Erciyes Üniversitesi
İktisadi ve İdari Bilimler Fakültesi Dergisi
ISSN: 1301-3688/e-ISSN: 2630-6409

Araştırma Makalesi | Research Article
Yayın Tarihi: 30 Nisan 2025 | Published: April 30, 2025
doi: 10.18070/erciyesiibd.1517825

THE ROLE OF DIGITALIZATION, RENEWABLE ENERGY SUPPLY AND ECONOMIC GROWTH IN ENVIRONMENTAL QUALITY: EVIDENCE FROM OECD COUNTRIES ON THE AXIS OF SUSTAINABLE DEVELOPMENT

***HABİBE YAMAN*[1*]**

[1] *Dr. Öğretim Üyesi, Burdur Mehmet Akif Ersoy Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, hyaman@mehmetakif.edu.tr, https://orcid.org/0000-0002-9212-3264.*

ABSTRACT

Investments in renewable energy sources are considered having an important place in achieving sustainable development goals. The impact of renewable energy on environmental quality is at the center of researchers' attention. In addition, the development of Industry 4.0 and the philosophy of Society 5.0 have brought a different dimension to digitalization and technological advances. With the impact of these developments that trigger regional and global competition, the connection of digitalization and economic growth, which is a prominent factor in this process, with environmental quality, has become a matter of curiosity. This research aims to reveal the role of digitalization, renewable energy supply and economic growth in environmental quality. In this study, 38 OECD countries and the 2005-2020 period is taken as a basis. Dumitrescu & Hurlin (2012) panel causality analysis has been used as a method in the study and a heterogeneous VAR model has been estimated. The findings from the panel causality analysis reveal that there is a causal relationship between digitalization, renewable energy supply and economic growth variables and environmental quality. Panel VAR model results also show that digitalization is significant in 4 countries, renewable energy supply is significant in 10 countries and growth is significant in 11 countries in explaining environmental quality. The findings of this study reveal that policymakers must prioritize digitalization and renewable energy in the process of protecting and improving environmental quality.

Keywords: Growth, Renewable Energy, Digitalization, Environmental Quality, OECD.

DİJİTALLEŞME, YENİLENEBİLİR ENERJİ ARZI VE EKONOMİK BÜYÜMENİN ÇEVRESEL KALİTEDEKİ ROLÜ: SÜRDÜRÜLEBİLİR KALKINMA EKSENİNDE OECD ÜLKELERİNDEN KANITLAR

ÖZ

Yenilenebilir enerji kaynaklarına yapılan yatırımların sürdürülebilir kalkınma hedeflerine ulaşmada önemli bir yeri olduğu düşünülmektedir. Yenilenebilir enerjinin çevresel kalite üzerindeki etkisi son yıllarda konuyla ilgili araştırmacıların ilgi odağında yer almaktadır. Ayrıca Endüstri 4.0'ın gelişimi ve Toplum 5.0'ın felsefesi dijitalleşme ve teknolojik ilerlemelere farklı bir boyut getirmiştir. Bölgesel ve küresel açıdan rekabeti tetikleyen bu gelişmelerin etkisiyle dijitalleşmenin ve bu süreçte öne çıkan bir faktör olan ekonomik büyümenin çevresel kaliteyle bağlantısı merak konusu olmuştur. Bu araştırma dijitalleşme, yenilenebilir enerji arzı ve ekonomik büyümenin çevresel kalitedeki rolünü ortaya koymayı amaçlamaktadır. Bu çalışmada 38 OECD ülkesi ve 2005-2020 dönemi temel alınmıştır. Bu çalışmada yöntem olarak Dumitrescu & Hurlin (2012) panel nedensellik analizi kullanılmış ve heterojen VAR modeli tahmini yapılmıştır. Panel nedensellik analizinden elde edilen bulgular dijitalleşme, yenilenebilir enerji arzı ve ekonomik büyüme değişkenlerinin çevresel kalite ile arasında bir nedensellik ilişkisi olduğunu ortaya koymaktadır. Panel VAR modeli sonuçları da dijitalleşmenin 4 ülkede, yenilenebilir enerji arzının 10 ülkede ve büyümenin 11 ülkede çevre kalitesini açıklamada anlamlı olduğunu göstermektedir. Bu çalışmanın bulguları, politika yapıcıların çevresel kaliteyi koruma ve iyileştirme sürecinde dijitalleşme ve yenilenebilir enerjiye önem vermeleri gerektiğini ortaya koymaktadır.

Anahtar Kelimeler: Büyüme, Yenilenebilir Enerji, Dijitalleşme, Çevresel Kalite, OECD.

