

Article

The Role of ICT and Institutions in Sustainable Energy Transition: Empirical Evidence on E7 Countries

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Abstract

Sustainable energy transition is vital for the achievement of economic sustainability, environmental sustainability, and social inclusion. Hence, this paper explores the effect of ICTs, institutions, and per capita GDP on sustainable energy transition in the E7 economies between 2000 and 2024 in favor of causality and cointegration tests appropriate to the characteristics of the dataset. The causality test points out the existence of a one-way Granger causal relation from ICTs, institutions, and per capita GDP to sustainable energy transition. The estimated cointegration coefficients refer to a positive long-term association of ICTs and per capita GDP on sustainable energy transition in most of the E7 countries. Further, institutional quality positively impacts sustainable energy transition in China, India, and Indonesia in the long term, while it negatively impacts sustainable energy transition in Mexico. Our outcomes highlight the significant roles of ICTs, institutions, and per capita income for sustainable energy transition.

Keywords: sustainable energy transition; ICTs; institutions; per capita GDP; panel econometrics

1. Introduction and Theoretical Background

The concept of sustainable development was proposed to protect environment and natural resources, reduce inequalities and poverty, and achieve economic sustainability as of 1960s, but this concept became widespread with the report of “Our Common Future or Brundtland in 1987”, which defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” [1]. Then, the United Nations (UN) launched the Millennium Development Goals in 2000 and the Sustainable Development Goals (SDGs) in 2015 to accomplish sustainable development across the world [2,3]. One of the 17 SDGs, SDG7, is to make affordable, clean, and sustainable energy accessible for everybody. Achievement of SDG7 is also crucial to make progress in the rest of the SDGs.

Therefore, many researchers have explored the factors behind renewable energy transition, and numerous environmental, economic, and energy-related factors, along with demographical, institutional, political, and regulatory characteristics, have been proposed as factors of renewable energy transition, but a strong consensus on these determinants



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has not been established yet [4,5]. This empirical study concentrates on the effects of ICTs (information and communication technologies), institutions, and per capita GDP (gross domestic product) for sustainable energy transition rather than renewable energy transition in the E7 (emerging seven) countries. Sustainable energy transition is a multidimensional concept including the adoption of renewable energy, improvements in energy efficiency, access to clean cooking technologies, and decreases in CO₂ emissions [6]. In other words, sustainable energy transition not only involves transitioning to energy sources with lower CO₂ emissions but also improving energy efficiency, utilizing advanced technologies for decarbonization of industry, transportation, electricity production, and energy storage [7]. Furthermore, the E7 classification was proposed by the economists of John Hawksworth and Gordon Cookson in 2006, and these countries consist of China, India, the Russian Federation, Brazil, Mexico, Türkiye, and Indonesia, which already have a significant share in global GDP and population [8].

ICTs are one of the key factors for a sustainable energy transition. ICTs support the renewable energy transition through smart energy management and grid stability, and they increase energy efficiency [9–11]. Further, ICTs can abate CO₂ emissions by favoring improvements in energy efficiency and resource management, but can also negatively increase CO₂ emissions through growing energy demand and economic growth [9–14]. In this regard, various theoretical views, including the theory of technological determinism, socio-technical systems theory (STST), ecological world systems theory (EWST), first-, second-, and third-order effects, and the hypothesis of the EKC (environmental Kuznets curve), can be used to explain the nexus between ICTs and sustainable energy transition. The theories of technological determinism and the STST put forward that ICTs support sustainable energy transition via progress in efficiency, real-time monitoring, and social structure, respectively [15,16]. The EWST implies that the effects of ICTs on sustainable energy transition differ in core and periphery countries [17]. Additionally, first-, second-, and third-order effects also imply that the effects of ICTs on sustainable energy transition can differ because the use of growing energy during the lifecycle of ICTs can negatively affect the environment, while improving energy efficiency and resource management, which has a positive impact on the environment [18,19]. However, the negative effects of ICTs on the environment are higher than the positive effects, thus revealing the Jevons paradox [20]. Lastly, the hypothesis of the EKC (environmental Kuznets curve) asserts that the nexus between economic growth and the environment can differ based on the development levels of the countries [21]. Consequently, the net influence of ICTs on sustainable energy transition can be different among countries based on the associated theories.

