How Digitalization and Financial Advancement Contribute to the Green Energy Transition: The Malaysian Experience

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Abstract

One of the most important strategies for reducing CO_2 emissions and addressing climate change is the development of renewable energy (RE). Digitalization is viewed from this perspective as a means of achieving an energy transition. However, there is a lack of empirical data confirming the significance of digitalization in driving the transition to green energy. To answer this question, this study aimed to empirically measure the impact of digitalization and financial development in Malaysia on the green energy transition from 2000 to 2021. The results show that the transition to green energy is positively impacted by the digitalization sector. The variables related to the transition to green energy were also statistically significant. This study provides practical policy recommendations. For instance, the research findings present empirical support and policy impetus for advancing the development of RE sources and achieving carbon-zero targets, serving as a useful resource for decision-makers and stakeholders. In addition, it has been argued that adopting regulations recognized by the European Union is essential for Malaysia's transition to digital green energy.

Keywords: *Digitalization, Green energy transition, Renewable energy, Econometric approach, Malaysia*

1. Introduction

The term "digitalization" describes the more extensive use of digital technologies to coordinate and optimize existing business operations and procedures, resulting in increased commercial potential and customer value (Olanipekun and Sutrisna, 2021). The goal of digitalization, in line with its connotation, is to produce value using digital technology and to have an impact on changing things (Rachinger et al. 2018). Therefore, the index system for digitalization is built using the physical foundation, namely, the participant, the dealer, and the form of digitalization. These are network infrastructure (NI), communications service development (CSD), IT industry development (ITID), and digital technology innovation (DTI), all of which relate to the four directories (Niu et al. 2022).

The growth of RE is essential for the decarbonization, transformation of the energy system, and carbon neutralization of the energy sector (Lin and Huang, 2023; Handayani et al. 2022). The current energy system must be changed to include zero-carbon energy to meet carbon-neutral aims and slow climate change. More effort must be made to develop wind and photovoltaic (PV) electricity in the face of this energy revolution. For all nations worldwide, the question of how to encourage the integration of variable RE to quicken energy transition is of significant importance.

RE has grown rapidly since the beginning of the 21st century, but still only contributes to a small portion of a nation's overall worldwide energy system, as integration, energy security, and supply issues must be addressed (Kwon, 2020). Digital technology offers a new approach to address this issue. Digital technology has long been used in the energy sector (Sharifi et al. 2021; Park and Kim, 2021). The administration and performance of the

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energy grid were improved as the main goal of the earliest application of digital technology in the energy sector (Lin and Huang, 2023; Rhodes, 2020). The new aim of digital technology is to improve the ability of RE resources to integrate (Dong et al. 2023; Samylovskaya et al. 2022). The difficulty of RE integration will be faced by an increasing number of nations as the global carbon-zero objective progresses, and it will only worsen as the depth of energy transitions increases. The use of digital technology in the energy sector is an effective approach (Kotilainen et al., 2019), and digitization of the energy sector is a critical technology for energy transition (Lyu and Liu, 2021).

In this context, it is crucial to investigate Malaysia, which has made significant efforts in the last few years in terms of digitalization and transition to green energy (Aleluia et al. 2022; Wang et al. 2022). Malaysia’s government has made digitalization a top priority and has started several efforts to encourage the use of digital technologies across the economy (Low et al. 2022). The financial industry is one of the primary industries contributing significantly to a country's green economy expansion. Backed by a strong digital infrastructure spanning the broadband Internet and 5G networks, Malaysia appears to have made good progress in digitalization, with the approval of five digital banks in April 2022, the introduction of robot advisors, and the use of blockchain technology to improve security and efficiency (Peng, 2022). Another indication of Malaysia's growing commitment to supporting digitalization and a sustainable green economy is the Digital Economy and Cooperation in Green Economy agreement signed between Malaysia and Singapore on January 30, 2023, which is the first green economy agreement Malaysia has ever had (Wang et al. 2023).

Several studies have highlighted the importance of digitalization in scaling up green finance to achieve a more resilient and sustainable economy (Hao et al. 2023; Salman and Ismael 2023; AFI 2020; UNEP 2018; Kilinc-Ata and Tanriover, 2018) and specifically the potential of green energy transition and digitalization in Malaysia (Khalili et al. 2023; Ordoñez de Pablos 2023; Chua and Oh 2011). Furthermore, a comprehensive methodology to advance digitalization through the use of Fintech and digital currency in Islamic green financing was underlined because Malaysia is recognized as one of the top centers for Islamic finance (Thaker et al. 2022). Therefore, the current study intends to provide a record of Malaysia's financial sector's digitalization initiatives and explore the potential role they may play in the transition to green energy. The current research study specifically tries to address the following questions: “How has the adoption of digitalization improved the effectiveness and accessibility of the provision of financial services in the energy sector?” and “How can digitalization contribute to the green energy transition?” To answer these questions, this study aims to fill the gap in the literature by revealing the effectiveness of Malaysia's adoption of digitalization in the energy sector and how digitalization in the financial sector contributes to the switch to green energy.