Sorumlu Yazar/ Corresponding Author:
Habibe YAMAN,
hyaman@mehmetakif.edu.tr

JEL:
R11, Q20, O44, O30

Geliş: *17 Temmuz 2024*
Received: *July 17, 2024*
Kabul: *18 Aralık 2024*
Accepted: *December 18, 2024*
Yayın: *30 Nisan 2025*
Published: *April 30, 2025*

Atıf / Cited as (APA):
Yaman, H. (2025), The Role of Digitalization, Renewable Energy Supply and Economic Growth in Environmental Quality: Evidence from OECD Countries on the Axis of Sustainable Development, Erciyes Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi, 70, 31-36, doi: 10.18070/erciyesiibd.1517825

INTRODUCTION

Breakthroughs in technology have an important impact on both economic and social development of societies. Advances in science and technology have a positive impact on numerous sectors, old technologies are replaced by new technologies, and societies benefit significantly from the opportunities brought by digital transformation. Effective use of technology is critical to access the right information, using information effectively and increasing competitiveness. In this rapid change and transformation process, the impact of digitalization on environmental quality (EQ) cannot be ignored. Because the rapid development of technology presents various opportunities and some risks to the environment. As Usman et al. (2021) state, views on the effect of technology on the environment are divided into two. While some experts believe that information and communication technology (ICT) positively impact on the environment, others think that ICT involves serious threats to the environment. Although digitalization and technological innovations have the potential to tackle crucial environmental issues and improve EQ, it is important to recognize that economic expansion impacts EQ and that developments in this process can lead to raised pollution and resource consumption (Ullah et al., 2024, p.4).

Digitalization has significant effects both globally and regionally. For example, with the impact of the digital economy, the regional economy has developed rapidly, new job opportunities have arisen, and people's living standards have improved. However, the number of motorized vehicles has also increased rapidly in this process. The significant amount of vehicle exhaust emissions also aggravates the degree of atmospheric pollution (Li et al., 2021, p.4). Overall, in the era of the knowledge economy, the integrating of the Internet and traditional industries is driving the shift of the world economy towards a more smarter, innovative and greener direction (Ren et al., 2023, p.1533). Increasing concerns about mitigating the effects of climate change intensify the search for alternative energy. Renewable energy (RE) sources, known for being clean and eco-friendly, appear as suitable candidates in this process (Adebayo et al., 2024).

There is worldwide investment in natural energy conversion, driven by a number of factors, such as the fossil fuels consumption, the growth of RE technology, ecological sustainability and energy independence. RE resources are becoming more important day by day because of factors such as the near depletion of fossil fuels and the rapid rise in emissions in the 21st century (Zhang et al., 2022, p.995). Clean and renewable energy transformation measures and the development of new eco-friendly technologies are also prominent in regional development policies. The reality that energy matters in climate change leads to an increase in measures and investments for transformation to clean and renewable energy all over the world. This situation is viewed as an important economic opportunity for all regions aiming to expedite their development by advancing in more competitive sectors (Çelik, 2021). As is known, the debate on EQ and growth has been ongoing for a long time. These discussions have acquired a different dimension with the 'Limits to Growth' report prepared and presented by the members of the Club of Rome in 1972 (Meadows et al., 1972) and more comprehensive research has begun to be conducted on the subject. Therefore, economic growth (EG) is also a crucial parameter in this process. Within this framework, the purpose of this research is to explore the role of digitalization, RE supply (RES), and EG in EQ.

In this study, first, we have investigated the causality relationship between digitalization and EQ and in this context, we have constructed the first model of the study. Second, we have constructed a model for the link between RES and EQ. Then, we have considered the link between EG and EQ. We have conducted descriptive tests for the causality test and, based on the tests we have applied, we have revealed the relationship in question with the Dumitrescu & Hurlin (2012) panel causality method. We have estimated the heterogeneous panel VAR model to see the results for the units. Based on the findings, we have made inferences for the OECD country group. We have designed the content of the study as follows. Following the introduction, in the first section, we discuss the literature and hypothesis development. In the second section, we address data and analysis methods. In the third section, we present the analysis results and discuss the findings. In the following section, we conclude our study by providing conclusions and recommendations.

I. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

The deterioration of EQ has deepened efforts to explain the causes of this deterioration. Numerous studies underline the existence of the impact of digitalization, RE and EG on EQ or environmental performance. For example, in their OECD-specific study on the link between EQ and digitalization, Ullah et al. (2024) state that digitalization increases carbon emissions. Adebayo et al. (2024) emphasize that digitalization has a negative impact on the ecological footprint. Khan et al. (2023), in their study covering 41 Sub-Saharan countries for the period 2004-2021, have determined that the use of RE significantly improves EQ, while technologies and digitalization positively increase carbon emissions. Usman et al. (2021) have identified that ICT significantly influences CO2 emissions in their study based on the example of Asian economies.

The findings of Zeeshan et al. (2022) on South-East Asia reveal that ICT use causes more environmental degradation rather than improving environmental performance, while RE has a significant contribution to EQ. Similarly, Danish et al. (2018) have determined that ICT worsens EQ in their research, focusing on developing economies. However, in their study focusing on the association between financial development, RE consumption, digitalization, EQ, and EG in Central European countries for the period 1995-2019, Jó´zwik et al. (2023) have found that there is a negative link between digitalization, RE consumption, and carbon emissions, while there is a positive link between EG and carbon emissions. In addition, Charfeddine et al. (2024), in their study of the ten most polluted countries for the period 1995-2018, provide strong evidence that digitalization has a positive impact on EQ and emphasize that ICT and RE have an important role to play in enhancing environmental sustainability. Also, in their research on EU countries for the period 2000-2020, Dzwigol et al. (2023) argue that RE is crucial for advancing a country's green EG.