Institutions are a determining factor for the effectiveness of regulations, laws, and governance, which are significant for the business environment. Institutional theory implies that strong institutions can support the sustainable energy transition through encouraging investments and innovation by increasing transparency, accountability, governance, enforcing regulations, and clear property rights based on institutional theory [22–25]. Furthermore, institutional quality has been offered as a significant determinant of economic expansion [22,26,27], thus it can impact sustainable energy transition via economic expansion within the EKC hypothesis. Consequently, the net effect of institutional quality on sustainable energy transition can differ among countries based on these aforementioned factors.

Finally, per capita GDP can impact sustainable energy transition via different channels. In this regard, increases in per capita GDP can contribute to the process of sustainable energy transition by advancing the technologies related to renewable energy and energy productivity and increasing environmental awareness of individuals and firms, which, in turn, leads to their use of clean energy sources [28,29]. However, economic expansion may increase energy requirements [30], and increases in per capita GDP can negatively impact sustainable energy transition if the increased energy requirements are met from fossil fuels rather than clean

energies. In conclusion, the nexus between per capita GDP and sustainable energy transition can vary among countries based on their development levels.

In sum, this research is carried out to answer the following questions:

Is there a long-term association amongst ICTs, institutions, per capita GDP, and sustainable energy transition?

Is there a Granger-causal relationship amongst ICTs, institutions, per capita GDP, and sustainable energy transition?

Additionally, the research hypotheses of the study based on the associated literature are as follows:

H1. *There exists a significant long-term association between ICTs and sustainable energy.*

H2. *There exists a significant long-term association between institutions and sustainable energy.*

H3. *There exists a significant long-term association between per capita GDP and sustainable energy.*

H4. *There exists a significant Granger causality amongst ICTs, institutions, per capita GDP, and a sustainable energy transition.*

In the empirical literature, the factors to enhance renewable energy transition have been widely explored by scholars in the face of increasing concern for the environment across the world. Therefore, this article aims to make two contributions to the associated empirical literature. First, this research aims to analyze the impression of ICTs, institutions, and per capita GDP on sustainable energy transition rather than renewable energy transition. Further, the nexus between ICTs and sustainable energy access has been researched by a few researchers until today. Thus, the other contribution of the research is to focus on the nexus between ICTs and sustainable energy access. In the remaining part of the article, the empirical studies on the association amongst ICT development, institutional quality, per capita GDP, and sustainable energy access are summarized, the dataset and methodological approach of the research are explained, and the empirical analyses are carried out and their results discussed.

2. Literature Review

Affordable and clean energy is a critical factor for the achievement of economic and environmental sustainability and social inclusion. Therefore, the factors underlying renewable energy transition have been researched widely since the 2000s [4,5]. Considering the limited empirical literature on sustainable energy transition, this study examines the influence of ICT development and institutional quality, along with per capita GDP, on sustainable energy transitions in the E7 countries.

2.1. ICTs and Sustainable Energy Transition

ICTs can impact sustainable energy transitions mainly through renewable energy transition, improvements in energy efficiency, and decarbonization. In this context, the studies on the nexus between ICTs and renewable energy transitions for different heterogeneous panels of countries have usually discovered a positive association between ICTs and the renewable energy transition [31–34]. But Luo [31] found that the short-term effect of ICTs on renewable energy investments was insignificant in most of the top-polluted countries.

Luo [31] analyzed the relationship between ICTs and investing in renewable energy in the top-polluted 83 countries during the years of 1998–2021 through the CS-ARDL (cross-sectionally augmented autoregressive distributed lag) approach and specified a positive long-run influence of ICTs over investments in renewable energy, but the short-

term effect was found to be insignificant in most of the countries. Lee et al. [32] also studied the influence of ICTs on renewable energy in 126 states for the years 2000–2019 through MMQR (method of moments quantile regression) and discovered a positive effect of the ICT indicator on renewable energy output.

Fambeu and Yomi [33] researched the association between ICT indicators and renewable energy utilization in African countries for the years 2000–2019 through the AMG (augmented mean group) estimator and unveiled that the ICT service export and internet positively impacted renewable energy utilization. Last, Zheng and Wong [34] researched the association between digitalization and the development of renewable energy in 31 provinces of China through regression and unraveled a positive link between the digital economy and the development of renewable energy.

On the other hand, Zahid et al. [14] and Zhao et al. [35] revealed that ICTs had a positive effect on energy efficiency in G20 countries and emerging Asian countries, respectively. Similarly, a literature review on the nexus between ICTs and energy by Hu et al. [36] also supported the positive effect of ICTs on energy efficiency. Last, the empirical studies on the nexus between ICTs and the environment have remained inconclusive. Wen et al. [37] and Linghu et al. [38] uncovered the negative influence of ICTs on CO₂ emissions, while Chatti [39] and Kim [40] unveiled a positive relationship between ICTs and CO₂ emissions. Additionally, Li et al. [18] and Altinoz et al. [41] have obtained mixed results.

