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Role of Innovations to Mitigate CO_2e: Theory and Evidence for European Economies

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Abstract: Even though numerous researchers have analyzed the factors of carbon emissions, technological innovation's linear and non-linear effects on carbon emissions have not been thoroughly examined in the energy–environment literature with the Environmental Kuznets Curve framework for European economies. For this purpose, this study has employed linear and non-linear autoregressive distributed lagged models, the novel bounds testing methodologies of dynamic simulations. Renewable energy and resident and non-resident patents are the indicators of technological innovations. The findings of this study demonstrate a significant negative association of renewable energy use and technological innovation with carbon emissions, while economic growth, non-renewable energy, and urbanization have depicted a positive relationship. These findings confirm the validity of the Environmental Kuznets hypothesis for the sampled countries. It is suggested that research and development facilities are required to mitigate environmental pollution by using innovation and discouraging more use of coal in electricity generation. This study also provides policymakers with particular statistics on sector-based renewable energy initiatives, highlighting the greenhouse gas impacts in European countries.

Keywords: non-renewable energy and renewable; technology innovation; economic growth; Environmental Kuznets Curve; European economies

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1. Introduction

Since the late twentieth century, greenhouse gas emissions (GHGe) have led to global warming, resulting in a change in the global climate [1]. Worldwide GHGe from fossil fuel consumption and industrialization increased over the period of industrialization [2,3]. The European Union (EU) share in world GHGe was 80.3% in 2007, while Germany (19.0%), the United Kingdom (12.6%), Italy (11.05), and France (10.5%) were the 4 top emitters of GHGe [4]. A significant reduction in EU's GHGe was reported by 34.4% during 1990–2020. A major decline in GHGe in all economic sectors was observed in 2020 due to a big decline of economic activity arising from the COVID-19 pandemic. In addition, the aggregate share of CO_2e in GHGe was 1.9 billion metric tons during 2019, but increased to 2.54 billion metric tons in 2020 [5], which is considered quite high. On the other hand, if we divide CO_2e as sector wise, its share from fossil fuel and industry increased to 90% during 2021, while it was 78% during 1970–2011 [2]. CO_2e from fossil fuel and industrial practices increased by 90% during 1970–2011, while its share in GHGe was 78% [2]. It reached its highest level (3.99 billion metric tons) in 1979 [6]. The EU has a leading role in addressing climate change mitigation challenges. The EU has adopted various policies over the past decades to promote the move toward a lower-carbon society. In February 2011, the European Council reset the goal of reducing greenhouse gas emissions by 80 percent to 90 percent by 2050, relative to 1990 levels under the Intergovernmental Panel on Climate Change (IPCC) guidelines. The current goal of European countries is to achieve the status of a resource-efficient and environmentally friendly economy that is globally competitive. They also set their new binding climate change policy goals for CO_2e reduction in January 2014 [7,8].

Human well-being has increased as a result of the many advances in technology that have occurred since the beginning of the industrial revolution. The subsequent surging pace of economic activities depleted the natural assets of this sphere and increased GHGe (for instance, CO_2e, NOx, and SO_2). In the last two centuries, when the rising trend of innovation was noted as the most important component of economic growth, it also caused environmental challenges to the society. The last few decades are evident of innovations' favorable impacts for sustainable environment [7,8]. Despite the advantages of innovations, they have a variety of disadvantages, either to the environment or the living organism. In this regard, [9] has discussed the influence, population, affluence, and technology (IPAT) equation framework to evaluate how population (P), affluence (consumption per/capital or economic growth) (A), and technological innovations (T) impact (I) the environment. Theoretically, innovations are assumed to promote environment-friendly lifestyles and reduce CO_2e. They are commonly considered the critical instrument for achieving green growth [10,11]. However, the literature on innovations CO_2e nexus is mixed and contradictory based on different empirical scenarios. In [12], the authors state that innovations efficiently resolve the trade-off between output growth and environmental security, while a rebound effect may exist. That is, green innovations may have both direct and scale impacts on CO_2e. In direct impact, innovations can efficiently cut CO_2e by efficiently utilizing energy. In the scale impact, innovations expand the output level, which needs more energy use and indirectly results in rising CO_2e [13]. Therefore, the combined impact of innovations on the environment is not clear. Thus, this study empirically analyzes the comprehensive impact of innovation on CO_2e and whether the EU has achieved its sustainable environment goal using innovations or not.

