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The Significant Role of ICT Growth and Innovation in Boosting Renewable Energy Sector Development in Malaysia

Syahrill Mat Shariff[1], and Barjoyai Bardai*[1]

[1] *Tun Razak Graduate School, Universiti Tun Abdul Razak (UNIRAZAK), Kuala Lumpur, Malaysia.*

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ABSTRACT

The global shift toward low-carbon energy systems has prompted governments to expand renewable energy programmes, yet the effectiveness of these efforts depends on a wide range of enabling factors that extend beyond energy technology itself. This study examined whether growth in Information and Communication Technology (ICT), captured through internet and mobile subscription penetration, moderated the development of renewable energy across 30 International Energy Agency member and Southeast Asian countries between 2000 and 2019. Secondary panel data covering renewable energy production and consumption, GDP per capita, carbon emissions, and renewable energy and system patents were sourced from the World Bank, Our World in Data, and the International Energy Agency, and analysed using dimension reduction factor analysis and multiple linear regression. The factor analysis extracted three components, an economic-ICT factor, a renewable energy factor, and a technology-innovation factor, jointly explaining 79.6 percent of total variance. Regression results showed that renewable energy consumption and GDP per capita were the strongest predictors of renewable energy output, while a parsimonious model confirmed that ICT development significantly moderated the relationship between renewable energy consumption and output. However, ICT growth was also found to correlate positively with carbon emissions, suggesting a trade-off linked to the energy footprint of digital infrastructure. The findings imply that internet and digitalisation growth can meaningfully strengthen renewable energy development and should be incorporated into national renewable energy policy design.

1. INTRODUCTION

Renewable energy has become a central pillar of national strategies to mitigate climate change, given that the energy sector remains the largest single contributor of global carbon emissions. In Malaysia, awareness of renewable energy has grown steadily, yet policy attention has historically concentrated on reducing conventional energy usage rather than accelerating renewable substitution. The country's renewable energy journey formally began with the 8th Malaysia Plan (2000), which introduced the Five-Fuel Diversification Policy and established the Special Committee on Renewable Energy, targeting five percent renewable production by 2005. Subsequent policy instruments, including the National Biofuels Policy (2006), the National Green Technology Policy (2009), and the New Energy Policy (2011), extended this agenda, yet the pace of implementation through state-linked utilities remained slow, and Malaysia fell short of its two-decade renewable energy targets.

Comparative evidence from the BRICS economies, whose upper-middle-income status and rapid fiscal development parallel Malaysia's own trajectory, illustrates a similar pattern: with the exception of China, fossil fuels continue to dominate the energy mix even as GDP has expanded, and renewable energy generation has yet to rise to a level commensurate with economic growth. Globally, the number of countries enacting renewable-energy support policies more than tripled, from 48 in 2005 to 128 by 2017, underscoring the growing recognition that government support is essential to lowering the barriers facing renewable energy development. In Malaysia, renewable energy's contribution to the national energy mix remains modest and is achieved largely through the geographical advantage of hydropower, which in turn keeps the sector heavily dependent on government financing rather than private or international capital.

Development and innovation in renewable energy technology are widely credited with reducing implementation

*Corresponding author.
E-mail address: Barjoyai Bardai < barjoyai@unirazak.edu.my >
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and operating costs and with enabling broader participation in the sector. However, prior research has concentrated mainly on renewable energy technology itself, with comparatively little attention paid to the supporting role of Information and Communication Technology (ICT) as an enabling industry. As next-generation network technologies such as big data, cloud computing, and mobile internet mature, ICT is increasingly positioned to play a larger role in enhancing renewable energy transformation and in supporting the sustainable development of national economies. Grid reinforcement, energy storage, and prosumer demand-and-supply management, all core elements of Malaysia's peer-to-peer (P2P) electricity trading infrastructure implemented through Tenaga Nasional Berhad, depend on digital system operations, innovative business models, and real-time control and monitoring capabilities that only ICT innovation can deliver.

This study therefore investigates the correlation between ICT growth and renewable energy sector development, treating ICT as a moderating variable operating alongside renewable energy consumption, GDP per capita, carbon emissions, and technology innovation patents. The research is intended to give policymakers a clearer, empirically grounded picture of the driving forces and gaps in current renewable energy programmes, and to identify how the continued expansion of ICT infrastructure and digitalisation might be leveraged to strengthen Malaysia's renewable energy sector and its broader sustainability agenda.