2.2. Institutions and Sustainable Energy Transition

Institutional theory implies that strong institutions can support the sustainable energy transition through multiple channels, but the EKC hypothesis suggests that the nexus between institutions and sustainable energy transitions can be varied based on the development levels of the countries. The literature summary on the nexus between institutions and renewable energy utilization in Table 1 supports both of these theoretical views. On the one hand, Wang et al. [25], Uzar [42], Mehmood et al. [43], Rahman and Sultana [44], Mukhtarov et al. [45], Rafiq et al. [46], Iormom et al. [47], and Le and Tran [48] disclosed a positive impression of institutional indicators over the utilization of renewable energy, but Inglesi-Lotz [49] identified a negative impression of institutional quality over the utilization of renewable energy, and Oguz et al. [50] determined an insignificant relation between institutions and the utilization of renewable energy. However, Satrianto et al. [51] suggested that the connection between institutions and the utilization of renewable energy varied based on the institutional quality proxy. Furthermore, Adolphus et al. [52] and Makun [53] uncovered that the economic development level of a country was a determinant for the link between institutions and the utilization of renewable energy.

Additionally, Uzar [42] identified a Granger causality running from institutions to the utilization of renewable energy, while Rahman and Sultana [44] discovered a Granger causality from the utilization of renewable energy to institutional quality. However, Mehmood et al. [43] unraveled a two-way Granger causal association between institutional quality and the usage of renewable energy.

Table 1. The literature on the nexus between institutions and the utilization of renewable energy.

Research	Sample	Methods	Impact of Institutional Quality on Renewable Energy Utilization
Wang et al. [25]	OECD (Organization for Economic Co-operation and Development) states, 1997–2019	Panel ARDL (augmented autoregressive distributed lag)	Positive

Table 1. *Cont.*

Research	Sample	Methods	Impact of Institutional Quality on Renewable Energy Utilization
Uzar [42]	38 countries, 1990–2015	Pedroni cointegration test and D-H (Dumitrescu and Hurlin) causality test	Positive; unidirectional causality from institutional quality to renewable energy utilization
Mehmood et al. [43]	BRICS countries, 1988–2017	Cointegration and causality tests	Positive; bidirectional causality
Rahman and Sultana [44]	19 emerging countries, 2002–2019	PMG (pooled mean group), ARDL	Positive; unilateral causality from renewable energy to control of corruption
Mukhtarov et al. [45]	Poland, 1996–2021	Regression	Positive
Rafiq et al. [46]	OECD members, 1980–2014	FMOLS (fully modified ordinary least squares), DOLS (dynamic ordinary least squares), dynamic regression	Positive
Iormom et al. [47]	Nigeria, 2016–2023	QARDL (quantile autoregressive distributed lag)	Positive
Le and Tran [48]	Asian states, 1998–2020	Regression	Positive
Inglesi-Lotz [49]	South Africa, 1990–2018	ARDL	Negative
Oguz et al. [50]	22 developed economies, 2002–2021	Cointegration and regression	Insignificant
Satrianto et al. [51]	20 developing countries, 2003–2022	Regression	Negative (government effectiveness and voice and accountability); insignificant (regulatory quality and rule of law)
Adolphus et al. [52]	61 countries, 2005–2022	Regression	Positive (political stability) in low- and lower-middle-income countries; positive (rule-based governance structure and legal system) in upper-middle-income countries
Makun [53]	91 countries, 2002–2022	Regression	Positive (the whole sample), positive (developed economies), and insignificant (developing economies)

2.3. Income and Sustainable Energy Transition

The association between per capita GDP and sustainable energy transformation is complicated. In this context, the studies on the nexus between per capita GDP and renewable energy transitions have not yet reached a consensus. Sadorsky [54], Gozgor et al. [55], and Sart et al. [56] found a positive link between per capita GDP and usage of renewable energy. Additionally, Tudor and Sova [57] and Ergun and Rivas [58] argued that the influence of per capita GDP over the utilization of renewable energy became positive subsequent to a threshold value of per capita GDP. On the other hand, Chen et al. [59] suggested that democratization is a critical factor for the relationship between per capita GDP and the utilization of renewable energy. However, Ozcan and Ozturk [60] identified an insignificant interplay between GDP and the use of renewable energy in emerging markets.