In the conceptual framework of innovation, diverse classifications of innovation are discussed. Traditional classification refers to the radical innovations versus incremental innovations. Another well-known classification has been done into four outlooks: (1) service/product innovation; (2) process innovation; (3) organizational innovation; and (4) marketing innovation [14]. Another important classification of innovation concerns the use of suitable indicators for its measurement. It contains three indicators of innovations: input, throughput, and output. Input innovations demonstrate the context, scope, and structure of innovations. After a transformation process, they become throughputs (intermediaries) and finally, they are converted into outputs [15]. The existing literature has enlisted these three indicators of innovations: research and development (R&D) investment (input), patents (throughputs), and new product launches (output), among others. The use of intermediate indicators (patents) gives property rights of protecting new products. They are particularly used in the research projects to cognize the cross-country effect of innovation over time [16]. In line with this discussion, this study takes renewable energy consumption and patents as throughput innovations.

The question now is: does innovation increase energy demand or lower it and give mixed outcomes of CO_2e? The economists of the 19th century found that innovations failed to lower CO_2e because the adoption of technological innovation led to greater energy use and hence increased CO_2e [15]. Later, further improvement in energy efficiency (innovation) led to lower energy use and hence lowered CO_2e. Therefore, few studies estimated the non-linear (inverted U-shaped) nexus of innovations with CO_2e using the Environment Kuznets Curve (EKC) [9,17]. Firstly, the EKC highlighted an asymmetric link between output growth and CO_2e. This EKC expression was augmented to explain the non-linear association of innovation with CO_2e. In the initial phase, an upward shift in innovation brings a decrease in carbon dioxide emissions, but further increases in technology raise CO_2e [17].

The European industrial revolution brought social and economic changes. The rise of the industrial structure increased industrial investment and economic growth, and resulted in high CO_2e emissions [8]. In recent years, the primary policy issue has been working for sustainable economic growth. Initially, sustainable economic growth analysis was done by [18] under the title of EKC to explain the influence of output growth on climate [19]. According to ECK, these two variables of interest show a U- and an inverted U-shaped relationship. The reason behind the inverted U-shaped association is that, initially, the main focus of the economy is on output growth and people's income; hence, environmental degradation is often neglected. However, after achieving a certain level of income and growth, people start considering the influence of their income on the climate. At this stage, people start spending their excess income on environmental improvement, so the environmental quality starts improving. Similarly, inverted U-shaped EKC also states the availability of extra income to be consumed to meet sustainable environmental standards as well as to improve technology. After a particular time, countries started shifting their economies from industrialization to technologically innovative industries that were less harmful to the environment. On the other hand, U-shaped EKC shows that, initially, balance growth time improves the quality of the environment while at the second stage, over-development deteriorates it [17]. Hence, EKC validates that economic development, to some extent, benefits the environment.