Beyond Malaysia's own policy trajectory, the emergence of peer-to-peer (P2P) electricity trading and prosumer-based energy markets illustrates why ICT can no longer be treated as peripheral to renewable energy planning. Key success factors for a functioning P2P electricity trading environment, namely system reliability, service quality, a conducive regulatory framework, and a resilient grid, are all mediated by the digital layer that sits above the physical energy infrastructure. Malaysia's distribution system operators, including Tenaga Nasional Berhad, Sarawak Energy Berhad, NUR Power, and Sabah Electricity Sdn Bhd, are increasingly expected to adopt smart meters, smart sensors, the Internet of Things, cloud computing, and artificial-intelligence-driven automation to manage the injection of variable renewable power and to enable real-time data exchange with prosumers. Digital media and smartphone applications further extend this engagement by allowing consumers to track consumption, manage accounts, and participate directly in energy markets. These developments motivate the present study's central question: does the empirical record, drawn from a broad panel of countries over two decades, support the intuition that ICT growth measurably strengthens renewable energy outcomes, and if so, through which channel does that influence operate?

2. LITERATURE REVIEW

A substantial body of literature links renewable energy consumption to positive economic outcomes. Studies across developing and developed economies report that renewable energy consumption contributes to financial development and economic growth (Li Zhe, 2021), reduces reliance on volatile fossil fuel prices, and supports broader sustainability goals such as energy security and socio-economic resilience (Fotourehchi, 2017; Bhuiyan et al., 2022; Chen et al., 2022). Systematic reviews of this nexus generally conclude that the positive impact of renewable energy consumption on growth is conditional on the presence of coherent legal frameworks and supportive government policy (Bhuiyan et al., 2022), a conclusion consistent with earlier work identifying financial, market, administrative, and sociocultural barriers as the principal obstacles to renewable energy policy development in Malaysia (Yusoff & Kardooni, 2012; Khairudin, 2020).

A parallel and more recent stream of research has begun to examine ICT as a determinant, rather than merely a consumer, of energy outcomes. Findings in this literature are mixed. Some studies report that higher levels of ICT development or digitalisation, proxied by internet access and mobile phone penetration, are associated with higher power consumption but show no significant relationship with carbon emissions (Lange, Pohl, & Santarius, 2020). Others find that ICT innovation in application, infrastructure, and system optimisation reduces energy consumption through efficiency gains (Wu, Hao, Ren, Yang, & Xie, 2020; Niu, Lin, Luo, Zhang, & Lian, 2022). At the country level, ICT has been found to make a broadly positive contribution to economic growth, though its effect on energy efficiency is not uniform: for example, India was the only South Asian country found to have achieved measurable energy-efficiency improvements attributable to increased ICT use between 1990 and 2018 (Usman, Ozturk, Ullah, & Hassan, 2021).

Studies that examine ICT, renewable energy, and environmental quality jointly remain comparatively scarce, and most existing work is confined to a single country (Kahouli, Hamdi, Nafla, & Chabaane, 2022) or a single region (To Trung Thanh, Le Thanh Ha, Hoang Phuong Dung, & Tran Thi Lan Huong, 2022), rather than treating ICT as a cross-cutting moderating factor across a diverse multi-country panel. Related evidence from South-East Asia indicates that the combined growth of ICT, advanced technologies, and renewable energy has contributed significantly to environmental sustainability outcomes (Zeeshan, Han, Rehman, Ullah, & Mubashir, 2022), while research on ICT-driven environmental degradation in South Africa similarly points to ICT as a variable whose energy and environmental effects run through several indirect channels simultaneously (Atsu, Adams, & Adjei, 2021).

Beyond direct energy-use effects, ICT innovation is credited with facilitating the smart grid transformation needed to accommodate variable renewable energy (VRE). The Landscape of Innovation to Integrate VRE identifies a suite of thirty digitally enabled innovations spanning market design, business models, system operation, and enabling technologies, including smart meters, remote monitoring (SCADA), automation, and distributed ledger technologies such as blockchain, which collectively reduce transaction costs and support platform-based prosumer business models. Malaysia's own P2P electricity trading framework, built on the Power Ledger platform and also piloted in Australia, Japan, Thailand, and the United States, exemplifies this trend, relying on distribution system operators to manage the injection of variable renewable power through enhanced digital monitoring and control.

