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Digital Infrastructure and Renewable Electricity Profiles in ASEAN: A Data-Driven Comparative Analysis

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Abstract

This study develops a comparative technology–energy profile of ten ASEAN economies using fixed broadband subscriptions, renewable electricity generation, and annual GDP per capita growth. Rather than estimating causal relationships from a small cross-sectional population, the study applies standardized-distance profiling to identify country configurations and examine how digital connectivity, renewable electricity penetration, and short-run economic dynamics coexist. The dataset combines internationally comparable indicators from the International Telecommunication Union, World Bank, Ember, and Our World in Data, using the most recent comparable observations available for 2024–2025. Each indicator is standardized through z-scores, and countries are classified according to their Euclidean distance from analytically defined reference profiles. The results identify three empirical configurations characterized by different combinations of connectivity, renewable electricity, and economic growth. Viet Nam displays relatively strong performance across all three dimensions, while Laos combines very high renewable electricity penetration with limited fixed broadband infrastructure. Singapore and Brunei demonstrate relatively strong connectivity alongside comparatively low renewable electricity shares. The findings indicate that digital infrastructure and energy transition are interconnected but non-equivalent dimensions requiring differentiated comparative analysis.

Keywords: *ASEAN, broadband, digital infrastructure, renewable electricity, technology–energy transition.*

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INTRODUCTION

Digital infrastructure has become an increasingly important component of contemporary economic and technological development because connectivity determines how households, firms, governments, and markets participate in digital activities. Broadband networks facilitate access to cloud computing, digital platforms, online public services, data-intensive applications, and knowledge resources, thereby extending the productive role of information and communication technologies beyond basic communication functions (Goldfarb & Tucker, 2019; Koutroumpis, 2019). The expansion of digital infrastructure, however, does not occur independently from other technological systems because the operation of telecommunications networks, data centers, and digital services requires substantial and increasingly reliable electricity supply. Consequently, the simultaneous development of digital connectivity and electricity systems has become an important dimension of contemporary technology and innovation transformation (ElMassah & Mohieldin, 2020; OECD, 2024).

The relationship between digitalization and energy systems is particularly relevant because digital technologies can generate both efficiency-enhancing and energy-demanding effects. Digital applications can improve resource allocation, facilitate real-time monitoring, optimize industrial processes, and support more efficient energy management, while the expansion of connected devices, communication networks, and computing infrastructure can simultaneously increase electricity consumption (Sadorsky, 2012; Sun et al., 2021). This duality means that higher digital connectivity cannot automatically be interpreted as evidence of environmental improvement or energy transition. The environmental implications of digitalization depend on technological adoption, institutional conditions, energy-system characteristics, and the extent to which efficiency gains compensate for additional electricity demand (Zhao & Wang, 2022; Xu et al., 2024).

Renewable electricity constitutes another major dimension of technological transformation because the composition of electricity generation determines the extent to which economic and digital activities rely on low-carbon energy sources. Renewable deployment can be influenced by natural resource endowments, investment capacity, grid architecture, technological availability, regulatory frameworks, and long-term energy policy, making its development structurally different from telecommunications infrastructure expansion (Bhattacharya et al., 2016; Cheng et al., 2019). Digital technologies may support renewable integration through forecasting, automated control, energy monitoring, and demand management, but these technological complementarities do not imply that digital infrastructure and renewable electricity will expand at identical rates. The coexistence of digitalization and renewable energy therefore needs to be examined as a multidimensional phenomenon rather than reduced to a simple assumption that technological connectivity necessarily produces energy transition (IEA, 2024; Zhang & Zhou, 2023).

The ASEAN region provides an important empirical context for examining these differences because its member economies display substantial heterogeneity in economic structure, infrastructure development, geography, energy resources, and technological capabilities. Economies with extensive hydropower resources may achieve relatively high renewable electricity shares even when fixed broadband infrastructure remains comparatively limited, whereas highly urbanized and digitally connected economies may continue to rely heavily on conventional electricity generation (Bekun et al., 2019; IEA, 2024). Differences in market size, telecommunications investment, electricity-generation portfolios, industrialization, and institutional capacity further contribute to divergent technology–energy trajectories across the region. Such heterogeneity makes ASEAN particularly suitable for comparative analysis that examines combinations of infrastructure characteristics rather than relying on a single indicator of technological development.