Furthermore, income has been uncovered as a significant determinant of energy efficiency by Ameli and Brandt [61], Nevskaya et al. [62], and Sineviciene et al. [63]. Lastly, the empirical studies about the nexus between income and environment have mainly explored the validity of the EKC hypothesis, and these studies have resulted in different outcomes for different countries [64–66].

3. Data and Methods

Our research examines the impression of ICTs, institutions, and per capita GDP on sustainable energy transitions over the 2000–2024 period by utilizing panel-level econometric tests. The variables of the empirical analyses are presented in Table 2. From these variables, a sustainable energy transition (SUSENG) is proxied by the SDG7 index. This index is calculated from a combination of factors, such as access to clean fuels and technologies for cooking, a share of renewable energy in overall energy consumption, the level of electricity access, and CO₂ emissions resulting from fuel combustion [67]. In this context, upper and lower bounds are determined, and each variable is rescaled between 0 (worst performance) and 100 (best performance) based on these bounds. Then, the SDG7 index is calculated using the arithmetic mean of four identified indicators for SDG7 [67]. This study prefers to use the SDG7 index rather than the renewable energy transition as the dependent variable because the sustainable energy transition is a multidimensional process connected not only with the share of renewable energy, but also with broader SDG implementation, consisting of access to clean energy and technologies, CO₂ emissions, and renewable energy use [68]. ICT development and institutional quality are respectively proxied by ICTs and institutions indices of UNCTADSTAT [23]. The ICT index is figured out based on the data of fixed telephone, broadband, and mobile subscriptions, the internet usage of individuals, and internet servers provided from the ITU, and the institutional quality index is calculated using the World Bank’s worldwide governance indicators [69]. In this regard, a principal component analysis (PCA) is conducted for both indices, and the number of components extracted equals the number of components with both eigenvalues over 1.0 and explained variance over 10%. The components are rotated through varimax rotation if more than one component is extracted (please visit [69] for loadings for each principal component of ICTs and INST indices). Lastly, per capita GDP is represented by GDP per person (base year: 2015 US\$) and acquired from the World Bank [70].

Table 2. Dataset of the study.

Variables	Explanation	Source Links of the Data
SUSENG	SDG7 index	https://sdgtransformationcenter.org/reports/sustainable-development-report-2025 , accessed on 5 April 2026
ICTs INST	ICT index Institutional quality index	https://unctadstat.unctad.org/datacentre/ , accessed on 5 April 2026
PERGDP	Real GDP per capita	https://data.worldbank.org/indicator/NY.GDP.PCAP.KD , accessed on 5 April 2026

The calculation of SDG7, ICTs, and institutions’ indices as of 2000 has caused us to carry out empirical analysis during the years 2000–2024. All series representing SUSENG, ICTs, INST, and PERGDP are available for E7 countries for all years. From the applied econometric tests, homogeneity, cross-sectional dependence (CD), stationarity, and estimation of the AMG are performed in favor of Stata 17.0, and the LM bootstrap cointegration test is conducted via Gauss 12.0.

The summary statistics of SUSENG, ICTs, INST, and PERGDP are displayed in Table 3. The averages of these series are 65.8612, 40.344, 47.718, and 6878.182 USD, respectively. However, PERGDP displays a remarkable variation amongst E7 countries, while other series of INST, ICTs, and SUSENG show a mid-level variation between E7 countries.

Table 3. Summary statistics of SUSENG, ICTs, INST, and PERGDP.

Series	Mean Figures	Standard Deviation	Minimum	Maximum
SUSENG	65.861	12.892	37.0025	91.8605
ICTs	40.344	16.923	8.59	74.15
INST	47.718	6.207	30.68	58.62
PERGDP	6878.182	3653.249	756.7041	15,395.03

The nexus amongst sustainable energy transition, ICT development, and institutional quality, along with per capita GDP, is questioned through the Westerlund and Edgerton [71] LM bootstrap cointegration test and the E-K (Emirmahmutoglu and Kose) [72] causality test. Both tests, along with the AMG estimator, are preferred because they result in robust outcomes for panel datasets with heterogeneity, cross-sectional dependency, and small sample sizes [71–73].