Rising economic activities in European economies have stimulated the demand for traditional and renewable energy (RE) sources. RE sources are illustrated as strategic commodities for sustainable growth [20]. RE sources such as biomass and solar are considered economical and good for the green environment [14]. In European countries, RE consumption was targeted at 18%, 19.7%, and 20% in 2018, 2019, and 2020, respectively. The rising use of RE has reduced CO_2e in this region. Among these countries, Sweden has the highest rate of RE usage at 54.6%, while Malta utilizes only 8% of clean energy [4]. They have set numerous climate policy goals to meet potential environmental trends, such as a 32-percent rise in the share of RE, a 32.5-percent increase in energy quality, and a 40-percent reduction in CO_2e [8]. In this regard, recent studies estimated the positive role of RE in improving the environment [14]. In contrast, another study concluded the negative influence of RE on the environment due to a lack of innovation and poor transmission systems. However, it is argued that such negative impacts of RE can be mitigated by updated technology [20]. Historically, rising CO_2e has been noted as an outcome of continuous overdependence on NRE sources such as oil, coal, etc. CO_2e absorbs heat reflection from the earth, and later on, it results in global warming due to the depletion of the ozone layer [3]. This increasing trend of CO_2e is an outcome of rising worldwide energy demand by 2.1% in 2017, where the share of fossil fuels was 70%, and coal, natural gas, and oil consumption grew by 1%, 3%, and 1.65%, respectively [21]. From 2017 to 2018, the use of non-renewable energy (NRE) in European economies decreased by 0.9% due to increased RE demand, for instance, the consumption of coal, oil, and natural gas was about 14.4%, 31.6%, and 24.4%, respectively, whereas the demand for renewable energy was 50% [4,8]. This growing demand for RE in European countries tends to investigate the empirical impact of clean energy on the environment to promote green environment, and suggests policy measures to approach environmental sustainability.

To further investigate the causes of rising carbon emissions, urbanization is considered as the primary indicator of pollution. In [17], the author describes urbanization as the migration of the labor force from rural to urban areas (or from agriculture to the urban industrial sector). The migration of the labor force from rural to urban centers drastically alters settlement patterns and urban economic activities, leading to a rise in energy consumption. This migration from rural to urban areas has direct effects on energy consumption via various channels. For instance, urbanization may lead to an increase in energy consumption for sustenance, urban transportation, electric devices, and road use. In recent years, urbanization has developed at an accelerated rate. The global urban population increased from 751 million in 1950 to 4.2 billion in 2019; currently, 55 percent of the world's population resides in urban areas, and this proportion is projected to rise to 68 percent by 2050, indicating that urbanization will have a significant impact on energy consumption [17]. Urbanization is believed to substantially contribute to the rise in CO_2e emissions. Researchers and policymakers are becoming increasingly concerned about the overlapping challenges of climate change mitigation and sustainable development because of urbanization.

This paper has the following contribution to the present literature: first, it is among those pioneering studies [22–28], which empirically measured the role of innovation and RE to alleviate the indirect impacts of CO_2e on European economies during 1995–2018, with a focus on T.I. The past literature has rarely discussed innovation's role in mitigating CO_2e specially in the case of European countries. However, if we study the existing literature, we will see that, previously, European economies have not been investigated in the energy–environment nexus. Furthermore, previously the linear connection among variables has been examined instead of the non-linear relationship. Therefore, this study fills the gap in the existing literature by examining the non-linear connection among TI (patent resident and patent non-resident), industrialization, fossil energies, economic growth, RE, and CO_2e for European countries. This paper covers this gap by estimating the aforementioned non-linear nexus to confirm the validity of EKC and suggests necessary evidence and a better understanding to policymakers, researchers, and individuals to deal with climate issues. Thirdly, this research focuses on European countries because they are less innovative than South Korea, Japan, and the United States. Sweden is the most innovative, while Bulgaria is the least innovative among the European countries [4]. Therefore, this region is selected for empirical investigation and its respective policy implications to promote sustainable growth. Lastly, this study has used patents and renewable energy (throughputs) to present innovations and to do panel data empirical analysis following [29–31].

Thus, this study has answered the following research questions: (a) are renewable energy and innovation linearly and non-linearly associated with CO_2e, and (b) are there linear and non-linear relationships between urbanization, economic growth, NRE, and CO_2e in the case of European economies.

The remaining paper contains the following segments: Section 2 evaluates the related literature; Section 3 deals with the data and econometric modeling; Section 4 consists of the results and discussion; and Section 5 gives the conclusion and policy recommendations.

