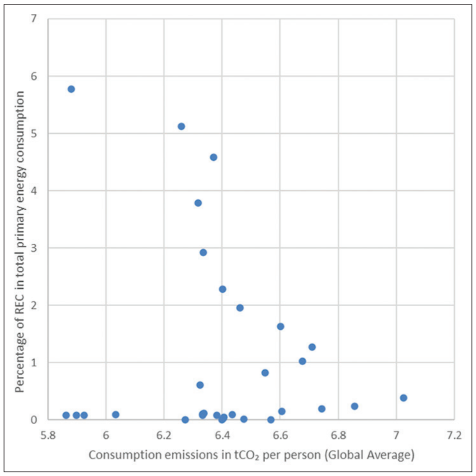
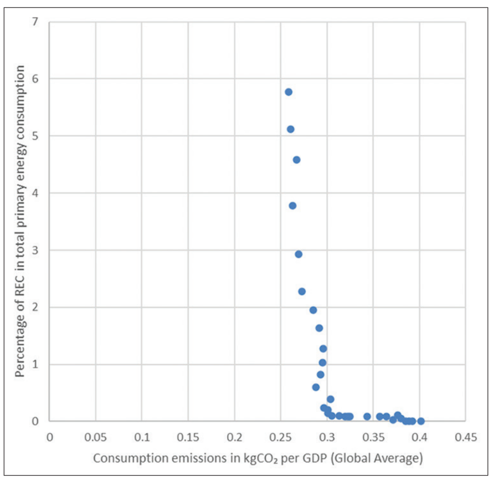


Figure 8: Renewable energy consumption and per person consumption emissions relationship



not validated. Benavides et al. (2017) investigated Austria from 1970 to 2012 using the autoregressive distributive lag (ARDL) and found that REC reduced methane emissions (CH4). Moreover, the EKC was validated. Paweenawat and Plyngam (2017) investigated Thailand from 1986 to 2012 by using the ARDL technique and found that REC did not reduce CO_2 emissions in the manufacturing sector. In addition, the EKC was also corroborated. Shahbaz et al. (2017) investigated the US economy from 1960-2016 by using ARDL and found that biomass energy, exports, and imports reduced CO_2 emissions. Moreover, the EKC was also substantiated. Dogan and Ozturk (2017) investigated the US from 1980 to 2014 by using ARDL and found that REC reduced CO_2 emissions. Non-REC increased emissions and the EKC was not validated. Solarin et al. (2017) studied China and India from 1965 to 2013 by using ARDL and found that hydroelectricity consumption reduced CO_2 emissions. Urbanization increased emissions and the EKC was validated in both countries.

El-Aasar and Hanafy (2018) examined the Egyptian economy from 1971 to 2012 by using the ARDL technique and found that REC reduced GHG emissions. However, the EKC was not corroborated, and trade openness also did not affect GHG emissions. Bekhet and Othman (2018) examined Malaysia from 1971 to 2015 and found that REC reduced CO_2 emissions. However, the EKC was not confirmed in Malaysia. In another study, Gill et al. (2018) examined Malaysia from 1970 to 2011 by using the ARDL framework and found that REC decreased CO_2 emissions. However, the EKC was not found valid in their analysis. Dong et al. (2018) investigated China considering ARDL, FMOLS, and DOLS in a sample period ranging from 1993-2016 and confirmed the evidence of the EKC hypothesis. REC also reduced emissions. Sinaga et al. (2019) investigated Malaysia from 1978 to 2016 using ARDL and found that hydroelectricity reduced CO_2 emissions. Moreover, the EKC was also validated.

Sasana and Aminata (2019) investigated Indonesia from 1990 to 2014 using regression analysis and noticed that REC decreased CO_2 emissions. Nevertheless, the EKC was not substantiated, and economic growth, population, and primary energy accelerated CO_2 emissions. Saudi et al. (2019) applied the ARDL for the Malaysian economy from 1980 to 2017 and substantiated the EKC. They further found that REC significantly reduced carbon emissions in Malaysia. Stadniczeńko (2020) explored Poland from 1980 to 2018 by using the ARDL technique and found that REC reduced CO_2 emissions. The EKC was also validated. In Koc and Bulus's (2020) study, we see that GDP significantly left an N-shaped influence on emissions in South Korea. They considered the ARDL approach from 1971 to 2017 and further exposed that REC reduced emissions.