This study contributes several new perspectives to the literature. First, to our knowledge, this is the first econometric analysis to use the most recent data from 2000 to 2021 to examine how digitalization has affected Malaysia's shift to green energy. Second, this study provides new perspectives on the function of digitization in the switch to green energy. The connection between digitization and the switch to green energy has not been empirically studied. This study empirically investigated the regulatory impact of digitization on the switch to RE in Malaysia. These findings offer proof of the expansion of RE sources that are variable. Finally, the findings present a regional perspective as well, with implications for policy for Malaysia's adoption of European Union energy and climate regulations/policies

The remainder of this study is organized as follows. Section 2 provides an overview of the literature. Section 3 provides an explanation of the methodology of the model and data, and Section 4 presents and discusses the findings. Section 5 summarizes the study's conclusions and presents policy recommendations.

3. Literature Review

Globally, significant efforts have been made to implement zero-carbon policies and pursue green energy development (Pan & Pan, 2019; Kilinc-Ata, 2016). Converting fossil fuels to RE is the most important challenge, and one way to address this is digitalization (Tayal, 2017). Digitalization plays a significant role in advancing the switch to green energy (Lin and Huang, 2023). Many studies have been conducted to determine the impact of digitization on the green energy transition, and they have achieved similar results. For instance, Lin and Huang (2023) examine the role of digitalization in encouraging variable RE sources for 33 countries, and the findings imply that the integration of RE is positively moderated by digitization. Similarly, Wang et al. (2023) examined the effects of the digital economy on RE production in Asian nations between 2003 and 2019. The findings show that the digital economy has a favorable impact on RE generation. According to Karlilar et al. (2023), environmental sustainability is significantly aided by digitalization, green innovation, and RE. Additionally, the relationship between digitization, green innovation, and the use of RE sources strengthens the impact of digitalization on reducing the ecological footprint. Table A1 provides a recent and empirical evaluation of the digitization of the switch to the green energy transition.

Malaysia's energy demand grows faster than supply growth (Husaini and Lean, 2022); therefore, research on the possible effects of digitalization on energy consumption for unsafe energy will assist policymakers in understanding the effects of digitalization on energy consumption. However, examining the effect of digitalization on Malaysia's transition to green energy reveals a lack of relevant literature. A recent study by Suki et al. (2022) investigated how technological advancements and RE affect Malaysia's ecological footprint and CO_2 emissions, and the results showed that technological innovation helps the green energy transition by reducing carbon emissions and the ecological footprint.

In addition to warning that climate change could represent a systemic risk to Malaysia's financial system, the Central Bank of Malaysia has stated that over one-fourth of the assets in the country's insurance business may be susceptible to the financial risk associated with climate change (Apanada, 2020). The Sustainable Energy Development Authority (SEDA) of Malaysia claims that distributed RE sources, such as solar roofs paired with smart building energy management systems, can advance digitalization (SEDA, 2021). In addition, to achieve its target of a net zero greenhouse gas (GHG) emissions nation as early as 2050, Malaysia is progressing to develop a Long-Term Low Emissions Development Strategy (LT-LEDS) as a vital policy tool to enable businesses and financial institutions to align their strategies to reduce their GHG emissions (Central Bank of Malaysia Annual Report 2022).

On the financial technology front, Malaysia has witnessed significant strides in digitalizing its financial sector, driven by the recognition of the transformative potential of technology. These efforts aim to enhance efficiency, accessibility, and innovation in financial services, ultimately fostering economic growth and inclusion. According to Firmansyah et al. (2023), the emergence of financial technology-based institutions in Malaysia is primarily driven by the accommodative laws and regulations imposed by the Central Bank of Malaysia and Securities Commission, the strength of the infrastructure to withstand potential cyber security threats, and embracing financial sustainability via digital financial inclusion. It is no surprise that Malaysia has been at the forefront of digital banking licenses and frameworks, offering digital payments and regulatory sandboxes that strike a balance between encouraging experimentation and ensuring consumer protection and regulatory compliance.

A review of the literature reveals that prior research has mostly concentrated on detecting the direct consequences of digitalization on the environment using only one digitization indicator, namely the Internet user. However, the digitization process includes complex mechanisms. Nonetheless, all financial advancements, including the adoption of digitalization and fintech, as discussed above, are reflected in the financial development index compiled by the IMF. In addition to fostering green innovation, increasing energy efficiency, and establishing more efficient financial systems, the use of digital technology has the potential to enhance environmental sustainability. Furthermore, there is a lack of studies on this subject in Malaysia; consequently, addressing it may help analyze the country's present environmental policy. This study examines how financial digitalization affects the transition to green energy using various digital parameters to close these gaps in the literature.

4. Methodology

4.1. Data

The present study used several datasets covering Malaysia, spanning a period of 2000–2021. Data on the transition to green energy, macroeconomic indicators, and digitalization were included in the analysis. All data were collected from the World Bank database, International Renewable Energy Agency (IRENA), International Monetary Fund (IMF), and Our World in Data. Table 1 presents definitions of the variables used in the empirical analysis. Tables A2 and A3 show the descriptive analysis results and the correlation matrix, respectively. All variables were expressed using natural logs.