2. Review of the Literature

This study has been strengthened by the following literature regarding the factors (innovations, NRE, urbanization, RE, and economic growth) influencing the CO_2e. Improvements in technology and efficient energy utilization are two main ways to reduce CO_2e emissions [32,33]. Furthermore, ref. [34] argued that the innovation efficiency in economic outcomes had cut environmental contamination. In [14], the authors built a system to assess the innovation efficiency of Chinese industrial companies. Then, the overall innovation efficiency in the given companies was estimated via data envelopment analysis (DEA). They concluded that the innovation efficiency of these companies was comparatively low to meet environmental challenges due to pure technical efficiency (PTE). In [35], the authors investigated the effect of technological innovations (TI) on energy consumption and CO_2e in the EU using the dynamic system GMM during 1995–2019. The empirical results demonstrated that TI reduced CO_2e at the pace of efficient energy use. The non-linear analysis depicted a U-shaped relationship between innovation and GDP. This study suggested the creation of a competitive environment to stimulate innovations for CO_2e reduction innovation. Furthermore, EU countries must emphasize TI to reach energy efficiency. In [36], the authors used the IPAT equation to discuss the drivers of stress on the environment with empirical evidence from modern nation-states. They concluded that affluence (economic growth) and the growing population had enhanced environmental stress. The cumulative results provided useful guidance for climate projections and policy design. However, the role of urbanization and institutions was noted as ambiguous. This study recommended that environmental stress rising from population and its consumption can be controlled by the technology employed for production. In [37], the authors analyzed the long-run dynamics of environmental innovations, REC, and per-capita GDP, on CO_2e for 15 European countries over 23 years. Their empirical results estimated the significant long-term effect of ecological innovations and REC to lower CO_2e, while the short-term effects were the opposite, suggesting a rebound effect. The impact of per-capita GDP on CO_2e was also highly significant in cutting carbon emissions. They suggested introducing new policies that could integrate economic benefits with regulatory changes and raise individuals' spirits to consume differently by favoring products and services less negatively impacting the environment. In addition, ref. [22] estimated the impacts of green innovations on CO_2e in the 27 European economies between 1992 and 2014. They used the GMM (Generalized Method of Moments) estimation setting for empirical analysis. Patent applications were used as an indicator for green innovation. This study found a meaningful contribution of green innovation to cutting CO_2e. Similarly, ref. [37] analyzed the asymmetric association of green technology with CO_2e in China using the panel threshold method. The empirical results showed that as green technology was increasing, CO_2e was significantly decreasing. In the less developed regions of China, CO_2e reduction effect was more significant. In [12], the authors reported that the successful implementation of innovations in industries had significantly reduced CO_2e. Furthermore, they noted that firms were more competitive and efficient in reducing CO_2e in the market with innovations research. Furthermore, ref. [27] empirically measured the impact of innovations, per capita income, and REC on CO_2e for 42 sub-Saharan countries during 1995–2011. They used panel methodologies for short- and long-term analysis. The empirical findings examined the long-run relationship among the variables of interest. Granger causality outcomes highlighted the short-run one way causation from GDP per/capita to CO_2e and from GDP to REC, and a two-way causation between REC and CO_2e. These results were highly important for policymakers in this region. REC was noted as the key driver of CO_2e reduction. They investigated the long-run negative association between innovations, RE resources, and CO_2e with highly significant signs. They included hydropower, solar, wind, geothermal, biomass, and ocean energy as RE sources. In [38], the findings also supported these outcomes in REC to cut CO_2e. In [29], the authors explored the impact of TI GDP growth on CO_2e in China during 1985–2019. Smooth transition regression (STR) was used to estimate the threshold impacts of the nexus among the variables of interest. The empirical outcomes showed that 1% rise of TI led to 2.91664% increase of CO_2e, whereas a 1% increase in GDP growth resulted in 1.16441% decreases in CO_2e. These outcomes had suggested supporting the publicity in line with the environmental protection and further extend green production. In [30], the authors tested a quadratic nexus of innovations and CO_2e for 30 provinces of China. This hypothesis was tested using panel methods like instrumental variables, fixed and random effect models (IVFR), and fixed effect panel data quintile (FEQ) regressions. This study estimated an inverted U-shaped relationship between innovations and CO_2e for the whole panel. This outcome suggested that a high rank of TI should be "green", while low levels of TI were considered "dirty for developed states of China. In [13], the authors analyzed an asymmetric association of green innovations with CO_{2e} in China using the panel threshold method. The results show that as green TI was increasing, CO_2e was significantly decreasing. In the less developed regions of China, the emissions reduction effect was more significant.