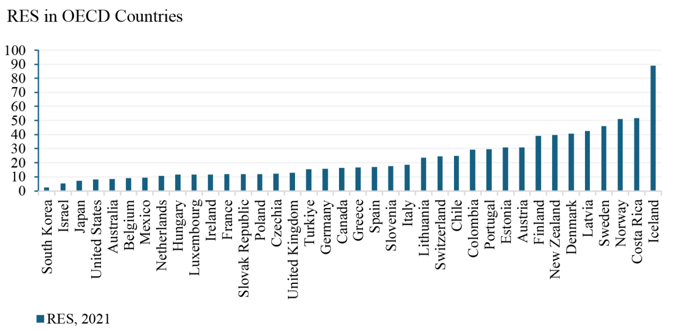
Saud et al. (2019) have determined that the increase in EG and electricity consumption reduces EQ. Cialani (2007), focusing directly on the link between growth and CO2 emissions, states that the link between these two variables is positive. On the other hand, Ergün and Atay Polat (2015), in their study covering 30 OECD countries and the period 1980-2010, have identified a unidirectional causality between EG and CO2 emissions. However, there are also studies in the literature that draw different conclusions according to country income groups. For example, Ben Youssef and Dahmani (2024), based on research findings involving 88 countries, state that technological progress significant contributions to EQ in high-income nations, while low and middle-income countries require special strategic approaches in energy management and environmental policy.

Faisal et al. (2020) assert that there is a one-way causality between CO2 emissions and ICT, suggesting that RE sources can be adopted to promote clean energy and reduce carbon emissions. Analyzing the association between environmental performance and digitalization for 25 European countries during the period of 2015-2020, Ha et al. (2022) emphasize that while the digital transformation process may have negative impacts in the short term, it produces positive effects in the long term. In addition, there are studies suggesting that digitalization has a positive impact on EQ. For instance, Ramos-Meza et al. (2021), utilizing an ARDL approach covering the period from 1990 to 2019, suggest that digitalization positively affects EQ in Asia. Ren et al. (2023) reveals that the internet can improve the ecological environment in their research based on the years 2006-2017 and 30 Chinese provinces. On the other hand, Chen et al. (2020) state that digitalization in manufacturing has a positive contribution to environmental sustainability. In addition, Karlilar et al. (2023), employing the system-GMM approach for the period from 2000 to 2018 across 36 OECD countries, emphasize that RE, digitalization and financial development substantially support environmental sustainability.

If we evaluate the studies on digitalization, RE, EG and EQ, which form the basis of this study, empirical studies that focus directly on EG and EQ concentrate on a wide range of topics. These topics include examining the existence of the commonly assumed inverted-U shaped link between income and environmental degradation, known as the Environmental Kuznets Curve; ecosystem resilience and sustainability; the consequences of ecological thresholds and irreversible damages for the inverted-U shaped link; and the role of environmental policies in the process (Panayotou, 2000, p.5). Additionally, in the literature, EQ is frequently addressed with titles such as RES and digitalization besides EG, and it is analyzed in both theory and policy perspectives for various countries and period intervals. These studies reveal that digitalization, RE and EG are prominent terms in achieving sustainable development goals. However, based on the studies in the literature, we can say that it is difficult to make a clear inference about the impact of digitalization, RE, and EG on EQ.

Energy is one of the basic inputs of economic and social development. For economic development to be achieved or sustained, energy must be provided uninterruptedly and sustainably (Lebe, 2012, p.1). Currently, the importance of clean and renewable energy sources has increased significantly. Within the framework of sustainable development, it is accepted that preventing negative impacts can be achieved through RE sources (Yıldırım and Nuri, 2018, p.107). The potential for RE varies among countries. For example, when we look at the current situation of OECD countries, which are the subject of this study, we see that Iceland, Costa Rica and Norway lead in RES, while South Korea, Israel and Japan are at the bottom (Graph 1).

GRAPH 1 | RES in OECD Countries



Data source: OECD (2024).

The rapid development of technology requires integration into this change to have a competitive advantage. The topic of the Society 5.0 discussions is technology-supported social transformation. This not only involves the development of technology but also the adaptation of its skills and capacities to be human- and society-oriented, which is essentially the digital transformation process. In this transformation, factors such as environmental policies and clean energy are important (KPMG, 2021, p.9). Globally, the momentum in RE is expected to continue, and it is expected that the need to strengthen energy security and decarbonization efforts will push many governments to move even faster on RE deployment (EIU, 2023). In this framework, this study has aimed to reveal the role of digitalization, RES, and economic growth (EG), which are prominent concepts in terms of EQ, on EQ across 38 OECD countries during the period 2005-2020. Using panel causality analysis and heterogeneous VAR model, we have extensively investigated whether digitalization, RES and EG are a cause of EQ for 38 OECD countries in this study. We believe that the findings specific to 38 OECD countries, our choice of variables, and the implications of our findings will contribute to the literature.

II. DATA AND METHODS OF ANALYSIS

A. DATA

In this study, we have aimed to analyze the role of digitalization, RES and EG in EQ. In the study, we have considered 38 OECD countries, and we have performed the analysis based on the 2005-2020 period. Table 1 displays the variables we used. In the period we are handling this study, EQ data is not available for the years after 2020, and RES and digitalization data are not available for the years after 2021, so we have not included the years after 2020 in the study. We have taken the RES variable we used in the study from the OECD database, and the digitalization, EQ and EG variables from the World Bank database.