Table 1. Information about Data

Variables	Definition	Unit of measurement
Dependent Variable		
RE	Renewable energy	% Equivalent primary energy
Digitalization Variables		
IU	Internet users	% of population
MCS	Mobile cellular subscriptions	Per 100 people
FBS	Fixed broadband subscriptions	Per 100 people
Green Energy Transition Variables		
CO_2	Carbon emission	Metric tons per capita
EE	Energy Efficiency	Primary energy consumption per capita, kWh/person
FFEC	Fossil fuel energy consumption	Fossil fuels per capita (kWh)
Macroeconomic/Control Variables		
GDP	Economic growth	GDP per capita (current US$)
FD	Financial Development Index	%
FDI	Foreign Direct Investment	Balance of payment (BoP), current US$

The dependent variable, RE, was selected as the green energy transition data, and RE was measured as the% equivalent primary energy. Eleven independent variables—three of which are data on digitalization, three of which are data on the transition to green energy, and five of which are control variables—are taken into account in the analysis of the study.

The first digitalization variable is Internet users, which is measured as a percentage of the population. At the beginning of 2023, when Internet penetration reached 96.8%, there were 33.03 million Internet users in Malaysia. This demonstrates that from 2022 to 2023, there was an increase of 362k (1.1%) Internet users in Malaysia (Kemp, 2023). The second digitalization data were mobile cellular subscriptions measured per 100 people. Early in 2023, there were 44.05 million active mobile phone subscriptions in Malaysia, which represents 129.1% of the country's population. Between 2022 and 2023, Malaysia recorded a 1.2 million (+2.9%) growth in the number of mobile subscriptions (Kemp, 2023). Fixed broadband subscriptions, which were the final digital data, were calculated for 100 persons.

The main determinant of the switch to green energy is CO_2 emissions. Many studies in the literature have aimed to explore the link between RE sources and CO_2 emissions to optimize the green energy transition pathway (Xu et al. 2023; Dong et al. 2022; Koengkan and Fuinhas, 2020). The findings are consistent, and the switch to green energy is favorably associated with meeting CO_2 emission targets. For instance, Bekhet and Othman (2018) discovered that RE has a considerable negative impact on CO_2 emissions in Malaysia and that it is causally related to CO_2 emissions. In addition, Chachuli et al. (2021), Malaysia's shift to a green energy policy between 2012 and 2018 decreased CO_2 emissions by up to 0.16%.

Energy efficiency is another type of data related to green energy and is measured as primary energy consumption per capita, or kWh/person. According to IRENA (2020), the IEA's Sustainable Development Scenario indicates that energy efficiency reduces CO_2 emissions by 37%. Nam and Jin (2021) found that regulations for energy efficiency could reduce CO_2 emissions by 0.003%. Energy efficiency is the most effective energy policy instrument for climate mitigation, as evidenced by the fact that a 1% increase in energy intensity results in a 0.74 percent increase in CO_2 emissions because of inefficient energy use. Fossil fuel energy consumption is another clean energy indicator that is calculated as fossil fuel per capita (kWh). Despite the severe requirements for the switch from fossil fuels to RE, various variables (such as financial concerns, technological challenges, resource location, and a lack of resources) impede the progress of the green energy transition (Taghizadeh-Hesary et al. 2021).

The final data group, the control variables, consists of macroeconomic variables. GDP per capita (current US dollars) is an indicator of economic growth. The last two variables are financial development and foreign direct investment (FDI). The financial development index used by the IMF (2023) was used, FDI is net inflows, and BoP is measured as current US$. Based on the study by Murshed et al. (2021), FDI inflows directly damage environmental quality by increasing its ecological footprint. In contrast, Pradhan et al. (2021) claimed that FDI inflows aid in reducing CO_2 emissions, proving that the pollution halo effect theory is true for BRICS countries.

4.2. Methods

This study empirically explains how digitalization, green energy transition, and macroeconomic factors affect the clean energy transition and analyzes how these factors contribute to the energy transition. The model is defined as follows.

$$RE_t = f(IU_t, MCS_t, FBS_t, CO2_t, EE_t, FFEC_t, GDP_t, FD_t, FDI_t) \qquad \textbf{(1)}$$

$$RE_t = \alpha_t + \beta_1 IU_t + \beta_2 MCS_t + \beta_3 FBS_t + \beta_4\, CO2_t + \beta_5\, EE_t + \beta_6\, FFEC_t + \beta_7\, GDP_t + FD_t + \beta_{11} FDI_t + \varepsilon_t \qquad \textbf{(2)}$$

$$RE_t = \alpha_t + \beta_1 Digital_t + \beta_2 Green\, EnergyTrans_t + \beta_3 ControlV_t + \varepsilon_t \qquad (3)$$

In equations (2) and (3), RE stands for the transition to green energy, while the symbols $\alpha, \beta, \varepsilon, and\ t$ denote the constant term, variable coefficients, error terms, and number of periods, respectively.