In [38], the authors estimated the influence of economic growth and innovations on CO_2e following the EKC theory. An inverted U-shape trend was found in the relation of economic growth with CO_2e in the short and long timespans. Innovations had only a significant linear negative relationship with CO_2e. In [39–43], the authors also incorporated the EKC theory to relate economic growth to the environment quality. They reported a significant influence of economic growth on CO_2e under the EKC theory, whereas few studies found no consistency in the EKC hypothesis [44]. In [45], the authors found a significant negative impact of RE consumption on CO_2e. They also found direct linkage between economic growth and CO_2e in both short and long runs. They also found one-way causation from the utilization of fossil energy to CO_2e. In [27], the authors also estimated a significant negative long-term association of RE use with CO_2e; however, this link is inconsistent in the short time span.

The EKC was also accounted for as the dominant approach among economists to model the non-linear relationship of energy resources with CO_2e [46]. In [47] as well as [48], the authors explored the inverted U-shape relationship of energy use with CO_2e following the EKC theory.

Many studies analyzed urbanization and CO_2e [47–49]. Their empirical outcomes estimated the positive association of urbanization with CO_2e. On the other hand, several studies discussed urbanization as a reason for the decrease in CO_2e [49,50]. Furthermore, ref. [49] measured a U-shaped urbanization nexus with CO_2e.

The literature review widely discussed the short- and long-run dynamics of the variables of interest. Only a few studies empirically investigated the presence of the EKC hypothesis in innovations, REC, NREC, economic growth, urbanization CO_2e nexus [22,29,46–50]. Thus, this study will contribute to the literature by testing the EKC among the variables of interest.

3. Data and Econometric Model Specification

This research investigates the impact of technology, economic growth, renewable and non-renewable energy, and carbon emissions for European states during 1995–2017. Following [51], this study proposes the following model:

$$2e_{it} = f(GDP_{it},\ REC_{it},\ NREC_{it},\ I_{it},\ URB_{it}) \tag{1}$$

In Equation (1), CO_2e is an environmental indicator; per capita GDP represents economic growth; REC is renewable energy consumption; NREC is non-renewable energy consumption; *I* is innovation and URB is urbanization. $i = 1, \ldots \ldots, 34$ stands for countries, and t = 1995–2017 represents the time span. We have extended the models in [52,53] by adding non-renewable energy consumption to the original models. Because the environment is rapidly deteriorating all around the world, we must investigate strategies to slow the deterioration and make the environment cleaner. This panel data for the aforementioned countries were taken from [54,55]. The following Table 1 gives the variables' descriptions.

Table 1. Variables Description.

Abbrv.	Indicator Name	Measurement Scale	Source
Co_2e	Carbon dioxide-emissions	Metric tons	[54]
GDP	Gross domestic product	Constant 2010$	[54]
REC	Renewable energy consumption	Share of RE in total energy consumption	[55]
NREC	Non-renewable energy	Share of non-renewable energy in total final energy consumption	[55]
I	Innovation	Patent Resident & Patent Non-Resident	[54]
URB	Urbanization	Urbanization rate	[54]

Panel data are more useful than other types of data because it shows specific cross-sectional and heterogeneity impacts. The extensive sample size has improved the reliability of the results and made the estimation more robust. On the other hand, panel data is more valuable because it comprises of more information, is more efficient, and has less collinearity [56,57]. In the first step, all variables' stationarity is checked to avoid misleading results and spurious regression. The variables' stationarity has been examined by three separate panel unit root tests; namely, ref. [58] panel unit tests. To reject the null hypothesis, both of the aforementioned panel unit tests assume unanimity of process in unit root across distinct data types (Ho). Ho does not include a unit root; however, the alternative hypothesis is exactly the opposite. The results of the panel co-integration test will indicate whether the long-run analysis is applicable. The *p*-value results confirm the long-term relationship between variables, so we will proceed with the relevant econometric method.