B. METHODOLOGY

In this study, we use panel causality analysis as a method and estimate a heterogeneous panel VAR model to observe the results across the units. The models we have created for the determination of causality are as follows:

$$\ln EQ_{it} = a_0 + a_1 * DG_{it} + u_{it} \quad (1)$$

$$\ln EQ_{it} = \delta_0 + \delta_1 * RES_{it} + \varepsilon_{it} \quad (2)$$

$$\ln EQit = \theta_0 + \theta_1 * \ln EG_{it} + \nu_{it} \quad (3)$$

In Equations 1, 2, and 3, t is the time series dimension, i is the cross-sectional unit, a_0, δ_0 and θ_0 are the constant terms. In addition, a_1, δ_1 and θ_1 represent the degree of effect of the independent variable, and u_{it}, ϵ_{it} and v_{it} represent the error terms. Table 1 shows the variable definitions and explanations in the models. In empirical research within the literature, the CO2 emissions variable is used to represent EQ. As examples of this, we can show the studies by Ullah et al. (2024); Jó´zwik et al. (2023); Ramos-Meza et al. (2021); Cialani (2007). On the other hand, the ICT-related exports (% of total exports) variable can be used to represent digitalization. The study by Li et al. (2024) can be given as an example in this context. Accordingly, we have used the ICT goods exports variable to represent digitalization.

TABLE 1 | Variable Symbol and Definition

Variables	Symbol	Definition	Sources
Environmental quality	lnEQ	CO2 emissions (metric tons per capita)	World Bank (2024)
Digitalization	DG	ICT goods exports (% of total goods exports)	World Bank (2024)
Renewable energy supply	RES	Renewable energy supply (% of energy supply)	OECD (2024)
Economic growth	lnEG	GDP per capita (current US$)	World Bank (2024)

Table 2 shows the summary statistics of the variables used in the study and Table 3 presents the correlation values of the variables.

TABLE 2 | Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
YEAR	608	2012.5	4.613568	2005	2020
CNO	608	19.5	10.97489	1	38
RES	608	18.13893	16.83389	0.51	89.75
DG	608	6.582976	6.387426	0.0677304	29.99614
lnEQ	608	1.913907	0.5548334	0.3074815	3.243
lnEG	608	10.29203	0.7103714	8.145706	11.72544

TABLE 3 | Matrix of Correlations

	(1)	(2)	(3)	(4)
(1)lnEQ	1.0000			
(2) DG	0.0641	1.0000		
(3) RES	-0.4163	-0.2974	1.0000	
(4)lnEG	0.6139	-0.2415	0.0300	1.0000

III. RESULTS AND DISCUSSIONS

A. CROSS-SECTION DEPENDENCE, UNIT ROOT, AND HOMOGENEITY TESTS

One of the two main points that are important for the panel data analysis method is to determine whether there is a dependence between the cross-sections and the other is to test the existence of homogeneous structure among the series (Gültekin and Uğur, 2019, p.331). In this context, we have tested cross-section dependence using the Pesaran (2004) CD test and homogeneity using the Swamy S test. In the Pesaran test, the null hypothesis (H0) shows no cross-section dependence, while in the Swamy S test, the null hypothesis (H0) shows that the coefficients are homogeneous. Table 4 summarizes the results of the Pesaran test and the Swamy S test. In addition, random and fixed effects estimation results are presented in the appendix (see APP-1).

TABLE 4 | Pesaran Test and Swamy S Test Results

Pesaran (2004) CD test		
	Statistics	p-value
Fixed effects	10.973	0.0000
Random effects	13.753	0.0000
Swamy S Test		
chi2(148): 57223.36		Prob > chi2: 0.0000

According to the results of the Pesaran test (p-value < 0.05), there is cross-section dependence, and according to the results of the Swamy S test (p-value < 0.05), the series exhibits heterogeneous distribution. Due to the presence of cross-section dependence, we have used the Fisher ADF panel unit root test, a second-generation panel unit root test. Table 5 summarizes the unit root test results.

TABLE 5 | Unit-root Test Results

	lnEQ	DG	RES	lnEG
Inverse chi-2(76) (P)	186.8487 (0.000)	370.8163 (0.000)	187.6901 (0.000)	188.4616 (0.000)
Inverse normal (Z)	-7.3920 (0.000)	-13.7285 (0.000)	-6.8179 (0.000)	-8.1094 (0.000)
Inverse logit t(194) (L*)	-7.3455 (0.000)	-16.4148 (0.000)	-7.1487 (0.000)	-7.9800 (0.000)
Mod. inv. chi-2(Pm)	8.9910 (0.000)	23.9128 (0.000)	9.0593 (0.000)	9.1218 (0.000)

Note In the table, values in parentheses represent the significance level, while values without parentheses represent the statistical value. Lag length is chosen as 1 for all variables in the table.*

As seen in Table 5, according to the results of Fisher ADF panel unit root test, the variables are significant.