Ridzuan et al. (2020) analyzed Malaysia from 1978 to 2016 by using ARDL and found that REC, crops, and fisheries reduced CO_2 emissions. The EKC was also validated. Sarkodie et al. (2020) investigated China from 1961 to 2016 by using ARDL and found that fossil fuels increased CO_2 emissions. REC reduced emissions and the EKC was corroborated. Sharif et al. (2020) investigated Turkey from 1965 to 2017 and validated the EKC by using ARDL and found that REC reduced ecological footprint. Muchran et al. (2021) tested the inverted U-shaped relationship in the Indonesian economy. They considered the ARDL from 1980 to 2018 and confirmed the EKC. The empirical findings further concluded that REC reduced carbon emissions. Nguyen et al. (2021) utilized the ARDL from 1980-2018 and found a U-shaped influence of per capita GDP growth on carbon emissions while REC reduced emissions in Vietnam.

The validity of the EKC was also tested by Salari et al. (2021) for 50 US states. After using the system GMM technique over the period from 1997 to 2016, they concluded that per capita GDP had an inverted U-shaped effect on carbon emissions while energy consumption in aggregated and disaggregated forms significantly enhanced carbon emissions. REC was significantly reducing emissions. Besides them, Murshed et al. (2021) utilized the ARDL, FMOLS, and DOLS estimators over the sample from 1980 to 2015 and found the EKC in Bangladesh. Further, hydropower consumption as a proxy for REC significantly curtailed emissions. Afterward, Pata (2021) utilized FMOLS and DOLS from 1980-2016 and substantiated the validity of the EKC in the US. The results further uncovered that REC played a facilitating role in reducing pollution. Murshed et al. (2022a) investigated Argentina

Table 1: The EKC testing in the country-specific analyses

Authors	Journal	Sample period	Geographical sample	Technique	Pollution proxy	The EKC is validated or not	The effect of REC on pollution
Ohler (2015)	The Energy Journal	1990–2008	The US	Panel regression	CO_2	No	Reducing
Benavides et al. (2017)	IJEEP	1970–2012	Austria	ARDL	CH_4	Yes	Reducing
Paweenawat and Plyngam (2017)	Economics Bulletin	1986–2012	Thailand	ARDL	CO_2	Yes	No effect
Shahbaz et al. (2017)	Energy Economics	1960–2016	The US	ARDL	CO_2	Yes	Reducing
Dogan and Ozturk (2017)	ESPR	1980–2014	The US	ARDL	CO_2	No	Reducing
Solarin et al. (2017)	RSER	1965–2013	China and India	ARDL	CO_2	Yes	Reducing
El-Aasar and Hanafy (2018)	IJEEP	1971–2012	Egypt	ARDL	CO_2	No	Reducing
Bekhet and Othman (2018)	Energy Economics	1971–2015	Malaysia	ARDL	CO_2	No	Reducing
Gill et al. (2018)	EDS	1970–2011	Malaysia	ARDL	CO_2	No	Reducing
Dong et al. (2018)	JCP	1993–2016	China	ARDL, FMOLS, and DOLS	CO_2	Yes	Reducing
Sinaga et al. (2019)	IJEEP	1978–2016	Malaysia	ARDL	CO_2	Yes	Reducing
Sasana and Aminata (2019)	IJEEP	1990–2014	Indonesia	Multiple regression model	CO_2	No	Reducing
Saudi et al. (2019)	IJEEP	1980–2017	Malaysia	ARDL	CO_2	Yes	Reducing
Stadniczeńko (2020)	IJEEP	1980–2018	Poland	ARDL	CO_2	Yes	Reducing
Koc and Bulus (2020)	ESPR	1971–2017	South Korea	ARDL	CO_2	Yes	Reducing
Ridzuan et al. (2020)	Resources, Conservation and Recycling	1978–2016	Malaysia	ARDL	CO_2	Yes	Reducing
Sarkodie et al. (2020)	Science of the Total Environment	1961–2016	China	ARDL	CO_2	Yes	Reducing
Sharif et al. (2020)	Sustainable Cities and Society	1965Q1–2017Q4	Turkey	ARDL	Ecological footprint	Yes	Reducing
Muchran et al. (2021)	IJEEP	1980–2018	Indonesia	ARDL	CO_2	Yes	Reducing
Nguyen et al. (2021)	IJEEP	1980–2018	Vietnam	ARDL	CO_2	No	Reducing
Salari et al. (2021)	Economic Analysis and Policy	1997–2016	50-US States	System Generalized Method of Movement	CO_2	Yes	Reducing
Murshed et al. (2021)	ESPR	1980–2015	Bangladesh	ARDL, FMOLS, DOLS	CO_2 and GHG	Yes	Reducing
Pata (2021)	ESPR	1980–2016	The US	FMOLS and DOLS	CO_2 and ecological footprints	Yes	Reducing
Murshed et al. (2022a)	ESPR	1971–2014	Argentina	ARDL	CO_2	Yes	Reducing
Bouyghrissi et al. (2022)	ESPR	1980–2017	Morocco	ARDL	CO_2	Yes	Reducing