The bootstrap cointegration test accounts for CD and heterogeneity and results in robust outcomes for small datasets [71], and it follows from the numbered Equation (1).

$$y_{it} = \alpha_i + x_{it}\beta_{it} + Z_{it} \quad (1)$$

where $y_{it} = SUSEN$, and $x_{it} = ICT$, $INST$, and $PERGDP$

$$Z_{it} = \mu_{it} + V_{it} = \sum_{j=1}^t ij \quad (2)$$

where i is the E7 countries, t is the years between 2000 and 2024, and Z_{it} is the disturbance term. Finally, the LM test statistic is derived from Equation (3), and the probability values are calculated through bootstrapping.

$$LM_N^+ = \frac{1}{NT^2} \sum_{i=1}^N \sum_{t=1}^T \hat{w}_i^{-2} S_{it}^2 \quad (3)$$

The AMG estimator proposed by Eberhardt and Bond [73] is chosen to forecast cointegration coefficients in deference to its high reliability for the datasets with CD and heterogeneity. In addition to this, the AMG estimator can simultaneously predict both panels' and countries' coefficients differently from regression. The AMG estimator utilizes the model in Equation (4) and accounts for CD by adding the common dynamic effect produced from the period dummy coefficients of pooled regression to group-specific regression [73].

$$y_{it} = \beta_i' x_{it} + u_{it} \quad u_{it} = \alpha_i + \lambda_i' f_t + \varepsilon_{it} \quad (4)$$

$$x_{mit} = \pi_{mi} + \delta_{mi}' g_{mt} + \rho_{1mi} f_{1mt} + \cdots + \rho_{nmi} f_{nmt} + v_{mit} \quad (5)$$

where x_{mit} represents observable covariates, and u_{it} is a combination of α_i (group-specific effects), f_t (common factors), and λ_i' (group-specific factor loadings). Additionally, the cointegration coefficients are also estimated by the CCEMG (common correlated effects mean group) estimator of Pesaran [74] robustness control.

Lastly, the causal nexus amongst SUSENG, ICTs, INST, and PERGDP is examined with the E-K causality test, which is derived from the Toda-Yamamoto causality test for heterogeneous panels with CD. The forecasted VAR (vector autoregression) model for each E7 country is as follows:

$$y_{it} = \delta_i + A_{1i} y_{i(t-1)} + \cdots + A_{pi} y_{i(t-pi)} + \cdots + A_{(p+d)i} y_{i(t-pi-di)} + u_{i,t} \quad (6)$$

where y_{it} is an endogenous variable, δ_i is the fixed-effects vector with p dimensions, d_i is the highest integration level, and p_i is the optimal lag length based on the Schwarz information criterion. Additionally, this test allows the lag length to vary for each cross-section and thereby decreases the loss of long-term information [68].

4. Empirical Results

In the empirical results part of the research, LM, CD, and delta tests are applied to decide which econometric tests we employ for this research. The consequences of the LM, CD, and delta tests are reported in Table 4. The H_0 hypothesis of CD independence is abnegated because the p -values of these tests are lower than 5%. Consequently, CD's existence amongst SUSENG, ICTs, INST, and PERGDP is inferred. Additionally, the H_0 hypothesis in favor of homogeneity is rejected for two delta tests, and heterogeneity's existence is inferred. As a consequence, the utilization of causalities, cointegration, unit root tests, and estimators sensitive to CD and heterogeneity are needed to increase the reliability of the outcomes.

Table 4. CD and delta tests.

Test	Test Statistic (p Value)	Test	Test Statistic (p Value)
LM	38.24 (0.012)	Delta	17.891 (0.000)
Adj.LM	5.744 (0.000)	Adj. delta	20.002 (0.000)
LM CD	9.312 (0.001)		

The stationarity characteristics of SUSENG, ICTs, INST, and PERGDP are analyzed by the Pesaran [75] CIPS unit root test in deference to CD's presence in the dataset, and the test's consequences are introduced in Table 5. The null hypothesis of the unit root test posits that all series contain a unit root (or non-stationary), while the alternative hypothesis demonstrates that some cross-sectional units do not include the unit root (or stationary). Accordingly, if the p -value of the CIPS statistic is lower than 5%, the null hypothesis is rejected, and it is concluded that the series is stationary. Thus, the series of SUSENG, ICTs, INST, and PERGDP are not found to be stationary at their original values because their p -values are higher than 5%. However, SUSENG, ICTs, INST, and PERGDP are inferred to be stationary at their first-differenced values because their p -values are lower than 5%.

Table 5. Stationarity analysis.