Table 2 represents the summary statistics and normality estimates. The summary statistics present the maximum, minimum, the median and mean values for all the variables. Table 2 also includes the probability values for kurtosis and skewness to declare the normality of data. The skewness and kurtosis assumptions demand a near-zero mean and mesokurtic distribution. Skewness, kurtosis, and J.B. statistically significant findings show that the dataset is asymmetric in distribution for the given sample countries. The rejection of the null hypothesis in the normality test indicates that all variables are not regularly distributed.

Table 2. Summary Statistics.

Variables	Mean.	Median.	Maximum	Minim	Std.	Skw	Kur
CO_2e	0.844	0.838	1.394	0.428	0.181	0.250	772.740
GDP	0.473	0.531	1.537	−1.593	0.372	−1.259	6.465
REC	1.033	1.107	1.888	−0.069	0.457	0.403	2.432
NREC	1.839	1.893	1.996	1.01	0.173	−2.39	9.504
I	3.105	3.181	4.831	1.38	0.755	0.162	2.68
URB	6.817	6.819	8.036	5.389	0.608	−0.1	2.695

4. Results and Discussion

The stationarity test is the primary step for empirical work (see Table 3). The stationarity tests confirm that the integration of the relevant variables is of order zero or one. The literature proposes the presence of co-integration among the relevant variables if the integration order is one. The [59] panel unit tests presuppose unanimity of process in unit root across data of different types in order to reject the null hypothesis (H_0). H_0 contains no unit root, while the alternative hypothesis is absolutely the reverse. The stationarity outcomes in Table 3 will help to confirm the suitability of the autoregressive distributed lagged (ARDL) approach, and non-linear autoregressive distributed lagged (NARDL) methods to estimate the coefficients of interest. Furthermore, the robustness of the linear outcomes will be checked by fixed effects and random effects regressions.

Table 3. Unit Root Outcomes.

Var	LLC		IPS	
	Level	Diff	Level	Diff
CO_2e	−2.998	−13.893 **	−2.976	−16.819 *
GDP	−9.87	−19.907 *	−8.011	−18.412 ***
REC	−4.109	−9.452 ***	−2.457	−12.755 **
NREC	−1.341	−11.504 **	−2.443	−13.453 *
I	0.729	−9.784 **	−1.859	−11.683 **
URB	1.517	−5.325 *	2.31	−5.179 ***

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

This study uses both the panel linear and NARDL methods [58,60]. The panel NARDL methodology gives the following three benefits. Initially, it assesses the degree to which the data exhibits non-linear asymmetries. Second, it evaluates the impact of data heterogeneity.

The following form of the panel NARDL model is written below:

$$CO_{2eit} = \partial_i ECT_{it} + \sum_{k=1}^{q-1} \varnothing_{ik}^{'} \Delta y_i, j-k + \sum_{k=0}^{p-1} (\gamma_{ij}^{'+} \Delta X^{+}{}_{i}, j-k + \gamma_{ij}^{'-} \Delta X^{-}{}_{i}, j-k) + \varepsilon_i + \mu_{it} \quad (2)$$

where, $ECT_{it} = \partial_i Y_{i,t-1} (\delta_i^{'+} X_{i,j-k}^{'+} + \delta_i^{'-} X_{i,j-k}^{'-})$.