IJEEP: International Journal of Energy Economics and Policy, ESPR: Renewable and Sustainable Energy Reviews, ESPR: Environmental Science and Pollution, GHG: Greenhouse gas, EDS: Environment, development and sustainability, JCP: Journal of Cleaner Production, EKC: Environmental Kuznets Curve, REC: Renewable energy consumption, ARDL: Autoregressive distributive lag, FMOLS: Fully modified ordinary least square, DOLS: Dynamic Ordinary Least Square

from 1971 to 2014 by using ARDL and found that REC and innovation reduced CO_2 emissions. Globalization increased emissions and the EKC was validated. Bouyghrissi et al. (2022) investigated Morocco from 1980 to 2017 by using ARDL and found that REC reduced, and Foreign Direct Investment (FDI) and financial development increased CO_2 emissions. The EKC was also validated.

3.2. The Testing of the EKC Including REC in the Panel Analyses

After discussion of the EKC studies in a single country, we reviewed the studies investigating the EKC in a panel and Table 2 displays these studies. For instance, Sharma (2011) examined 69 countries from 1985 to 2005 by using the GMM approach and found that REC and urbanization reduced CO_2 emissions.

Table 2: The EKC testing in the panel analyses

Authors	Journal	Sample period	Geographical sample	Technique	Pollution proxy	The EKC is validated or not	The effect of REC on pollution
Sharma (2011)	Applied Energy	1985–2005	69 countries	GMM	CO_2	Yes	Reducing
Burke (2012)	Australian Journal of Agricultural and Resource Economics	1960–2006	105 countries	Binomial dependent variable modeling	CO_2	Yes	Reducing
Ben Jebli et al. (2015)	African Development Review	1980–2010	24 SSA economies	Cointegration and causality tests	CO_2	No	No effect
Halkos and Psarianos (2016)	Environmental economics and policy studies	1990–2011	43 countries	GMM	CO_2	No	Reducing
Dogan and Seker (2016)	Renewable Energy	1980–2012	15 EU countries	DOLS	CO_2	Yes	Reducing
Jebli et al. (2016)	Ecological Indicators	1980–2010	25-OECD countries	FMOLS and DOLS	CO_2	Yes	Reducing
Al-Mulali et al. (2016)	Ecological Indicators	1980–2010	7 regions in the globe	DOLS	CO_2	Yes, except for SSA and MENA	Reducing, except SSA and MENA
Zaghdoudi (2017)	Economics Bulletin	1990–2015	OECD	FMOLS and DOLS	CO_2	Yes	reducing
Hasnisah et al. (2019)	IJEEP	1980–2014	13 Asian countries	FMOLS and DOLS	CO_2	Yes	No effect
Ng et al. (2019)	International Journal of Business and Society	1990–2013	25 OECD countries	FMOLS and DOLS	CO_2	Yes	Reducing
Majeed and Luni (2019)	Pakistan Journal of Commerce and Social Sciences	1990–2017	166 countries	Fixed Effects (FE) and Random Effect (RE)	CO_2	No	Reducing
Baležentis et al. (2019)	Resources, Conservation and Recycling	1995–2015	27 EU nations	FMOLS and DOLS	GHG	Yes	Reducing
Lau et al. (2019)	Economic Modelling	1995–2015	18 OECD countries	GMM	CO_2	Yes	Reducing
Zafar et al. (2019)	Resources Policy	1990–2016	G-7 and N-11	Bootstrap panel cointegration method	CO_2	Yes	Reducing
Salim et al. (2019)	Applied Economics	1980–2015	Selected Asian developing countries	ARDL	CO_2	Yes	Reducing
Sharif et al. (2019)	Renewable energy	1990–2015	74 economies	FMOLS and Cross-sectional Dependence (CD) tests	CO_2	Yes	Reducing
Ehigiamusoe (2020)	The Singapore Economic Review	1990–2016	Asia	PMG	CO_2	Yes	Reducing
Florea et al. (2020)	Agricultural economics	2000–2017	11 European economies	ARDL	GHG	No	Reducing
Dong et al. (2020)	The World Economy	1995–2015	120 countries	GMM	CO_2	Yes	Reducing
Elshimy and El-Aasar (2020)	Environment, Development and Sustainability	1980–2014	Arab world	ARDL	Carbon footprint	Yes	Reducing
Hanif et al. (2020)	Environment, Development and Sustainability	1990–2017	16 OECD and 14 non-OECD nations	RE	CO_2	Yes	Reducing
Vural (2020)	Resources Policy	1980–2014	8 SSA nations	DOLS	CO_2	Yes	Reducing
Kamoun et al. (2020)	Journal of the knowledge economy	1990–2013	13 OECD countries	GMM	Net savings from emissions	Yes	Reducing