Existing studies have generated substantial evidence concerning broadband, digitalization, technological innovation, renewable energy, electricity consumption, and economic growth, but these dimensions are frequently examined separately or through causal models focused on individual relationships. Research on digital economies emphasizes the contribution of connectivity and technological innovation to economic transformation, while energy studies commonly focus on renewable-energy deployment, environmental performance, or the relationship between energy consumption and economic growth (Fu et al., 2018; Ding et al., 2022). Although recent research increasingly examines digitalization and green transition jointly, relatively limited attention has been given to identifying country-level configurations in which digital infrastructure, renewable electricity, and contemporaneous economic growth exhibit different combinations. A comparative profiling framework can therefore complement existing causal research by first establishing the empirical heterogeneity that subsequent longitudinal or econometric analyses need to explain (Jiang et al., 2023; Li et al., 2023).

A further analytical challenge concerns the interpretation of economic growth within technology–energy comparisons. GDP per capita growth captures short-run changes in economic activity but does not directly measure innovation capacity, productivity, environmental performance, or the quality of digital infrastructure. Nevertheless, incorporating this indicator provides contextual information about whether different combinations of connectivity and renewable electricity occur alongside contrasting contemporary economic dynamics. Previous research demonstrates that economic growth is associated with technological innovation, energy consumption, trade, investment, and institutional conditions through multiple channels, indicating that a single-year growth rate should be interpreted descriptively rather than as evidence of a technological or energy effect (Pradhan et al., 2018; Shahbaz et al., 2015).

Against this background, a multidimensional empirical profile offers an alternative to conventional country rankings based on a single technological or environmental indicator. Standardizing fixed broadband subscriptions, renewable electricity generation, and GDP per capita growth allows variables measured in different units to be examined within a common analytical space while retaining their substantive distinctions. Distance-based classification can then identify groups of countries that share similar combinations of connectivity, renewable electricity penetration, and short-run economic dynamics without imposing a causal interpretation on the observed relationships. Such an approach is particularly appropriate for a small cross-sectional population such as ASEAN because it emphasizes transparent descriptive comparison and preserves the underlying country-level observations for subsequent research (Ghazinoory et al., 2020; OECD, 2024).

This study therefore develops a comparative technology–energy profile of ten ASEAN member states using fixed broadband subscriptions, renewable electricity generation as a share of total electricity generation, and annual GDP per capita growth. The study asks how ASEAN economies differ in the joint configuration of digital connectivity, renewable electricity penetration, and short-run economic performance based on internationally comparable indicators. Its contribution is to provide an empirically transparent typology that distinguishes connectivity-intensive, renewable-intensive, and comparatively constrained configurations while avoiding unsupported claims about causal relationships among the indicators. By mapping these configurations, the study establishes a descriptive baseline for future longitudinal research examining whether digital infrastructure, energy transition, and economic transformation subsequently reinforce, complement, or diverge from one another across ASEAN (Ding et al., 2022; Xu et al., 2024).

RESEARCH METHODS

This study employs a comparative quantitative design to examine the technology–energy configurations of ten ASEAN member states: Indonesia, Malaysia, Singapore, Thailand, Viet Nam, the Philippines, Cambodia, Laos, Myanmar, and Brunei Darussalam. The analysis uses three internationally comparable indicators representing distinct dimensions of national development: fixed broadband subscriptions per 100 inhabitants as a measure of digital connectivity, renewable electricity generation as a percentage of total electricity generation as a measure of energy-transition penetration, and annual GDP per capita growth as a contextual measure of short-run economic dynamics. The dataset uses the most recent observations available in the compiled international sources, with broadband observations referring to 2024 and renewable electricity and GDP per capita growth referring primarily to 2025, subject to the availability conventions of the respective datasets. Broadband data are obtained from International Telecommunication Union indicators distributed through the World Bank and related international statistical series, renewable electricity data are derived from Ember and other sources compiled by Our World in Data, and GDP per capita growth is based on World Bank and corresponding national statistical sources; because the indicators may have different observation dates and revisions, the reported values are treated as published observations rather than reconstructed estimates.