B. PANEL CAUSALITY TEST AND HETEROGENEOUS VAR ANALYSIS

In the literature, when the units are homogeneous, the panel causality relationship between two variables is usually tested with the panel Granger causality test. When the units are heterogeneous, the causality relationship between the two variables is analyzed by the Dumitrescu & Hurlin (2012) panel causality test (Tatoğlu, 2018, p.152-154; Ağazade and Karakaya, 2019, p.477). In this study, we have used the Dumitrescu & Hurlin (2012) panel causality test because of cross-section dependence and heterogeneous distribution. We can present the null hypothesis stating that there is no causality relationship in all cross-section units as in equation 4, and the alternative hypothesis stating that there is causality in some cross-section units as in equation 5 (Güriş, 2018, p.410-411).

$$H_0 : \beta_i^{(k)} = 0 \qquad i = 1, 2, ..., N \tag{4}$$

$$H_1 : \begin{cases} \beta i(k) = 0 & i = 1, 2, \dots \dots N1 \\ \beta i(k) \neq 0 & i = N1+1, N1+2 \dots \dots N \end{cases} \tag{5}$$

In the equation, k defines the optimum lag length and i defines all units. In this study, because of the heterogeneity of the panel, we have preferred heterogeneous VAR analysis. Table 6 presents the estimation of the heterogeneous panel VAR model used in the panel causality analysis and the causality test results.

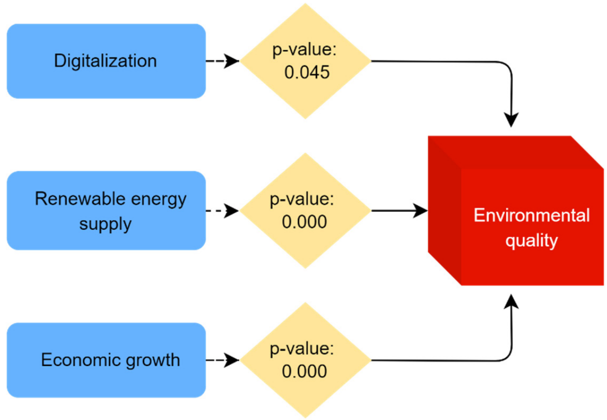
TABLE 6 | Panel Causality Test and Heterogeneous Var Model

	Ho: DG does not Granger-cause lnEQ	Ho: RES does not Granger-cause lnEQ	Ho: lnEG does not Granger-cause lnEQ
Australia	0.039 **(0.041)**	0.001 (0.954)	-0.038 (0.162)
Greece	0.021 (0.332)	0.036 (0.223)	-0.224 (0.052)
New Zealand	0.135 (0.138)	-0.021 (0.148)	-0.061 (0.611)
Austria	0.050 (0.152)	-0.006 (0.604)	-0.204 (0.233)
Hungary	-0.002 (0.433)	-0.007 (0.648)	-0.176 (0.143)
Norway	0.017 (0.652)	-0.002 (0.410)	-0.003 (0.960)
Belgium	0.029 (0.427)	-0.060 **(0.001)**	-0.090 (0.655)
Iceland	-0.421 (0.435)	-0.002 (0.752)	-0.079 (0.539)
Poland	0.002 (0.831)	-0.009 **(0.029)**	-0.125 **(0.006)**
Canada	0.027 (0.212)	0.010 (0.626)	-0.047 (0.659)
Ireland	0.002 (0.773)	-0.008 (0.410)	-0.092 (0.274)
Portugal	0.005 (0.752)	0.009 (0.423)	-0.234 (0.281)
Chile	-0.129 (0.583)	-0.003 (0.687)	0.364 **(0.022)**
Israel	0.000 (0.982)	0.029 **(0.037)**	-0.192 (0.065)
Slovakia	0.002 (0.639)	-0.023 (0.069)	-0.261 **(0.012)**
Czechia	-0.019 **(0.005)**	-0.001 (0.962)	-0.181 **(0.005)**
Italy	0.052 (0.311)	-0.055 **(0.039)**	-0.194 (0.244)
Slovenia	-0.032 (0.567)	-0.024 (0.162)	-0.275 **(0.036)**
Colombia	-0.392 **(0.048)**	0.022 **(0.030)**	0.156 **(0.007)**
Japan	0.003 (0.475)	-0.019 (0.093)	0.177 (0.079)
Spain	0.024 (0.694)	0.032 (0.331)	-0.310 (0.165)
Costa Rica	0.002 (0.225)	0.005 (0.406)	-0.050 (0.296)
S. Korea	-0.004 (0.093)	-0.036 (0.140)	-0.166 **(0.038)**
Sweden	0.020 (0.362)	0.000 (0.921)	-0.196 (0.149)
Denmark	0.057 (0.216)	-0.041 **(0.010)**	-0.635 **(0.018)**
Latvia	-0.046 (0.859)	0.004 (0.228)	-0.029 (0.647)
Switzerland	0.025 (0.556)	-0.022 (0.139)	-0.042 (0.734)
Estonia	0.009 (0.590)	-0.027 (0.143)	-0.596 **(0.013)**
Lithuania	0.018 (0.135)	0.001 (0.586)	-0.012 (0.803)
Türkiye	0.014 (0.582)	0.013 (0.067)	-0.038 (0.666)
Finland	0.016 **(0.016)**	-0.052 **(0.003)**	-0.682 **(0.025)**
Luxembourg	0.006 (0.692)	-0.031 (0.224)	-0.061 (0.714)
United Kingdom	0.001 (0.885)	-0.035 **(0.047)**	-0.226 (0.219)
France	0.002 (0.931)	-.045 **(0.012)**	-0.059 (0.704)
Mexico	0.007 (0.372)	0.000 (0.988)	-0.159 (0.268)
United States	0.014 (0.326)	-0.072 (0.076)	-0.503 **(0.020)**
Germany	-0.003 (0.824)	-0.006 (0.389)	-0.110 (0.409)
Netherlands	0.002 (0.838)	-0.069 **(0.007)**	-0.017 (0.910)
Panel Causality Test Results			
W-bar	1.4592	3.3147	3.2660
Z-bar	2.0015	10.0894	9.8773
p-value	0.0453	0.0000	0.0000
AIC	1	1	1
Decision	DG ⇒ lnEQ	RES ⇒ lnEQ	lnEG ⇒ lnEQ