(*Contd...*)

Table 2: (*Continued*)

Authors	Journal	Sample period	Geographical sample	Technique	Pollution proxy	The EKC is validated or not	The effect of REC on pollution
Danish et al. (2020)	Sustainable Cities and Society	1992–2016	BRICS	FMOLS and DOLS	Ecological footprints	Yes	Reducing
Aydogan, and Vardar (2020)	International Journal of Sustainable Energy	1990–2014	E-7	FMOLS and DOLS	CO_2	Yes	No effect
Ahmad et al. (2021)	Economics of Innovation and New Technology	1990–2014	26 OECD nations	FMOLS	CO_2	Yes	Reducing
Nathaniel et al. (2021a)	Studies of Applied Economics	1990–2016	MENA nations	FMOLS and DOLS	Ecological footprint	Yes	Reducing
Khan et al. (2021)	Applied Economics	1987–2017	RCEP countries	CS-ARDL	CO_2	Yes	Reducing
Tian et al. (2021)	Structural Change and Economic Dynamics	1995–2015	G-20 Countries	FMOLS and DOLS	CO_2	Yes	Reducing
Nathaniel et al. (2021b)	ESPR	1990–2017	G7	AMG	CO_2	Yes	No effect
Xue et al. (2021)	Sustainability	1990–2014	South Asia	FE, RE, GMM, and AMG	Ecological footprint	Yes	Reducing
Mehmood (2022)	ESPR	1990–2017	Pakistan, India, Bangladesh, Sri Lanka	CS-ARDL	CO_2	Yes	Reducing
Jun et al. (2022)	Economic Research-Ekonomska Istraživanja	1995–2019	Top-10 Carbon Emitter Countries	CS-cointegration	CO_2	Yes	Reducing
Jena et al. (2022)	ESPR	1980–2016	China, India, and Japan	PMG	CO_2 and ecological footprint	Yes	Reducing
Saqib et al. (2022)	Frontiers in Environmental Science	1995–2019	E-7 countries	CS-ARDL and AMG	CO_2	Yes	Reducing
Sarwat et al. (2022)	ESPR	1990–2014	BRICS countries	FMOLS, DOLS, and Panel Quantile Regression	CO_2	Yes	Reducing
Yu-Ke et al. (2022)	Renewable Energy	1995–2019	42-High Polluting Countries	PMG	Transport and production -based emissions	Yes	Reducing
Yang et al. (2022)	Renewable Energy	1995–2018	E-7 countries	MMQR	CO_2	Yes	Reducing
Murshed et al. (2022b)	Energy Sources, Part B	1995–2015	South Asia	AMG	Ecological footprint	Yes	Reducing
Djellouli et al. (2022)	Renewable Energy	2000–2015	Africa	PMG	CO_2	No	Reducing
Afshan et al. (2022)	Renewable Energy	1990-2017	OECD	MMQR	Ecological footprint	Yes	Reducing
Gao et al. (2023)	Resources Policy	1990–2021	Top-31 Carbon Emitting countries	PMG	Carbon emissions from industrial production	Yes	Reducing
Saqib et al. (2023)	ESPR	1990–2020	G-7 countries	CS-ARDL, AMG	Ecological footprint	Yes	Reducing
Jahanger et al. (2023)	Sustainable Energy Technologies and Assessments	1990–2020	Top-10 manufacturing countries	MMQR	GHG	Yes	Reducing