In time-series analysis, it is crucial to confirm the stationarity level of the variables because financial and economic data are typically not stationary and contain structural breaks (Shrestha and Bhatta, 2018). As a result, before conducting the analysis, the data were tested using both the conventional Augmented Dickey-Fuller (ADF) unit root test and the unit root test based on the Zivot Andrew (ZA) structural break. The ZA test successfully predicted the unit root analysis of data with a variety of structural breaks and trends in dynamic stochastics, whereas the ADF test effectively predicted the unit root analysis of data with these structural breakdowns and trends (Li et al. 2023).

Then, the Bayesian auto-regressive distributed lags (BARDL) cointegration test will then be used to determine the cointegration of the variables. Using the statistical results of the F-test and T-test, the BARDL test investigates the long-term cointegration of the studied variables. The statistical results of the F-test and T-test were used in the BARDL test to analyze the long-term cointegration of the variables under investigation (Shan et al. 2021). The BARDL method is generally selected over the conventional ARDL models. First, while this BARDL test allows for a heterogeneous order of integration in variables, it is not overly complex in terms of the cointegration features of model variables (Wan et al. 2022). The BARDL method solves the issues of inconclusive cases by creating more critical values, which makes it more appropriate for the dynamic time-series model than the conventional ARDL model (Shan et al. 2021). The BARDL model predicts an extra F2-test subject for the lag-independent variables, in contrast to the ARDL technique, which only estimates the critical values of the F1 and T-tests (Xin et al. 2023). The mathematical model specification of the traditional ARDL method with independent variables is as follows.

$$RE_t = \sum_{i=1}^{p} \alpha_t RE_{1-i} + \sum_{j=0}^{q} \beta_j \, Digital_{1-j} + \sum_{k=0}^{r} \gamma_k \; GreenEnergyTrans_{1-k} + \sum_{m=1}^{s} \tau_m \, ControlV_{1-m} + u_t \qquad \mathbf{(4)}$$

where t denotes the number of years and I, j, k, and m are the lags that change from p, q, r, and s, respectively. However, u_t represents the error correction value with zero mean and constant variance, thus, the following equation can be expressed using the BARDL method:

$$RE_t = \varphi RE_{t-1} + \gamma Digital_{t-1} + \theta GreenEnergyTrans_{t-1} + \vartheta ControlV_{t-1} + \sum_{i=1}^{p-1} \lambda_t RE_{1-i} + \sum_{j=0}^{q-1} \delta_j \, Digital_{1-j} + \sum_{k=0}^{r-1} \pi_k \, GreenEnergyTrans_{1-k} + \sum_{m=1}^{s-1} \vartheta_m \, ControlV_{1-m} + u_t \qquad \mathbf{(5)}$$

The terms used in this context to indicate the associated functions are $\lambda, \delta, \pi, and\ \vartheta$. However, after being transformed into an error-correction form, the equation can be expressed as follows, along with an autoregressive vector for level. The unconditional model is created using a constant term (c) as follows:

$$RE_t = \widetilde{c} + \tilde{\varphi} RE_{t-1} + \tilde{\gamma} Digital_{t-1} + \tilde{\theta} GreenEnergyTrans_{t-1} + \tilde{\vartheta} ControlV_{t-1} + \sum_{i=1}^{p-1} \widetilde{\lambda}_t RE_{1-i} + \sum_{j=0}^{q-1} \widetilde{\delta}_j \, Digital_{1-j} + \sum_{k=0}^{r-1} \widetilde{\pi_k} \, GreenEnergyTrans_{1-k} + \sum_{m=1}^{s-1} \widetilde{\vartheta_m} \, ControlV_{1-m} + \widetilde{u_t} \qquad \mathbf{(6)}$$

The above equations demonstrate the significance of the cointegration of variables, which is supported by the three null hypotheses. The error correction terms (ECTs) employed in this study were tested using the F1 Test. The null hypothesis for the independent variable was examined using the F2 test. The lagged dependent variable is examined using the F3 method.

Finally, a stability test is used, which validates the long- and short-run results of the BARDL modeling, to verify the model's robustness during the final stage of the estimation. According to Song et al. (2022), stability analysis is crucial for assessing the effectiveness and reliability of findings because time-series data contain inherent structural problems that could affect the consistency of the parameters.

5. Empirical Findings

The descriptive values of the variables and correlation matrix are given in Tables 2A and 3A in the Appendix, respectively. ADF unit root tests were then applied in the study, and the results are presented in Table 2.