Innovation-policy literature also cautions that the relationship between policy intervention and technological change is not mechanical. Environmental regulation and R&D investment have been shown to jointly stimulate green technology innovation in large emerging economies (Zhang,

Chen, & He, 2022), while broader reviews of renewable-energy penetration and building energy efficiency in Malaysia point to spatial and infrastructural constraints that mediate how quickly renewable technology adoption translates into measurable output (Aldhshan, Abdul Maulud, Wan Mohd Jaafar, Karim, & Pradhan, 2021). Firm- and household-level evidence from other developing markets similarly shows that purchase intention, attitude, and user behaviour condition the diffusion of renewable energy technology even where the underlying technology and financing are available (Ashinze, Tian, Ashinze, Nazir, & Shaheen, 2021). These findings collectively suggest that the ICT-renewable energy relationship, if it exists, is likely to be indirect and moderating rather than a simple, uniform, direct effect, reinforcing the rationale for modelling ICT development as a moderator rather than a standalone predictor. Taken together, the literature offers a reasonably strong theoretical foundation for expecting ICT growth to influence renewable energy outcomes, but leaves open the specific magnitude and direction of that influence when tested against a broad, multi-country panel that also accounts for economic growth, carbon emissions, and technology-innovation patenting activity, the gap this study addresses.

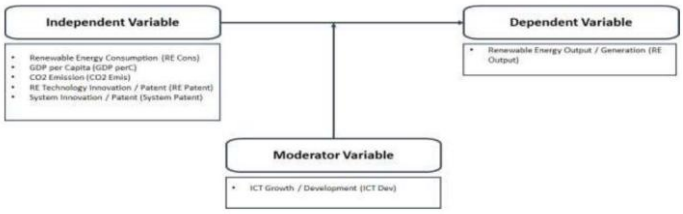

Fig. 1. Conceptual framework of the study

3. METHODOLOGY

This study adopted a quantitative research design using secondary panel data to examine the correlation between ICT growth and renewable energy sector development. Data were drawn from three publicly available sources, the World Bank (databank.worldbank.org), Our World in Data (ourworldindata.org), and the International Energy Agency (iea.org/data-and-statistics), covering International Energy Agency member countries and selected Southeast Asian nations, 30 countries in total, over the period 2000 to 2019. This country grouping and time frame were chosen for their geographic and economic comparability with Malaysia and for alignment with the timeline of Malaysia's own renewable energy policy programme.

The proposed theoretical framework comprised one dependent variable and five independent variables. Renewable energy output (RE Prod) was defined as the share of electricity generated from renewable sources out of each country's total energy output. The independent variables were renewable energy consumption (RE Cons), the share of electricity consumed from renewable sources out of total electricity production; GDP per capita (GDP PerC), reflecting economic performance and living standards; carbon emissions (CO2 Emis), the by-product of conventional fuel combustion; technology innovation, captured through renewable energy technology patents (RE Patents) and complementary system patents (System Patents); and ICT growth, measured jointly through mobile cellular subscriptions per 100 persons (MOB Subs) and internet users per 100 persons (INT Subs), which were subsequently combined into a composite ICT development index (ICT_Dev) for the regression stage.

Because the panel was compiled from open-access secondary data, the study acknowledged limitations around authenticity, methodological consistency across source agencies, and possible variation in how variables were originally defined or categorised. These limitations were weighed against the substantial benefit of secondary data, namely its scale and multi-decade longitudinal coverage, which would be impractical for an individual researcher to collect directly; the data were judged adequate for the exploratory, comparative purpose of this study.

Data analysis proceeded in three stages. First, a correlation (cross-tabulation) analysis was conducted to establish the statistical association between variables and to identify which variables carried the most explanatory weight. Second, dimension reduction factor analysis using Principal Component Analysis was performed to identify the underlying factors accounting for shared variance among variables and to screen out redundant predictors ahead of the regression stage. Sampling adequacy was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. Third, multiple linear regression was used to test the ten hypothesised relationships (H1 to H10), which specified direct associations between each independent variable and renewable energy output, and the moderating role of ICT development on each of those relationships.