Series	Constant		Constant + Trend	
	CIPS Stats	p Value	CIPS Stats	p Value
SUSENG	1.178	0.281	1.166	0.294
d(SUSENG)	−5.033	0.000	−3.175	0.000
ICTs	0.061	0.093	0.941	0.102
d(ICT)	−3.299	0.000	−3.201	0.000
INST	1.677	0.166	1.289	0.214
d(INST)	−3.655	0.000	−2.976	0.000
PERGDP	−0.791	0.315	1.066	0.401
d(PERGDP)	−4.164	0.000	−5.286	0.000

The cointegration nexus amongst SUSENG, ICTs, INST, and PERGDP is questioned in favor of the LM bootstrap cointegration test. The bootstrap and asymptotic probability figures for the models of constant and trend are displayed in Table 6. The probability values

of bootstrap for both models are identified to be higher than 5%, hence the null hypothesis of cointegration link amongst SUSENG, ICTs, INST, and PERGDP is accepted. In other words, there exists a significant cointegration amongst SUSENG, ICTs, INST, and PERGDP.

Table 6. LM bootstrap cointegration test.

Test Statistic	Constant		Constant and Trend		
	Asymptotic <i>p</i> -Value	Bootstrap <i>p</i> -Value	Test Statistic	Asymptotic <i>p</i> -Value	Bootstrap <i>p</i> -Value
6.382	0.417	0.495	7.560	0.511	0.583

The cointegration coefficients of ICTs, INST, and PERGDP are forecast in favor of AMG and CCEMG estimators and presented in Table 7. These coefficients by the AMG estimator uncover that ICT development positively affects sustainable energy transition in Brazil, China, India, Indonesia, Mexico, Türkiye, and the overall panel. Furthermore, institutional quality positively impacts sustainable energy transition in China, India, and Indonesia, but negatively impacts it in Mexico. Finally, per capita GDP has a positive influence on the sustainable energy transition in Brazil, China, India, Indonesia, and Türkiye. The similar coefficients by the CCEMG estimator also support the robustness of the AMG estimator.

Table 7. AMG and CCEMG estimation.

E7 Economies	AMG			CCEMG		
	ICTs	INST	PERGDP	ICTs	INST	PERGDP
Brazil	0.123 ***	0.037	0.174 **	0.128 ***	0.031	0.169 **
China	0.017 **	0.064 **	0.166 ***	0.013 **	0.069 **	0.171 ***
India	0.048 **	0.234 ***	0.108 ***	0.053 **	0.240 ***	0.113 ***
Indonesia	0.101 **	0.258 **	0.202 **	0.110 **	0.265 **	0.211 **
Mexico	0.029 **	−0.257 ***	−0.058	0.032 **	−0.260 ***	−0.064
Russia	0.012	0.037	0.021	0.019	0.044	0.031
Türkiye	0.157 ***	0.082	0.066 **	0.162 ***	0.090	0.071 **
Panel	0.029 **	0.123	0.743	0.033 **	0.130	0.752

*** and ** significant at 1% and 5%, respectively.

The causality link amongst SUSENG, ICTs, INST, and PERGDP is questioned in favor of the E-K causality test, and the test statistics are displayed in Table 8. The E-K panel causality test is carried out with the level values of the series following the confirmation of a long-run association amongst SUSENG, ICTs, INST, and PERGDP. The consequences unravel a one-way Granger causality from ICTs, INST, and PERGDP to SUSENG. Therefore, ICT development, institutions, and per capita GDP have a significant influence on sustainable energy transition.

Table 8. E-K causality test.

Null Hypothesis	Test Statistic	<i>p</i> Value
ICTs $\nRightarrow$ SUSENG	25.082	0.034
SUSENG $\nRightarrow$ ICTs	15.150	0.368
INST $\nRightarrow$ SUSENG	41.129	0.006
SUSENG $\nRightarrow$ INST	19.280	0.155
PERGDP $\nRightarrow$ SUSENG	34.674	0.024
SUSENG $\nRightarrow$ PERGDP	9.665	0.645

$\nRightarrow$: It indicates the non-existence of Granger causality between two variables.