Table 2: ADF Unit Root Test Results

		CO_2	EC	FBS	FD	FDI	FFEC	GDP	IU	MS	RE
At Level											
With Constant	t-Statistic	-3.83	-2.12	-3.38	-1.92	-3.94	-2.39	-1.52	-3.50	-6.95	0.78
P-value		**0.01****	**0.23**	**0.02****	**0.28**	**0.00*****	**0.15**	**0.50**	**0.01****	**0.00*****	**0.99**
With Constant & Trend	t-Statistic	-2.02	-1.07	-2.59	-3.36	-4.80	-0.79	-1.00	-3.70	-2.69	-2.67
P-value		**0.55**	**0.90**	**0.28**	**0.08***	**0.00*****	**0.95**	**0.92**	**0.04****	**0.24**	**0.25**
Without Constant & Trend	t-Statistic	1.21	1.48	-0.09	-3.21	0.41	1.11	2.29	3.64	1.15	1.45
P-value		**0.93**	**0.96**	**0.63**	**0.00*****	**0.79**	**0.92**	**0.99**	**0.99**	**0.92**	**0.95**
First Differences Level											
		CO_2	**EC**	**FBS**	**FD**	**FDI**	**FFEC**	**GDP**	**IU**	**MS**	**RE**
With Constant	t-Statistic	-3.61	-3.98	-1.59	-5.24	-7.26	-3.81	-4.33	-3.63	-1.52	-3.53
P-value		0.01**	0.00***	0.46	0.00***	0.00***	0.01***	0.00***	0.01**	0.49	0.01**
With Constant & Trend	t-Statistic	-4.84	-4.82	-2.63	-5.32	-4.98	-5.07	-4.90	-3.69	-4.78	-4.06
P-value		0.00***	0.00***	0.27	0.00***	0.00***	0.00***	0.00***	0.04**	0.00***	0.02**
Without Constant & Trend	t-Statistic	-4.87	-3.68	-1.03	-5.35	-7.41	-3.70	-3.42	-2.76	-2.07	-3.26
P-value		0.00***	0.00***	0.25	0.00***	0.00***	0.00***	0.00***	0.00***	0.03**	0.00***

Notes: *The symbols *, **, and *** represent the 1%, 5%, and 10% significance levels, respectively.*

The ADF unit root test findings reveal that, while some variables are stationary at level, others become stationary after the first difference. The findings of the structural unit test on ZA, however, are included in Table 3 because time-series data were used in the present study.

Table 3: ZA Unit Root Test Results

Variables	ZA (Δ0)	Break Year	ZA (Δ1)	Break Year
RE	-4.08***	2016	-3.41***	2011
IU	-3.85	2006	-5.09***	2014
MCS	-3.50*	2015	-1.45	2010
FBS	-3.02**	2013	-3.18*	2011
CO_2	-2.17	2010	-4.80*	2013
EE	-2.47***	2018	-6.12***	2012
FFEC	-2.29***	2017	-6.47***	2012
GDP	-2.84**	2015	-5.42	2013
FD	-4.31*	2013	-5.92*	2008
FDI	-5.31**	2011	-5.71**	2010

Notes: *The symbols *, **, and *** represent the 1%, 5%, and 10% significance levels, respectively.*

The stationary state of the variables matches that of the ADF unit root test results based on the results of the ZA unit test. After the first difference, the break years of the variables also changed. This study employed the BARDL cointegration approach to identify the long-run equilibrium condition among the independent variables chosen for analysis and the transition to green energy after examining the stationary levels of the variables with structural breaks and restricted data size. Table 4 presents the estimation results of the

BARDL cointegration test.

Table 4: BARDL Cointegration Analysis Results

Expected Model	Model Method	F_{JOINT}	T_{DEP}	F_{IND}
BARDL (1, 0, 0, 0, 1, 1, 0, 1, 1, 1)	AIC	471.19**	2.11**	351.12**
Diagnostic Test				
R^2	**Q Statistics**	**LM (2)**		**JB**
0.99	3.83	0.70		0.18
Model: $RE_t = f(IU_t, MCS_t, FBS_t, CO2_t, EE_t, FFEC_t, GDP_t, FD_t, FDI_t)$				

Notes: *The symbols *, **, and *** represent the 1%, 5%, and 10% significance levels, respectively.*

Table 4 shows that the BARDL (1, 0, 0, 0, 1, 1, 0, 1, 1, 1)) model was selected because it minimized the AIC standards. Table 4 shows that at the 10% significance level, the F-joint test and T-test significant values validate the long-run cointegration in the model. The null hypothesis that all relevant explanatory variables have a normal standard deviation is significantly accepted by Q-statistics. Additionally, the Jarque-Bera statistic shows that the data have a normal distribution, which means that the model's data are normal, in contrast to the null hypothesis that the data are not normal. The model also exhibited serial autocorrelation, as shown by the rejection of the alternative hypothesis of serial autocorrelation. The model fits the data well because the explanatory variable (R2) explains 99% of the variation in the shift to green energy.

The presence of cointegration links enables the study to use the BARDL technique to assess the model results, and Table 5 highlights both the short- and long-term BARDL outcomes.