Note The values in parentheses in the table represent the significance level.*

The results of the VAR model for units show that the lagged digitalization variable is significant in explaining EQ in 4 countries (Australia, Czechia, Colombia, Finland) out of 38. Additionally, the lagged RES variable is significant in explaining EQ in 10 countries (Belgium, Poland, Israel, Italy, Colombia, Denmark, Finland, United Kingdom, France, Netherlands), while the lagged lnEG variable is significant in explaining EQ in 11 countries (Poland, Slovakia, Czechia, Slovenia, Chile, Colombia, S. Korea, Denmark, Estonia, Finland, United States). When examining countries significant in causality findings, it is seen that the statistical values are generally negative in other variables except for digitalization. The coefficient values of lagged growth and RES variables, which are significant in explaining CO2 emissions, are mostly negative. According to the panel causality test results, the null hypothesis is rejected for the three models subject to this study. Based on these results, it is concluded that there is causality from the variables digitalization, RES, and lnEG to lnEQ. Graph 2 visually summarizes the causal relationships between these variables.

GRAPH 2 | Causality Results



In summary, according to our findings for OECD countries, digitalization, RE, and EG variables all have an impact on CO2 emissions, which we consider as an indicator of EQ. Our findings are consistent with the results of Karlilar et al. (2023), which states that RE and digitalization significantly support environmental sustainability, as well as with Faisal et al. (2020), which states that RE sources can be adopted to reduce carbon emissions. In addition, our findings are also consistent with the results of Ergün and Atay Polat (2015), who found unidirectional causality from EG to CO2 emissions. However, as a basis for the causal relationship we obtained from digitalization to EQ, we can cite numerous studies showing the positive or negative effect of digitalization on EQ (Charfeddine et al., 2024; Ullah et al., 2024; Adebayo et al., 2024; Khan et al., 2023; Ren et al., 2023; Ha et al., 2022; Ramos-Meza et al., 2021; Usman et al., 2021; Chen et al., 2020; Danish et al., 2018).

CONCLUSION AND RECOMMENDATION

Digitalization and RE are considered to have a significant potential in the transition to a low-carbon economy. With the advancement of ICT, digitalization makes business processes more efficient, provides innovative solutions in the fields of environmental management and energy efficiency, and enables more efficient use of resources. With digital technologies such as big data analytics, the Internet of Things, and smart cities making energy use and waste management more efficient, digitalization is perceived as playing a more effective role in improving EQ. On the other hand, the use of RE resources is also important in combating climate change by reducing carbon emissions. RE projects and investments in this sector create new job opportunities, contribute to local economies and environmental sustainability in the long term, and support economic growth and development. It is believed that projects and investments in this scope can promote socially and economically inclusive development by encouraging the participation of communities and co-operation with local authorities. Therefore, it is important to investigate the link between digitalization, RE, and growth with EQ. In the literature, discussions regarding the determinants of EQ have been ongoing for many years. However, there is no consensus on the impact of digitalization, RE, and growth on EQ. It is generally believed that these effects vary depending on the level of economic development.

In this research, we seek to demonstrate the role of digitalization, RES, and EG in EQ. In this study, we have taken 38 OECD countries and the period 2005-2020 as a basis and used panel causality analysis as a method. In this process, we have preferred Dumitrescu & Hurlin (2012) panel causality analysis and estimated a heterogeneous VAR model. As a result of the research, we have discovered that there is a causal connection between digitalization, RES and EG variables and EQ. In the results of the panel VAR model for units, we have determined that the lagged digitalization variable is significant in explaining the EQ variable in Australia, Czechia, Colombia and Finland. On the other hand, we have found that the lagged RES variable in 10 countries (Belgium, Poland, Israel, Italy, Colombia, Denmark, Finland, United Kingdom, France, Netherlands) and the lagged lnEG variable in 11 countries (Poland, Slovakia, Czechia, Slovenia, Chile, Colombia, S. Korea, Denmark, Estonia, Finland, United States) are significant in explaining EQ.