5. Discussion

Sustainable energy transitions are critical for the accomplishment of the 17 SDGs to a great extent. ICTs are a crucial multifaceted instrument to make headway in renewable energy transitions, energy efficiency, and environmental awareness, which are the key components of sustainable energy transitions. On the other hand, ICTs can reduce CO₂ emissions through resource management and energy efficiency, while also raising CO₂ emissions through increasing energy use and economic growth based on the development level of the countries. Our results uncover that ICTs have a positive long-term effect on sustainable energy transition in E7 countries except the Russian Federation. The Russian economy is highly dependent on fossil fuels, and the index of environmental policy stringency in the Russian Federation was 0.837 between 2000 and 2020 [76,77]. In other words, the environmental policy is highly weak in the Russian Federation. The insignificant long-term association between ICTs and sustainable energy transitions in the Russian Federation is mainly caused by the dominance of fossil fuels in energy consumption and weak environmental policies. In the literature, Luo [31], Lee et al. [32], Fambeu and Yomi [33], and Zheng and Wong [34] found a positive influence of diverse ICT indicators on investments and utilization of renewable energy. Further, Zahid et al. [14] unveiled a positive influence of ICTs on energy efficiency, and Guan et al. [13] also found a negative effect of digital technologies on energy intensity, but Li et al. [18] unraveled a positive influence of ICTs on CO₂ emissions. Therefore, the theories and the empirical literature on the link between ICTs and sustainable energy transition are found to be consistent with each other and also support our findings.

Furthermore, the one-way Granger causality from ICTs to sustainable energy transitions also supports the outcomes of the long-term analysis and is consistent with the predictions of theories of technological determinism, socio-technical systems, ecological world systems, first-, second-, and third-order effects, and the EKC hypothesis, which imply a significant effect of ICTs on sustainable energy transition through multiple channels.

Institutions are another significant tool to support sustainable energy transition through decreases in uncertainty and costs, improvements in transparency, accountability, rule of law, and property rights that foster innovation and investments. On the other hand, institutional quality as a significant determinant of economic growth can negatively affect sustainable energy transition based on the EKC hypothesis. Our findings uncover that institutions positively impact sustainable energy transitions in China, India, and Indonesia, but negatively impact sustainable energy transitions in Mexico. Additionally, the nexus between two variables is insignificant in Brazil, the Russian Federation, Türkiye, and at the panel level. The negative effect of institutions on sustainable energy transitions is a result of the inefficiency of institutions, the low share of renewable energy in overall energy use, and weak environmental policies [76,77]. Additionally, Mexico, along with Brazil, the Russian Federation, and Türkiye, has experienced deteriorations in institutional quality between 2000 and 2024. Therefore, these countries could not get institutions to make a significant contribution to the sustainable energy transition. In a similar way, the empirical studies have obtained different outcomes. On the one hand, Wang et al. [25], Uzar [42], Mukhtarov et al. [45], Rafiq et al. [46], Iormom et al. [47], and Le and Tran [48] disclosed a positive influence of institutional indicators on the utilization of renewable energy, but Inglesi-Lotz [49] identified that institutional quality had a negative influence on the utilization of renewable energy, and Oguz et al. [50] determined an insignificant relationship between institutions and the utilization of renewable energy. Furthermore, Adolphus et al. [52] and Makun [53] suggested that the link between institutions and renewable energy transitions varied based on the economic development levels of countries.

Our findings and the different outcomes of the empirical studies confirm the theoretical views on the association between institutions and sustainable energy transition.

Institutional theory and the EKC hypothesis imply that strong institutions can support the sustainable energy transition through multiple channels. Thus, the direction of Granger causality between institutions and sustainable energy transition can be varied in the context of the EKC hypothesis. However, our one-way Granger causality from institutions to sustainable energy transitions is compatible with the institutional theory and the EKC hypothesis predictions. Additionally, Uzar [42] revealed a unidirectional Granger causality link from institutions to the usage of renewable energy, but Rahman and Sultana [44] discovered a one-way Granger causal link from the utilization of renewable energy to institutions. However, Mehmood et al. [43] uncovered a two-way Granger causality between institutions and the usage of renewable energy.

Finally, per capita GDP can foster sustainable energy transitions through multiple channels by financing the investments of renewable energy and energy-efficient technologies and increasing environmental awareness, but it can negatively impact sustainable energy transitions if the increased energy requirements as a result of economic expansion are provided from fossil fuels. Our outcomes demonstrate that per capita GDP has a positive long-term association with sustainable energy transition in most of the E7 countries except Mexico and the Russian Federation. The insignificant long-term association between per capita GDP and sustainable energy transition mainly results from low renewable energy transitions and relatively weaker environmental policies [76,77]. In a similar vein, the empirical studies have obtained different results. Sadorsky [54] and Gozgor et al. [55] found a positive relationship between per capita GDP and the use of renewable energy, while Ozcan and Ozturk [60] identified an insignificant interplay between GDP and renewable energy use in emerging markets. Further, Tudor and Sova [57] and Ergun and Rivas [58] proposed that the nexus between per capita GDP and renewable energy use hinged upon the economic development levels of countries, and Chen et al. [59] suggested that democratization was a critical factor for the relationship between per capita GDP and utilization of renewable energy. Consequently, our findings are supported by Sadorsky [54], Gozgor et al. [55], and Sart et al. [56].