Table 5: Short and Long-Term BARDL Results

Dependent Variable: RE sources				
Variables	**Long Term**	**Short Term**	**Coefficient**	**T-statistics**
IU	0.091**	0.592	0.091**	0.592
MCS	-0.337	-1.569	-0.337	-1.569
FBS	0.089	0.720	0.361***	3.429
CO_2	0.747**	2.794	0.747**	2.794
EE	20.059***	9.564	20.059***	9.564
FFEC	-20.473***	-10.853	12.936**	2.337
GDP	0.138	0.798	0.138	0.798
FD	-0.538**	-2.469	-0.638**	-3.469
FDI	-0.000	-0.037	0.016	1.880
Long-Term Stability Test				
Test	**F Statistics**		**P Value**	
X^2_{NORMAL}	1.561		0.542	
X^2_{SERIAL}	1.423		0.585	
X^2_{ARCH}	1.197		0.652	
X^2_{HETERO}	1.874		0.425	
X^2_{RESET}	1.170		0.306	

Notes: *The symbols *, **, and *** represent the 1%, 5%, and 10% significance levels, respectively.*

As shown in Table 5, internet usage, energy efficiency, and RE capacity are all positively correlated in the long term. For instance, an increase in Internet usage resulted in a 0.09% increase in RE capacity. Similarly, there is a short-term positive correlation between fixed broadband subscribers, internet users, and RE capacity. This outcome is consistent with research done by Mehmood et al. (2023) and Lin and Huang (2023) found that the capacity of RE was impacted by digitalization. For instance, Hao et al. (2023) claimed that digitalization supports green energy transition growth in China, and digitalization is directly related to the use of RE in 90 countries, according to Lv et al. (2022). In addition, while CO_2 and RE capacity showed a positive correlation, fossil fuel energy sources and RE showed a negative correlation. This outcome was anticipated and is consistent with the findings of previous studies (Pata and Samour, 2023; Rehman et al. 2022; Koengkan et al. 2021).

Additionally, Table 5 reports the findings of short-run estimations using the BARDL technique, which demonstrates that the digitalization sector (Internet users and fixed broadband subscriptions) greatly accelerates the switch to green energy by 0.09% and 0.36%, respectively. Moreover, CO_2, energy efficiency, and the use of fossil fuels all contribute 0.74%, 20%, and 12%, respectively, to the green energy transition. However, financial development is detrimental to the switch to green energy, whereas the short-term effects of foreign direct investment, economic growth, and mobile cellular subscribers are insignificant. The last phase of the study involves evaluating the long-run estimation supported by the BARDL approach for dependability. The estimated results in Table 5 also demonstrate no issues with heteroscedasticity, autocorrelation, or model specification.

Finally, the stability of the ARDL model was evaluated using CUSUM and CUSUMQ tests. The CUSUM test establishes whether a structural break exists, whereas the CUSUMQ test establishes the duration of the breach (Kilinc-Ata and Alshami, 2023). Fig. 1 shows the test plots for CUSUM and CUSUMQ.