To identify country configurations, the three indicators are first standardized using z-scores, calculated as zij=(xij−x¯j)/sjz_{ij}=(x_{ij}-\bar{x}_{j})/s_j, where xijx_{ij} represents the observed value of country ii for indicator jj, x¯j\bar{x}_{j} represents the cross-country mean, and sjs_j represents the corresponding standard deviation. The resulting standardized matrix is evaluated through Euclidean-distance profiling against three analytically defined reference configurations representing relatively connectivity-intensive, renewable-intensive, and comparatively constrained technology–energy conditions. Each country is assigned to the reference profile with the minimum Euclidean distance, after which descriptive statistics are used to compare the mean characteristics of the resulting groups. The procedure is explicitly exploratory and descriptive rather than inferential; it does not estimate causal effects, predict economic outcomes, or interpret profile membership as a measure of national performance. All country-level observations are retained alongside the standardized values and profile assignments to ensure analytical transparency and enable replication or alternative classification using different normalization, distance, or indicator specifications.

RESULTS AND DISCUSSION

ASEAN Technology–Energy Profiles: Connectivity, Renewable Electricity, and Economic Growth

The empirical results reveal substantial heterogeneity across the ten ASEAN economies when fixed broadband subscriptions, renewable electricity generation, and GDP per capita growth are examined simultaneously. The broadband indicator ranges from only 2.7 subscriptions per 100 people in Laos to 27.8 in Singapore, indicating a wide difference in the availability of fixed connectivity infrastructure. This variation is consistent with the broader digital-economy literature, which emphasizes that connectivity infrastructure remains a fundamental condition for the diffusion of digital technologies and the reduction of information and transaction costs (Goldfarb & Tucker, 2019). The OECD likewise identifies connectivity availability, affordability, and quality as central foundations of digital transformation, although connectivity alone does not capture the full extent of digital adoption or capability (OECD, 2024).

The country-level distribution becomes more informative when broadband is considered together with renewable electricity. Singapore records the highest broadband density at 27.8 subscriptions per 100 people, followed by Viet Nam at 23.7 and Brunei Darussalam at 21.2, while Laos, Myanmar, and Cambodia remain substantially lower at 2.7, 2.9, and 4.1, respectively. The pattern demonstrates that fixed digital infrastructure and renewable electricity do not necessarily develop along the same trajectory because telecommunications investment and electricity-generation structures are governed by different technological, geographic, and institutional conditions. This distinction is important because digital technologies can support energy-system modernization while simultaneously possessing their own electricity requirements and environmental footprint (OECD, 2024).

Table 1. Country-level technology–energy indicators used in the profile analysis

Country	Fixed broadband 2024	Renewable electricity 2025 (%)	GDP per capita growth 2025 (%)	Profile
Indonesia	4.9	18.09	4.29	3
Malaysia	13.5	20.65	3.94	1
Singapore	27.8	5.49	3.75	1
Thailand	14.9	16.57	2.51	3
Viet Nam	23.7	45.42	7.37	1
Philippines	7.1	23.31	3.56	3
Cambodia	4.1	40.88	4.11	2
Laos	2.7	76.72	3.17	2
Myanmar	2.9	47.86	-2.64	3
Brunei	21.2	0.18	-0.11	3

Source: compiled dataset used in this study.

The renewable-electricity figures produce a markedly different regional configuration from the broadband results. Laos records the highest renewable electricity share at 76.72%, followed by Myanmar at 47.86%, Viet Nam at 45.42%, and Cambodia at 40.88%, whereas Brunei records only 0.18% and Singapore 5.49%. This dispersion reflects the importance of national electricity-generation structures and resource endowments, particularly the role of hydropower in several mainland Southeast Asian economies. The IEA identifies renewable expansion, grid modernization, regional interconnection, and investment as central components of Southeast Asia's evolving electricity system, while also emphasizing substantial differences in energy-system conditions across the region.