AMG: Augmented mean group, MMQR: Method of Moments of Quantile Regression, BRICS: Brazil, Russia, India, China, and South Africa, PMG: Pooled mean group, EKC: Environmental Kuznets Curve, REC: Renewable energy consumption

However, total energy usage and trade increased emissions. Moreover, the EKC was also validated. Burke (2012) investigated 105 countries from 1960 to 2006 by using binomial dependent variable modeling and found that REC reduced CO_2 emissions. Moreover, the EKC was validated. Ben Jebli et al. (2015) investigated 24 Sub-Saharan Africa (SSA) economies from 1980 to 2010 by panel cointegration and found that REC could not reduce CO_2 emissions. Exports increased and imports reduced emissions. Moreover, the EKC was not validated. Halkos and Psarianos (2016) investigated 43 economies from 1990 to 2011 by using the GMM approach and found that REC decreased CO_2 emissions. However, the EKC was not substantiated.

Dogan and Seker (2016) tested the EKC by considering the REC in their study. They used DOLS for 15 European economies from 1980 to 2012 and founded the EKC. They further confirmed that REC mitigated carbon emissions. Jebli et al. (2016) employed FMOLS and DOLS from 1980 to 2010 and found the EKC in 25 Organization for Economic Co-operation and Development (OECD) countries. They also described that carbon emissions were reduced because of REC. Al-Mulali et al. (2016) investigated 7 regions in the globe from 1980 to 2010 by using DOLS and discovered that REC reduced CO_2 emissions in all regions except SSA and MENA. The EKC was also validated in all regions except SSA and MENA. Zaghdoudi (2017) explored OECD countries from 1990-2015 and found that REC and oil prices reduced emissions. The EKC was substantiated in these economies.

Hasnisah et al. (2019) examined Asia from 1980 to 2014 by using FMOLS and DOLS techniques and found that REC reduced emissions and corroborated the EKC. Nevertheless, non-REC increased CO_2 emissions. Ng et al. (2019) examined 25 OECD countries from 1990-2013 and found that REC reduced emissions and substantiated the EKC. However, non-REC increased emissions. Majeed and Luni (2019) investigated 166 economies globally and found that REC from all sources helped in reducing CO_2 emissions. However, the EKC was not validated. Baležentis et al. (2019) explored 27 EU economies from 1995-2015 by using FMOLS and DOLS panel techniques and found that biomass and other REC reduced GHG emissions. In addition, the EKC was substantiated. Lau et al. (2019) examined 18 OECD economies from 1995 to 2015 by using the GMM and corroborated that nuclear power reduced CO_2 emissions. Moreover, the EKC was also found valid in their analyses and non-REC increased emissions. Zafar et al. (2019) examined G-7 and N-11 economies from 1990 to 2016 by using the bootstrap approach and found that REC reduced emissions and corroborated the EKC. The banking sector reduced carbon intensity in G-7 and increased in N-11. Moreover, capital formation increased emissions.

Salim et al. (2019) explored Asian developing economies from 1980 to 2015 by using the ARDL technique and found that REC, urbanization, and trade liberalization reduced CO_2 emissions. Moreover, non-REC and population increased emissions, but the EKC was substantiated. Sharif et al. (2019) investigated 74 economies from 1990 to 2015 by using FMOLS and CD-tests and found that REC and financial development reduced CO_2 emissions. Non-REC increased emissions and the EKC was validated. Ehigiamusoe (2020) examined Asia from 1990 to 2016 by using the PMG and found that REC, FDI, and trade reduced emissions. Non-REC increased emissions, but the EKC was substantiated. Florea et al. (2020) analyzed 11 European economies in the years 2000–2017 and found that REC reduced GHG emissions. However, the EKC was not substantiated. Dong et al. (2020) examined 120 world economies from 1978 to 2016 using GMM and found that REC reduced emissions and corroborated the EKC. Elshimy and El-Aasar (2020) investigated the Arabian economies from 1980 to 2014 by using ARDL and found that REC reduced carbon footprint. Moreover, non-REC and livestock increased carbon footprint, but the EKC was substantiated.