In Equation (2), CO_2e demonstrates carbon dioxide emissions; $i = 1, \ldots \ldots, 34$ stands for countries, t = 1995–2017 depicts the time period. The long-term impact of positive and negative changes is provided by θ+ and θ−, while $\sum_{k=0}^{p-1}(\gamma_{ij}^{\prime +} \Delta X^{+}{}_{i}, j-k+\gamma_{ij}^{\prime -} \Delta X^{-}{}_{i}, j-k)$ proposes the short-term asymmetric effects of positive and negative changes in CO_2e. In addition, error correction term (ECT) demonstrates error correction term, indicating the short run variations in the suggested indicators.

The unit root outcomes in Table 3 show the stationarity of the aforementioned variables of interest at the first difference. These unit root conclusions refer to the choice of co-integration tests, ARDL, and NARDL estimation strategies [59,61].

The Pedroni co-integration test's outcomes for intercept and intercept with the trend are presented in Table 4. As far as the co-integration results with intercept are concerned, H_0 is rejected. While in the case of an intercept with the trend, the null hypothesis is again rejected. The panel co-integration test results will tell us whether the long-run analysis is applicable. The p-value results confirm the long-run association among variables, so we will move towards the ARDL approach (see Table 4).

Table 4. Pedroni Co-integration Results.

Indicators	**Case A**				**Case B**			
	Coeff	***p*-Value**	**Weighted Stat**	***p*-Value**	**Coeff**	***p*-Value**	**Weighted Stat**	***p*-Value**
Panel v-stat	−0.831	0.797	−2.108	0.982	−2.163 **	0.984	−3.947	1.000
Panel rho-stat	1.186	0.882	0.456	0.676	3.048 *	0.998	2.281	0.987
Panel pp-stat	−4.506 **	0.002	−7.258	0.000	−5.223 **	0.000	−9.807	0.005
Panel ADF-stat	−6.247 **	0.004	−7.503	0.000	−7.574 **	0.000	−9.527	0.004
Alternative hypothesis: individual A.R. coefficients (between dimensions)								
Group rho-stat	2.158	0.984			3.750 *	0.999		
Group pp-stat	−9.504 *	0.002			−3.862 *	0.002		
Group ADF-stat	−8.815 **	0.004			−1.167 *	0.002		

Note: **, * means 5% and 10% significance levels, respectively.

Table 5 indicates the estimated outcomes using ARDL and NARDL techniques, where carbon dioxide emission is regress and, while renewable and non-renewable energy, economic growth, innovation, and urbanization are regressors.

First and foremost, the EKC hypothesis is validated for European economies. Our outcomes are consistent with [62–64]. Past studies indicated that increased economic growth initially harms air quality before improving it. As a result, the economic costs of long-term investments are relevant to income. In addition, it is acknowledged that the energy industry in these nations is reliant on fossil fuels, as is the case with many others in the early phases of growth. Sustainability awareness has evolved in this sector in the latter stages of development.

The findings indicate the long-run connection among renewable and non-renewable energy, innovation, economic growth, and urbanization. It is found that non-renewable energy, economic growth, and urbanization posits a direct impact on carbon dioxide emissions for the sampled countries. These outcomes are in line with [65–72].

In terms of the renewable energy coefficient, it has been determined that rising renewable energy use as a percentage of overall energy use has cut CO_2e in European countries. In some countries, renewable energy has been promoted as a feasible substitute for fossil fuels. The use of renewable energy reduces ecological deterioration, hence promoting sustainable growth in Europe. These outcomes are similar to previous research [73–83].

Table 5. ARDL and dynamic ARDL simulations results.