Income can impact sustainable energy transition through multiple channels, and in turn, one or two-way Granger causality between income and sustainable energy transition seems possible based on the aforementioned theoretical views. Therefore, our one-way Granger causal link from per capita GDP to sustainable energy transition is compatible with the associated theoretical views. Furthermore, the studies conducting a two-way analysis on the interplay between per capita GDP and utilization of renewable energy have resulted in different outcomes for the hypotheses of conservation, growth, feedback, and neutrality [56,60,78,79].

6. Conclusions

Sustainable energy transition is a multifaceted process and includes transition to clean energy, as well as improvements in energy efficiency and environmental quality. Furthermore, sustainable energy transition is a critical factor for the accomplishment of sustainable economic growth and social sustainability. Considering its crucial role for sustainable development, this study investigates the association amongst ICT development, institutional quality, per capita GDP, and sustainable energy transitions in E7 countries. However, the study contains the following restrictions:

The study covers the period between 2000 and 2024 because indices of sustainable energy access, ICTs, and institutions are calculated as of 2000 and last until 2024.

The study sample is confined to E7 countries that have made a remarkable economic expansion, accompanied by increases in greenhouse gas emissions. However, there exists a significant heterogeneity in terms of per capita GDP, utilization of renewable energy, and CO₂ emissions amongst the E7 countries, and the AMG estimator allowed us to carry out country-level analysis.

The findings of the causality analysis uncover a one-way causality from ICTs, institutions, and per capita GDP to SUSENG. In addition, the consequences of the cointegration analysis demonstrate a cointegration relation among SUSENG, ICTs, INST, and PERGDP. The cointegration coefficient of the AMG estimation indicates that ICTs and per capita GDP positively affect sustainable energy transition in most of the E7 states, and the effect of institutional quality on sustainable energy transition is positive in China, India, and Indonesia, but negative in Mexico. Consequently, ICTs, per capita GDP, and institutional quality are found to be effective tools for sustainable energy transitions in the short and long term.

Based on the findings of the empirical analyses, the following policy recommendations are suggested for E7 countries to achieve advancement in sustainable energy transition:

Governments should accelerate investments in smart grid infrastructure, promote the employment of smart meters and digital energy management systems, and expand digital infrastructure facilitating real-time energy monitoring and demand-side management in Brazil, China, India, Indonesia, Mexico, and Türkiye. Financial incentives such as investment subsidies and tax credits can foster the adoption of digital technologies. Additionally, investments in digital skills and public–private partnerships can support the effective integration of ICTs into the energy sector.

Mexico, Brazil, the Russian Federation, and Türkiye should make governance reforms to improve regulatory quality, strengthen the rule of law, reduce bureaucratic barriers, and increase transparency in energy policymaking. Governments should design predictable regulatory frameworks, simplify permitting procedures for energy projects, strengthen anti-corruption mechanisms, and enhance the independence of energy regulatory authorities, which can increase investor confidence and attract long-term private investments in sustainable energy projects.

Mexico and the Russian Federation, which are highly dependent on fossil fuels, should increase the renewable energy transition through competitive renewable energy auctions, feed-in tariffs, or market-based support schemes to make progress in the sustainable energy transition. Additionally, research and development activities should be supported by investment subsidies and tax credits to develop renewable energy technologies.

Finally, future studies should concentrate on the link between constituents of institutional quality and sustainable energy transitions in countries with different institutional qualities.

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Abbreviations

The following abbreviations are used in this manuscript:

AMG	Augmented mean group
ARDL	Augmented autoregressive distributed lag
CD	Cross-sectional dependence
CS-ARDL	Cross-sectionally augmented autoregressive distributed lag
D-H	Dumitrescu and Hurlin
DOLS	Dynamic ordinary least squares
E7	Emerging 7
EKC	Environmental Kuznets curve
FMOLS	Fully modified ordinary least squares
GDP	Gross domestic product
ICTs	Information and communication technologies
LM	Lagrange multiplier
PMG	Pooled mean group
QARDL	Quantile autoregressive distributed lag
SDG	Sustainable development goals
UN	United Nations

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