Hanif et al. (2020) investigated 16 OECD economies from 1990 to 2017 and found that human capital increased REC, which would help in reducing CO_2 emissions. Moreover, the EKC was also validated. Vural (2020) explored 8 SSA economies from 1980 to 2014 and found that REC reduced CO_2 emissions. Moreover, non-REC and trade increased emissions, but the EKC was corroborated. Kamoun et al. (2020) explored 13 OECD countries from 1990 to 2013 using GMM and found that REC increased net saving adjusted from emissions and non-REC reduced it. Moreover, the EKC was also corroborated. Afterward, Danish et al. (2020) examined the EKC in BRICS economies. They considered FMOLS and DOLS approaches from 1992 to 2016 and confirmed the validity of EKC for economies as a whole and as individuals. They also provided evidence of the negative effect of REC in curtailing ecological footprint. Aydogan and Vardar (2020) tested the EKC in seven emerging economies from 1990 to 2014 and found a significant EKC. The results also presented a mitigating effect of REC on CO_2 emissions.

Ahmad et al. (2021) explored 26 OECD nations from 1990 to 2014 by using FMOLS and found that REC and FDI reduced CO_2 emissions. The EKC was also substantiated. Nathaniel et al. (2021a) explored MENA economies from 1990 to 2016 and found that REC and urbanization reduced ecological footprint. The EKC was also corroborated. Khan et al. (2021) investigated the Regional Comprehensive Economic Partnership (RCEP) economies from 1987 to 2017 and found that REC and innovative technologies reduced CO_2 emissions and the EKC was substantiated. Tian et al. (2021) examined the EKC in G-20 economies. They applied FMOLS and DOLS methods over the period from 1995 to 2015 and substantiated the EKC. REC also reduced emissions. Nathaniel et al. (2021b) investigated G7 nations from 1990 to 2017 and found that REC did not reduce but nuclear power decreased emissions. The EKC was substantiated. Xue et al. (2021) investigated South Asia from 1990 to 2014 and found that REC reduced ecological footprint. FDI and non-REC increased ecological footprint, but the EKC was validated. Mehmood (2022) explored South Asia using CD-ARDL from 1990 to 2017 and concluded that the EKC was corroborated, and REC reduced carbon emissions. Jun et al. (2022) investigated the EKC in top-ten carbon-emitting nations. They employed CS-ARDL from 1995 to 2019 and established the EKC. They further exposed that REC had a negative impact on carbon emissions.

Jena et al. (2022) explored the EKC in China, India, and Japan from 1980 to 2016 by taking renewable energy as a control variable and substantiated the EKC. The results also concluded that REC curtailed emissions. Saqib et al. (2022) examined the EKC by taking renewable energy as a controlling factor. They utilized CS-ARDL and AMG methods for E-7 countries from 1995 to 2019 and supported the EKC. They further disclosed that REC condenses emissions. According to Sarwat et al. (2022), GDP growth had a significant and inverted U-shaped impact on emissions in BRICS economies from 1990 to 2014. The study further exerted a negative effect of REC on emissions. Using PMG estimators from 1995 to 2019, Yu-Ke et al. (2022) found that REC reduced emissions in 42 countries. Trade openness reduced carbon emissions while industrial production significantly enhanced emissions. The EKC was also substantiated. Yang et al. (2022) investigated E-7 countries from 1995 to 2018 using MMQR and found that REC reduced emissions in lower quantiles and substantiated the EKC. Murshed et al. (2022b) investigated South Asia from 1995 to 2015 using AMG and found that intra-regional trade, REC, and FDI reduced the ecological footprint. The EKC was also corroborated.

Djellouli et al. (2022) investigated Africa from 2000-2015 using PMG and found that REC reduced CO_2 emissions and FDI increased emissions. But the EKC was not substantiated. Afshan et al. (2022) investigated OECD economies from 1990-2017 using MMQR and found that REC and innovation reduced ecological footprint. The EKC was also validated. Gao et al. (2023) tested the role of renewable energy in the EKC model of top-polluted economies from 1990-2021 and substantiated the EKC. Moreover, REC reduced pollution. Saqib et al. (2023) investigated the EKC in G-7 nations by taking REC in a model. Using CS-ARDL and AMG techniques from 1990 to 2020, the study substantiated the EKC hypothesis. Besides this, REC reduced ecological footprint. Jahanger et al. (2023) studied the top 10 manufacturing countries from 1990 to 2020 by using MMQR and found that REC, technology, and energy efficiency reduced GHG emissions. The EKC was also validated.