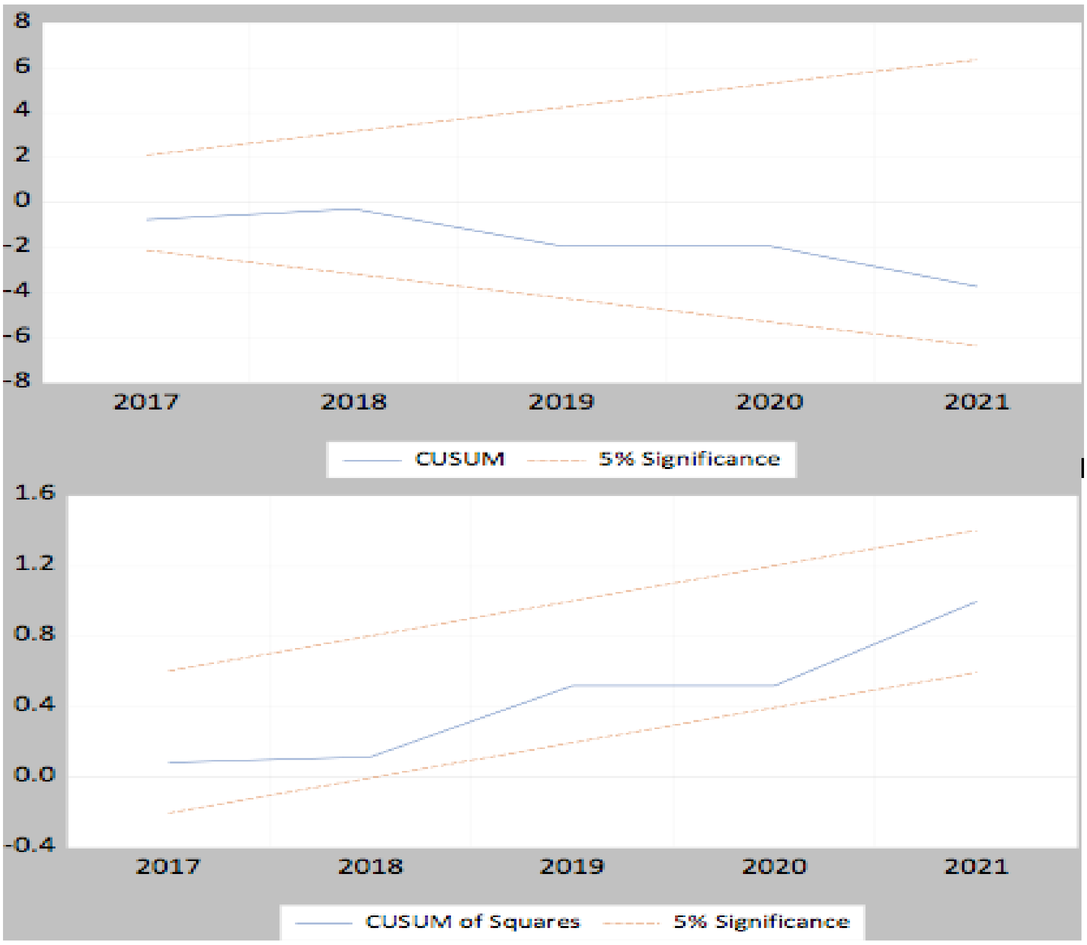

Fig.1. The CUSUM and CUSUMQ graphs of the BARDL model

The determined long-term association is likely structurally robust, and the parameters are significant according to the CUSUM and CUSUMQ plots, which demonstrate that the curves are within the critical value band at the 5% significance level. The results of the CUSUMSQ and CUSUM tests also show that the coefficients in the two ARDL models are stable.

6. Conclusion and Policy Implications

This study investigates the effects of digitalization on Malaysia's transition to green energy sources. In comparison to earlier research, this analysis used a dataset covering the years 2000 through 2021. Thus, this empirical study investigated the effects of digitization, economics, and green energy factors on RE utilization.

According to these findings, the digitalization industry is the major force behind the switch to green energy. The impact of CO_2 and energy efficiency, among other factors, accelerates the energy transition. Additionally, the transition to green energy is negatively affected by the use of fossil fuels and financial growth.

The study's research findings and analyses are combined with related policy recommendations. First, the energy sector's move to digitalization provides technical support for the growth of variable RE, which can significantly increase renewable integration. As a result, it should promote a thorough integration of digital technology into the energy industry while highlighting the significance of digitalization. Policymakers should create or strengthen policies, laws, and regulations to support the use of digitization in the transition to green energy in this environment. In other words, the use of modern technology and cutting-edge communication technologies such as cloud computing, big data, the Internet of Things, artificial intelligence, and the mobile Internet should be supported in the transition to green energy. Second, the favorable impact of renewable integration is affected by digitization at a threshold. The energy system should be further digitalized for all nations to gain more from the scale effect of digitization. Third, the integrated development of decarbonization and energy system digitization should receive more priority in emerging economies such as Malaysia. The emphasis should be on the entire system and its long-term advantages rather than short-term costs. The scalability and digitization of energy systems will have a significant positive impact on how well-developing nations manage their green energy transition.

This study has several limitations. For instance, the association between digitalization and the integration of green energy transition has been made within the scope of specific variables due to restricted data availability. By choosing both developed and emerging economies for future studies, a panel data analysis approach is envisaged, allowing for the introduction of crucial implementations for policymakers in developing nations.

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Appendixes

Table A1: A recent and empirical literature review on the digitalization of the green energy transition

Author/s	Periods	Country/ies	Method	Results
Lin & Huang, (2023	2000-2019	33 country	Benchmark model	According to the findings, digitization positively modifies the integration of RE. Asymmetrical moderating impact is also present.
Xu & Ullah, (2023)	1994-2020	China	QARDL	The findings imply that long-term improvements in RE consumption in China are facilitated by a variety of factors, including ICT, the growth of financial institutions and markets, education, GDP, and CO_2 emissions. The ICT, financial institutions and markets, education, GDP, and CO_2 emissions all showed promise in boosting the usage of RE in the short term.
Wang et al. (2023)	2003-2019	34 Asian countries	Traditional STIRPAT model	The findings show that the digital economy has a beneficial impact on RE. Additionally, the relationship between the digital economy and RE is positively moderated by advancements in finance, political stability, and the rule of law.
Li et al. (2023)	2000-2020	China	ARDL	Information and communication technology (ICT) and human resources support China's move to RE.
Haller et al. (2023)	2010-2018	European countries	Multiple liner regression & OLS	Economic expansion, digitalization, eco-innovation, and the use of RE all have an effect on the amount of GHG.
Razzaq et al. (2023)	2007-2019	China	Method of Moments Quantile Regression	The findings indicate that green growth is stimulated by digital finance at middle to upper quantiles (4th to 6th), which include the central and eastern areas.
Lu et al (2023)	1995-2020	China	ARDL	According to the findings, China can achieve green growth by raising demand for RE, lowering carbon intensity, and promoting digital financial inclusion and environmental policy rigor.
Shahbaz et al. (2022)	2003-2019	72 country	Panel data analysis	The energy transition is positively impacted by the digital economy. Additionally, the digital economy encourages the transition to RE by strengthening governments' governance capacities.
Zhang (2022)	2000-2019	29 world's major exporting	Multi-variate threshold	Digital trade competitiveness and digital technology exploitation also offer considerable single threshold