Overall, the results of this research show that digitalization, growth and RE play a critical role in improving EQ. Innovative solutions that promote environmental sustainability contribute to building a more livable future. For this reason, it is important that both policymakers and the business world focus on protecting and improving EQ by investing in these areas and develop environmental strategies. Various recommendations for policymakers can be offered within the scope of this study. For example, policymakers can increase awareness-raising activities on EQ for sectors and firms that stand out in this process and provide additional incentives to projects and new initiatives based on green transformation. In addition, policymakers can create strategies for advancing RE technologies. They can also consider the degree of EQ impact as a determining factor in the process of facilitating firms' access to financing resources. In addition, for those factors that have a significant negative impact on the environment, additional deterrent measures may be implemented proportional to the degree of risk to mitigate this impact. On the other hand, developing science-based solutions to maintain and improve EQ is also crucial and these processes need to be supported.

Finally, it is a well-known fact that digitalization alone cannot fully safeguard the environment by changing production and consumption patterns, reducing emissions and transforming the energy system. The influence of digitalization on the environment also depends on the cooperation of economic actors and the interaction of economic actors with digitalization (Karlilar et al. 2023, p.2). The positive effects of digitalization, growth, and the use of RE on EQ support the goals of sustainable development and regional development. Therefore, based on the findings of this study, we can assert that collaborative approaches are crucial for enhancing EQ in both OECD countries and other nations.

APP 1 | Results of Fixed Effect and Random Effect Regression

	Fixed Effect	**Random Effect**
Variables	**lnEQ**	**lnEQ**
DG	0.00732*** (0.00246)	0.00873*** (0.00249)
RES	-0.0129*** (0.000905)	-0.0134*** (0.000917)
lnEG	0.521*** (0.0211)	0.508*** (0.0214)
Constant	-3.260*** (0.224)	-3.129*** (0.227)
Observations	608	608
R-squared	0.591	
Number of year	16	16

Note Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

REFERENCES

Adebayo, T. S., Meo, M. S., Eweade, B. S., & Özkan, O. (2024). Analyzing the Effects of Solar Energy Innovations, Digitalization, and Economic Globalization on Environmental Quality in the United States. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-02831-0

Ağazade, S., & Karakaya, A. (2019). Finansal Gelişme ve Ekonomik Büyüme: OECD Ülkeleri Örneğinde Panel Nedensellik Analizi (Financial Development and Economic Growth: A Panel Causality Analysis For OECD Countries). *Journal of Mehmet Akif Ersoy University Economics and Administrative Sciences Faculty*, 6(2): 471-484.

Ben Youssef, A., & Dahmani, M. (2024). Assessing the Impact of Digitalization, Tax Revenues, and Energy Resource Capacity on Environmental Quality: Fresh Evidence from CS-ARDL in the EKC Framework. *Sustainability, 16*: 474. https://doi.org/10.3390/su16020474

Charfeddine, L., Hussain, B., & Kahia, M. (2024). Analysis of the Impact of Information and Communication Technology, Digitalization, Renewable Energy and Financial Development on Environmental Sustainability. *Renewable and Sustainable Energy Reviews, 201*, 114609.

Chen, X., Despeisse, M., & Johansson, B. (2020). Environmental Sustainability of Digitalization in Manufacturing: A Review. *Sustainability, 12*: 10298.

Cialani, C. (2007). Economic Growth and Environmental Quality: An Econometric and a Decomposition Analysis. *Management of Environmental Quality: An International Journal, 18*(5): 568-577.

Çelik, M. (2021). *Temiz Enerji Odaklı Akıllı Uzmanlaşma ve İzmir İçin Kalkınma Fırsatları (Clean Energy Focused Smart Specialisation and Development Opportunities for Izmir)*. Izmir Development Agency.

Danish, Khan, N., Baloch, M. A., Saud, S., & Fatima, T. (2018). The Effect of ICT on CO2 Emissions in Emerging Economies: Does the Level of Income Matters? *Environmental Science and Pollution Research, 25*: 22850–22860. https://doi.org/10.1007/s11356-018-2379-2

Dzwigol, H., Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2023). The Role of Environmental Regulations, Renewable Energy, and Energy Efficiency in Finding the Path to Green Economic Growth. *Energies, 16*(7), 3090.

EIU [Economist Intelligence Unit] (2023). Energy Outlook 2024: Surging Demand Defies Wars and High Prices.

Ergün, S., & Atay Polat, M. (2015). OECD Ülkelerinde CO2 Emisyonu, Elektrik Tüketimi ve Büyüme İlişkisi (The Relationship between CO2 Emission, Electricity Consumption and Economic Growth in OECD Countries). *Erciyes University Journal of Faculty of Economics and Administrative Sciences*, (45): 115-141.

Faisal, F., Azizullah, Tursoy, T. & Pervaiz, R. (2020). Does ICT Lessen CO2 Emissions for Fast-Emerging Economies? An Application of the Heterogeneous Panel Estimations. *Environmental Science and Pollution Research, 27*: 10778–10789. https://doi.org/10.1007/s11356-019-07582-w

Gültekin, E., & Uğur, A. (2019). OECD Ülkelerinde Yenilenebilir Enerji Tüketiminin Makro Ekonomik Belirleyicileri: Rüzgâr Enerjisi Modeli (Macro Economic Determinants of Renewable Energy Consumption in The OECD Countries: Wind Energy Model). *Erciyes University Journal of Faculty of Economics and Administrative Sciences*, (53): 325-342.