4. ANALYSES AND DISCUSSIONS

Table 3 shows a summary of the validity of the EKC in the 69 reviewed studies. 57 out of 69 studies validated the EKC and 12 studies could not find the validity of the EKC. Out of these, 64 studies reported that REC helped to reduce emissions and 5 studies reported the insignificant effect of REC on emissions.

In the country-specific studies, 18 out of 25 studies validated the EKC and 7 studies did not validate the EKC. Out of these, 24 studies found that REC reduced emissions and 1 study found an insignificant effect of REC on emissions. In the panel studies, 39 out of 44 studies confirmed the EKC and 5 studies could not find the validity of the EKC. Out of these, 40 studies found that REC helped to reduce emissions and 4 studies found the insignificant effect of REC on emissions. In comparison, 88.6% of panel studies found the validity of the EKC and 72% of country-specific studies reported the validity of the EKC. Alternatively, 96% of country-specific studies reported that REC reduced emissions. However, 90.9% of panel studies could find that REC reduced emissions. Thus, the EKC in panel studies is more pronounced than in country-specific studies and the positive environmental contribution of the REC is more evident in country-specific studies compared to the panel studies.

Table 3: Summary of the EKC and REC results

Studies	The EKC is valid	No. of studies	REC reduce emissions	No. of studies
All studies	Yes	57	Yes	64
	No	12	No	5
Country-specific studies	Yes	18	Yes	24
	No	7	No	1
Panel studies	Yes	39	Yes	40
	No	5	No	4

EKC: Environmental Kuznets Curve, REC: Renewable energy consumption

Table 4: Logistic regression: The EKC is validated as a dependent variable

Studies	Coefficient (P-value)
All studies	
REC reduce emissions	1.5724 (0.0000)
Country-specific studies	
REC reduce emissions	0.8873 (0.0480)
Panel studies	
REC reduce emissions	2.1957 (0.0000)

EKC: Environmental Kuznets Curve, REC: Renewable energy consumption

Table 4 shows logistic regression estimates to test the effect of REC on the validity of the EKC. The dependent variable carries 1 if the EKC is validated and 0 otherwise. The independent variable carries 1 if the REC reduced emissions and 0 otherwise. All results show positive effects. If REC reduced emissions, then the chance of the validity of the EKC is increasing. The results from a sample of all studies show that chance of the validity of the EKC is 4.82 times ($e^{1.5724}$) more than the non-validity of the EKC if REC reduced emissions in a model. In comparison, the coefficient of panel studies is much higher than the coefficient of country-specific studies. Thus, the chance of the validity of the EKC is more in the panel studies ($e^{2.1857}$ = 8.98 times) compared to country-specific studies ($e^{0.8873}$ = 2.43 times) if REC reduced emissions in a model.

5. CONCLUSION

REC would reduce emissions to shape the EKC. The present study discusses the theoretical argument for the relationship between REC and the EKC. Moreover, we conducted a review of the 69 empirical studies investigating the EKC hypothesis in country-specific and panel analyses. We find that 57 out of 69 studies validated the EKC but 12 studies did not confirm the EKC. Moreover, 64 studies found that REC reduced emissions and 5 studies substantiated the insignificant effect of REC on emissions. In the country-specific analyses, 18 out of 25 studies proved the EKC and 7 studies could not validate the EKC. Further, 24 studies substantiated that REC reduced emissions and 1 study could not find this evidence. In the panel studies, 39 out of 44 studies validated the EKC and 5 studies did not confirm the EKC. Moreover, 40 studies reported that REC reduced emissions and 4 studies found an insignificant effect of REC on emissions. Overall, 88.6% of panel studies reported the validity of the EKC and 72%

of country-specific studies substantiated the EKC. In contrast, 96% of country-specific studies found that REC reduced emissions and 90.9% of panel studies could validate it. Therefore, panel studies reported greater evidence of the EKC, and the positive environmental effects of the REC are reported more by country-specific studies. We also tested the effect of REC on the EKC by using logistic regression in a full sample of 69 studies and found that the chance of the validity of the EKC is 4.82 times more in the studies if REC reduced emissions in a model. In the same way, the chance of the validity of the EKC is 8.98 times more in the panel studies and 2.43 times more in the country-specific studies, if REC reduced emissions in a model. Comparatively, the chance of the EKC is found more in the panel studies compared to country-specific studies. Moreover, REC has been proven to be an important component of the EKC model. Thus, we recommend future EKC studies to include REC in the model.

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