4. RESULTS AND DISCUSSION

Descriptive statistics for the full panel (N = 400) showed a mean renewable energy output of 38.06 percent (SD = 29.38) and mean renewable energy consumption of 22.58 percent (SD = 16.41). Mobile subscription penetration averaged 98.44 per 100 persons (SD = 33.59) against a considerably lower internet penetration of 19.42 per 100 persons (SD = 13.81), while mean GDP per capita stood at USD 37,335 (SD = 16,583). Renewable energy patents (mean = 1,838) and system patents (mean = 1,138) exhibited very large standard deviations relative to their means, reflecting substantial concentration of patenting activity among a small number of countries. Among the variables considered, GDP per capita showed the strongest overall association with the renewable energy ecosystem.

Table 1. Regression Results for Determinants of Renewable Energy Output

Predictor	B	p	Significant
Renewable Energy Consumption	1.498	<.001	Yes
GDP per Capita	0.000294	<.001	Yes
System Patents	-0.000230	.762	No
Renewable Energy Patents	0.000270	.606	No

Note. Model R^2 = .724, F(4, 399) = 261.182, p < .001. ICT development added later as a moderator (B = .117, p = .005), raising R^2 from .457 to .465.

The correlation matrix revealed a strong positive relationship between renewable energy output and renewable energy consumption ($r = 0.834$, $p < .001$), and moderate positive associations between internet subscription and both mobile subscription ($r = 0.584$) and GDP per capita ($r = 0.656$). Carbon emissions correlated negatively with renewable energy output ($r = -0.207$) and consumption ($r = -0.389$), but positively with internet subscription ($r = 0.243$) and GDP per capita ($r = 0.596$), while renewable energy and system patents were almost perfectly correlated with each other ($r = 0.963$), indicating substantial overlap between the two innovation measures. Sampling adequacy for factor analysis was confirmed with a KMO statistic of 0.549, a barely acceptable but adequate level, and Bartlett's Test of Sphericity was significant (chi-square = 2388.268, df = 28, $p < .001$), confirming the correlation matrix was not an identity matrix and was suitable for data reduction.

Principal Component Analysis extracted three components with eigenvalues exceeding 1, jointly explaining 79.6 percent of total variance (30.8, 28.3, and 20.5 percent respectively), with communalities ranging from 47.6 percent upward. The rotated component matrix showed GDP per capita (0.886), internet subscription (0.878), and mobile subscription (0.657) loading heavily on the first factor, interpreted as an economic-ICT dimension; renewable energy consumption (0.916), renewable energy output (0.850), and carbon emissions (-0.626) loading on the second factor, interpreted as the core renewable energy dimension, with emissions carrying a negative loading; and system patents (0.979) and renewable energy patents (0.978) loading almost exclusively on the third factor, interpreted as a technology-innovation dimension. This structure indicates that ICT growth clusters empirically with economic development rather than with the technology-patenting dimension, an important distinction for interpreting the subsequent regression results.

The initial regression model, with renewable energy consumption, GDP per capita, system patents, and renewable energy patents as predictors of renewable energy output, produced an R-squared of 0.724, $F(4, 399) = 261.182$, $p < .001$, indicating the model explained 72.4 percent of the variance in renewable energy output. Renewable energy consumption ($B = 1.498$, $p < .001$) and GDP per capita ($B = 0.000294$, $p < .001$) were significant predictors, while system patents ($B = -0.000230$, $p = .762$) and renewable energy patents ($B = 0.000270$, $p = .606$) were not, consistent with the near-collinearity between the two patent measures observed in the correlation matrix. Adding ICT development as a fifth predictor left R-squared unchanged at 0.724 and did not reach significance ($B = 0.022$, $p = .595$), suggesting that in the presence of the two highly collinear patent variables, ICT development's incremental contribution could not be isolated.

A more parsimonious model retaining only renewable energy consumption and GDP per capita as predictors, and then adding ICT development as a moderator, produced a cleaner result. The two-predictor model explained 45.7 percent of variance, $F(2, 577) = 243.289$, $p < .001$ (RE Cons $B = 1.133$, $p < .001$; GDP PerC $B = 0.000554$, $p < .001$). When ICT development was added, explained variance rose modestly to 46.5 percent, $F(3, 576) = 167.092$, $p < .001$, and ICT development emerged as a statistically significant predictor ($B = 0.117$, $p = .005$), with a corresponding increase in the coefficient for renewable energy consumption. This confirms that ICT growth significantly moderates the relationship between renewable energy consumption and renewable energy output once collinear technology-patent variables are removed from the model.