		countries	model.	influence when the fraction of RE consumption is considered the major independent variable.
Yu et al. (2022)	2010-2020	60 emerging and non-emerging economies	Panel data analysis	The results show that promoting digitally available green finance aids in the development of green and RE sources and lowers CO_2 emissions.
Zhang et al. (2022)	2000-2020	G7 countries	Panel data analysis	The long-run parameter coefficients indicate a negative correlation between digital trade, usage of RE, and ecological footprint.
Wang et al. (2022)	2007-2017	China	Dynamic panel model	The key findings show that China's high-quality energy development is positively impacted by the digital economy; in other words, a 1% increase in the digital economy index will raise high-quality energy development by an average of 0.191%;
Sultanova et al. (2022)	2017-2021	25 EU countries	Panel data analysis	The findings show that the development of the digital economy has a beneficial impact on the switch to clean energy.
Niu et al. (2022)	2003-2019	China Zhejiang Province	Time Series regression estimation	Results indicate that approaches to increase energy efficiency include strengthening the physical base, participants, media, and pathways of digitalization.
Zhao et al. (2021)	2012-2019	China	Data development analysis	The findings showed that digital transformation increased the effectiveness of using RE.
Zhang et al. (2021a)	2006-2018	30 Chinese provinces	OLS & PVAR	As the level of the digital economy rises, it is evident that the effect of the digital economy on green total factor energy efficiency is first promoted and subsequently prevented. Further, when economic growth, urbanization, R&D input, and human capital levels rise, the beneficial effects of the digital economy on green total factor energy efficiency become stronger.

ARDL: *Autoregressive Distributed Lag Method;* ***EU:*** *European Union;* ***OLS:*** *Ordinary Least Square;* ***QARDL:*** *Quantile Autoregressive Distributed Lag Method;* ***PVAR:*** *Panel Vector Autoregression;* ***STIRPAT:*** *Stochastic Impacts by Regression on Population, Affluence and Technology*

Table A2: Descriptive analysis results

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
RE	22	3.792752	1.812285	2.13846	8.059835
IU	22	59.58272	20.43034	21.38473	96.75143
MCS	22	102.7075	41.71435	22.3217	146.7945
FBS	22	5.970534	3.993686	0	11.12204
CO_2	22	7.190409	0.8297721	5.500205	8.243607
EC	22	33146.34	3467.674	26586.07	37846.98
FFEC	22	31788.13	3008.259	25660.82	35279.06
GDP	22	8341.763	2793.361	3913.429	11432.83
FDI	22	7.54e+09	4.08e+09	.15e+08	1.51e+10
FD	22	0.6304545	0.0606691	0.51	0.75

Table A3: Correlation Matrix

	LRE	LMS	LIU	LGDP	LFFEC	LFDI	LFD	LFBS	LEC	LCO_2
LRE	1	0.4198689957401253	0.6074785330944305	0.5609589239611632	0.3661919712739751	0.2450222943472126	0.5652137053857262	0.4952293254997068	0.5273327531954597	0.5077407541405413
LMS	0.4198689957401253	1	0.9417440180138236	0.9594383222440904	0.9333281291882792	0.4537397790147175	0.8923434636619915	0.9815733885294096	0.9367473476243709	0.9518925994905396
LIU	0.6074785330944305	0.9417440180138236	1	0.9152102532436618	0.8734014653516394	0.450147176298657	0.9187634949615282	0.9286307504310832	0.9233794128956726	0.9164693276427765
LGDP	0.5609589239611632	0.9594383222440904	0.9152102532436618	1	0.8968919432566761	0.5355684809989081	0.8900139898979731	0.9852105121482729	0.9274586843867249	0.9325294709352214
LFFEC	0.3661919712739751	0.9333281291882792	0.8734014653516394	0.8968919432566761	1	0.5319506975972662	0.7645791885559652	0.9032179968324194	0.98318264436079	0.9359444801225494
LFDI	0.2450222943472126	0.4537397790147175	0.450147176298657	0.5355684809989081	0.5319506975972662	1	0.4506036069028053	0.4723656362182756	0.5351096031109772	0.4781169861810516
LFD	0.5652137053857262	0.8923434636619915	0.9187634949615282	0.8900139898979731	0.7645791885559652	0.4506036069028053	1	0.9093157840599892	0.8175198417534179	0.8419641677987944
LFBS	0.4952293254997068	0.9815733885294096	0.9286307504310832	0.9852105121482729	0.9032179968324194	0.4723656362182756	0.9093157840599892	1	0.9220577183842584	0.9338873979724148
LEC	0.5273327531954597	0.9367473476243709	0.9233794128956726	0.9274586843867249	0.98318264436079	0.5351096031109772	0.8175198417534179	0.9220577183842584	1	0.9544550744999976
LCO_2	0.5077407541405413	0.9518925994905396	0.9164693276427765	0.9325294709352214	0.9359444801225494	0.4781169861810516	0.8419641677987944	0.9338873979724148	0.9544550744999976	1