Regressors	NARDL		ARDL	
	Coefficient	T-Stat	Coefficient	T-Stat
GDP+	0.014 *	3.226		
GDP−	0.254 **	3.789		
GDP			0.244	0.207
REC+	−0.153 *	−2.383		
REC−	−0.178 *	−2.427		
REC			−0.020 **	−3.025
NREC+	2.965 **	3.100		
NREC−	2.056 ***	35.56		
NREC			2.083 **	3.776
I+	−0.056 *	−3.500		
I−	−0.059 **	−4.0968		
I			−0.146 *	−7.109
URB+	1.157 *	10.443		
URB−	0.315 **	2.888		
URB			0.177	1.442

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

Tables 6 and 7 summarize the findings of fixed effects and random effects regression outcomes and various diagnostic tests. We employ diagnostic tests to ensure that the econometric model is consistent. According to the findings of the Breusch–Godfrey LM test, there is no serial correlation in the model. The Breusch–Pagan results demonstrate that there is no heteroscedasticity present in the model. The skewness and kurtosis measures are used to determine the dataset's normality. Under the null hypothesis, the data demonstrate the existence of a normal distribution. Usually, a normal distribution is symmetric about the mean, indicating that data near the mean occur more frequently than data distant from the mean. For our econometric model, the normal distribution demonstrates that reliable and relevant variables are employed in the model, since we get into a number of issues if we make use of non-essential factors.

Table 6. Fixed Effects and Random Effects Regression Outcomes.

Independent Variables	Fixed Effect Coefficients	Random Effect Coefficients
GDP	−0.016 (0.019)	−0.016 (0.019)
NREC	−0.014 (0.137)	−0.012 (0.218)
REC	−0.137 (0.00)	−0.139 (0.00)
I	0.077 (0.00)	0.009 (0.00)
URB	0.830 (0.098)	0.870 (0.092)
Constant	10.239 (0.00)	10.084 (0.00)

Table 7. Diagnostic test results.

Diagnostic Tests	Coeff.	Prob.
Breusch–Godfrey LM (Autocorrelation)	1.4	0.266
Breusch–Pagan (Heteroscedasticity)	0.45	0.504
Skewness and Kurtosis (Normality)	0.52	0.77

5. Conclusions and Policy Implications

This research has investigated the influence of innovations, REC, NREC, GDP growth, and urbanization on CO_2e in 34 European countries.

The empirical outcomes have confirmed the long-run nexus of technology, renewable energy use, economic growth, and urbanization with CO_2e using Pedroni co-integration. The interesting outcome in this research is the existence of a significant U-shaped nexus of I, REC, and CO_2e for European economies. This outcome has increased the value of patents and the need for renewable energy resources. This conclusion is vibrant and makes this research prominent in the literature. A similar conclusion is also estimated by [30] for the panel of Chinese provinces. The second vivid conclusion is the presence of a significant asymmetric association among NREC and GDP growth with CO_2e. This outcome is noted as common in the aforementioned literature.

As our outcomes suggest that both innovations and REC have reduced CO_2e, this would imply that more policies should be developed to encourage patents and REC sources to attain a sustainable environment. Our outcomes also confirm that innovations, REC, and CO_2e are interrelated. In such circumstances, strengthening the economic tendency towards technological developments will help to reduce CO_2e. The European government should make policies to promote green innovations and REC. The local government must create incentive programs to increase clean energy use to get positive outcomes. At the same time, certain agreeable strategies are also mandatory to reduce the growing urban population, which in turn causes increased CO_2e. These outcomes have also been suggested to support the publicity in line with the environmental protection to cut CO_2e, and further extend green production. In addition, if we compare worldwide, we can see rising greenhouse gas emissions in the Next (N-11) economies, i.e., Bangladesh, Egypt, Indonesia, Iran, South Korea, Mexico, Nigeria, Pakistan, the Philippines, Turkey, and Vietnam. These economies were largely involved in higher energy use, air emissions, and waste production since 2008. To overcome these issues, these economies developed policies to promote the use of green energy—such as, 36% of businesses were run in an innovative environment and various innovative operations were also launched in 2018. One-fifth of the businesses in these economies successfully worked under productive innovations resulting in ecological preservation, pollution prevention, energy conservation, water conservation, and emissions reduction. Thus, the experience of N-11 economies exposes CO_2e reduction through innovations.

The research outcomes also emphasize the importance of effective strategies to control the direct impact of energy use and per capita income on CO_2e.

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