Hypothesis testing based on these results supported a significant relationship between renewable energy consumption and renewable energy output (H1) and confirmed that ICT development significantly moderates this relationship (H6). A correlation between carbon emissions and renewable energy output was likewise evidenced in the factor analysis, albeit with a negative loading direction (H2), while renewable energy patents and system patents showed no significant direct relationship with renewable energy output (H3, H4 rejected), nor did ICT development significantly moderate the relationship between either patent measure and output (H8, H9 rejected), or between carbon emissions and output (H7 rejected). The regression coefficients for GDP per capita, while statistically significant, remained substantively small (B consistently below 1), and ICT development did not significantly moderate the GDP-output relationship (H5, H10 rejected). Taken together, the results point to a specific and identifiable channel: ICT growth strengthens renewable energy development primarily by reinforcing the link between renewable energy consumption and output, rather than by directly amplifying the effect of economic growth or technology patenting.

A notable and somewhat counterintuitive finding was the positive correlation observed between internet subscription and carbon emissions ($r = 0.243$) within the ICT-economic factor. This is plausibly attributable to the energy footprint of ICT infrastructure itself, including cooling systems and continuous power demand from data centres and hosting facilities, which are typically powered by conventional fuel sources. This finding echoes broader evidence that ICT's energy and environmental effects operate through multiple, sometimes offsetting channels (direct equipment energy consumption, indirect efficiency gains in other sectors, and complementary intelligence gains in transmission systems), and indicates that the net environmental benefit of ICT-driven renewable energy expansion is conditional on how the ICT sector itself is powered.

The clustering of GDP per capita, internet subscription, and mobile subscription within a single factor also merits interpretation. Rather than functioning as an independent technological driver, ICT growth in this panel behaved empirically as part of a broader economic-development bundle, rising in step with national income rather than diverging from it. This is consistent with the view that ICT infrastructure investment is itself a function of economic capacity, and it helps explain why ICT development's standalone effect was undetectable in the full five-predictor regression model but became visible once the two highly collinear patent variables, which absorbed shared variance, were removed. Practically, this implies that renewable energy policies aiming to harness ICT growth should expect the strongest returns in economies that are simultaneously investing in general digital infrastructure and income growth, rather than treating ICT and renewable energy policy as separable levers.

5. CONCLUSION

This study examined the correlation between ICT growth and renewable energy sector development using panel data from 30 countries over 2000 to 2019. Dimension reduction factor analysis identified a distinct economic-ICT dimension, a core renewable energy dimension, and a technology-innovation dimension jointly explaining 79.6 percent of the variance in the data, and regression analysis confirmed that renewable energy consumption and GDP per capita were the strongest predictors of renewable energy output. Once collinear technology-patent variables were removed, ICT development emerged as a statistically significant moderator of the relationship between renewable energy consumption and output, supporting the study's central proposition that internet and digitalisation growth can meaningfully boost renewable energy development. At the same time, the positive correlation observed between ICT growth and carbon emissions highlights an important caveat: digital infrastructure carries its own energy footprint, and its net contribution to decarbonisation depends on the cleanliness of the power supplying it.

For Malaysian policymakers, these findings suggest that internet and digitalisation development programmes should be more deliberately aligned with renewable energy strategy rather than treated as a separate policy track. This includes crafting incentive structures that encourage ICT enterprises to develop local applications and energy-management solutions targeting the renewable energy sector, and promoting ICT-enabled products and services, such as energy-saving systems, automation, and security and control platforms, as complementary components of national renewable energy policy. The modest but positive causality observed between renewable energy growth and GDP per capita further suggests that policies encouraging public and prosumer participation, for instance through peer-to-peer electricity trading frameworks, can simultaneously advance sustainability goals and create supplementary domestic income opportunities, reducing reliance on any single utility or external funding source.

This study is not without limitations. The reduced regression model explained only 45.7 percent (46.5 percent with the ICT moderator) of the variance in renewable energy output, indicating that other predictors, such as public awareness and participation, enabling infrastructure, technology cost and availability, and geographic and weather feasibility, likely play meaningful roles not captured in the present model. The reliance on open-access secondary data also introduces uncertainty around data authenticity and consistency across source agencies. Future research should incorporate a wider set of predictors, particularly around R&D investment and ICT application intensity, and draw on more rigorously validated data sources, to build a more complete picture of how ICT growth and renewable energy development interact across diverse national contexts.

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