Güriş, S. (2018). *Uygulamalı Panel Veri Ekonometrisi (Applied Panel Data Econometrics)*. Der Publications: 481, Istanbul

Ha, L. T., Huong, T. T. L., & Thanh, T. T. (2022). Is Digitalization a Driver to Enhance Environmental Performance? An Empirical Investigation of European Countries. *Sustainable Production and Consumption, 32*: 230–247. https://doi.org/10.1016/j.spc.2022.04.002

Jóźwik, B., Doğan, M., & Gürsoy, S. (2023). The Impact of Renewable Energy Consumption on Environmental Quality in Central European Countries: The Mediating Role of Digitalization and Financial Development. *Energies, 16*(20). https://doi.org/10.3390/en16207041

Karlilar, S., Balcilar, M., & Emir, F. (2023). Environmental Sustainability in the OECD: The Power of Digitalization, Green İnnovation, Renewable Energy and Financial Development. *Telecommunications Policy, 47*: 102568.

Khan, S. A. R., Zia-Ul-Haq, H. M., Ponce, P., & Janjua, L. (2023). Re-Investigating the Impact of Non-Renewable and Renewable Energy on Environmental Quality: A Roadmap towards Sustainable Development. *Resources Policy*, 81, 103411.

KPMG (2021). *Dijitalleşme Yolunda Türkiye 2021 Trendler ve Rehber Hedefler (Türkiye on the Road to Digitalization 2021 Trends and Guiding Targets)*. https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2021/04/dijitallesme-yolunda-turkiye-raporu-2021.pdf (A.D. 21.06.2024).

Lebe, F. (2012). *Türkiye'de Enerji Piyasası ve Enerji Talebi: Elektrik ve Doğal Gaz Enerjisi İçin Ekonometrik Bir Uygulama (Energy Market and Energy Demand in Turkey: An Econometric Application for Electricity and Natural Gas)*, Atatürk University, Institute of Social Sciences, Doctoral Thesis, Erzurum.

Li, S., Hu, K., & Kang, X. (2024). Impact of Financial Technologies, Digitalization, and Natural Resources on Environmental Degradation in G-20 Countries: Does Human Resources Matter? *Resources Policy, 93*. https://doi.org/10.1016/j.resourpol.2024.105041

Li, Z., Li, N., Wen, H. (2021). Digital Economy and Environmental Quality: Evidence from 217 Cities in China. *Sustainability*, 13: 8058. https://doi.org/10.3390/su13148058

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). *The Limits to Growth-A Report to the Club of Rome's Project on the Predicament of Mankind*. NY: Universe Books.

OECD (2024). Green Growth. data-explorer.oecd.org (A.D. 05.06.2024).

Panayotou, T. (2000). *Economic Growth and the Environment*. CID Working Paper Series 2000.56, Harvard University, Cambridge, MA.

Ramos-Meza, C. S., Zhanbayev, R., Bilal, H., Sultan, M., Pekergin, Z. B., Arslan, H. M. (2021). Does Digitalization Matter in Green Preferences in Nexus of Output Volatility and Environmental Quality? *Environmental Science and Pollution Research*, 28, 66957–66967. https://doi.org/10.1007/s11356-021-15095-8

Ren, S., Hao, Y., & Wu, H. (2023). Digitalization and Environment Governance: Does Internet Development Reduce Environmental Pollution? *Journal of Environmental Planning and Management, 66*(7): 1533-1562.

Saud, S., Chen, S., Danish, & Haseeb, A. (2019). Impact of Financial Development and Economic Growth on Environmental Quality: An Empirical Analysis from Belt and Road Initiative (BRI) Countries. *Environmental Science and Pollution Research, 26*: 2253-2269.

Tatoğlu, F. Y. (2018). *Panel Zaman Serileri Analizi: Stata Uygulamalı (Panel Time Series Analysis: Stata Applied)*. Istanbul: Beta Publishing.

Ullah, A., Dogan, M., Pervaiz, A., Bukhari, A. A. A., Akkus, H. T., & Dogan, H. (2024). The Impact of Digitalization, Technological and Financial Innovation on Environmental Quality in OECD Countries: Investigation of N-Shaped EKC Hypothesis. *Technology in Society*, 102484.

Usman, A., Ozturk, I., Ullah, S. & Hassan, A. (2021). Does ICT Have Symmetric or Asymmetric Effects on CO2 Emissions? Evidence from Selected Asian Economies. *Technology in Society*, 67.

World Bank (2024). World Development Indicators. https://databank.worldbank.org/source/world-development-indicators (A.D. 29.06.2024).

Yıldırım, O., & Nuri, F. İ. (2018). Yenilenebilir Enerji ve Sürdürülebilir Kalkınma İlişkisi (The Relationship between Renewable Energy and Sustainable Development). *Journal of International Banking, Economy and Management Studies, 1*(1): 105-143.

Zeeshan, M., Han, J., Rehman, A., Ullah, I., & Mubashir, M. (2022). Exploring the Role of Information Communication Technology and Renewable Energy in Environmental Quality of South-East Asian Emerging Economies. *Front. Environ. Sci.* 10, 917468.

Zhang, L., Saydaliev, H. B., & Ma, X. (2022). Does Green Finance Investment and Technological Innovation Improve Renewable Energy Efficiency and Sustainable Development Goals. *Renewable Energy, 193*: 991-1000.