The contrast between Laos and Singapore is particularly useful for interpreting the multidimensional structure of the data. Laos combines the lowest fixed broadband value in the sample with the highest renewable electricity share, whereas Singapore exhibits the highest broadband value alongside one of the lowest renewable electricity shares. These two observations demonstrate that technological infrastructure cannot be represented adequately through a single modernization continuum because different infrastructure systems can produce substantially different national configurations. The result is also consistent with research examining the digital economy and renewable-energy relationship in Asia, which identifies regional heterogeneity rather than a uniform digitalization–renewable-energy pattern.

The GDP per capita growth indicator adds another dimension to this heterogeneity. Viet Nam records the highest value at 7.37%, followed by Indonesia at 4.29%, Cambodia at 4.11%, Malaysia at 3.94%, Singapore at 3.75%, and the Philippines at 3.56%, while Myanmar records -2.64% and Brunei -0.11%. These figures should not be interpreted as direct measures of technological performance because annual per-capita growth reflects numerous economic processes beyond infrastructure development. The distinction is particularly important when renewable electricity is high but economic growth is weak, as observed in Myanmar, demonstrating that renewable-energy penetration alone does not determine short-run economic outcomes.

Viet Nam presents a particularly distinctive combination because it simultaneously records relatively high fixed broadband penetration, a renewable electricity share of 45.42%, and the highest GDP per capita growth in the observed dataset. The configuration places the country above the regional mean on all three indicators and therefore represents a multidimensional rather than single-indicator

concentration of infrastructure and economic characteristics. The observation is compatible with literature suggesting that digitalization can interact with renewable-energy development through technological, financial, and institutional channels, although the present cross-sectional design cannot establish whether one dimension causes another (Jiang et al., 2023; Zhang & Zhou, 2023). Evidence from Asian countries also indicates that the relationship between digitalization and renewable electricity can vary according to development level and institutional conditions.

At the opposite end of the renewable-electricity dimension, Brunei combines relatively high fixed broadband penetration with only 0.18% renewable electricity generation. Singapore displays a similar directional configuration, although its renewable share is higher at 5.49%. These observations suggest that relatively mature digital connectivity can coexist with electricity systems in which renewable generation remains comparatively limited. Such a configuration is analytically important because it demonstrates that the expansion of digital infrastructure does not automatically imply a corresponding transformation of the electricity-generation mix, particularly where existing energy systems, resource structures, and investment patterns follow different trajectories (Sadorsky, 2012; ElMassah & Mohieldin, 2020).

The intermediate cases further reinforce the absence of a uniform ASEAN pattern. Malaysia records 13.5 broadband subscriptions and 20.65% renewable electricity, while Thailand records 14.9 and 16.57%, respectively; the Philippines combines 7.1 broadband subscriptions with 23.31% renewable electricity. These combinations indicate that countries with broadly intermediate levels of fixed connectivity can nevertheless occupy different positions in the renewable-electricity dimension. Such variation is consistent with the argument that green and digital transitions involve different infrastructure systems and investment requirements, even though digital technologies can increasingly contribute to the management and integration of renewable electricity (OECD, 2024).

The standardized profiling procedure makes these differences more visible than a simple comparison of individual indicators. Profile 1 contains Malaysia, Singapore, and Viet Nam and represents relatively stronger connectivity-oriented configurations, although Viet Nam differs substantially from the other two through its much higher renewable-electricity share. Profile 2 contains Cambodia and Laos, characterized by comparatively low fixed broadband penetration and high renewable-electricity shares, while Profile 3 includes Indonesia, Thailand, the Philippines, Myanmar, and Brunei, reflecting more heterogeneous combinations that do not fit the first two configurations as closely. Because these classifications are based on standardized multidimensional distances rather than a single score, membership should be interpreted as similarity in configuration rather than as an overall assessment of national technological development.

The findings demonstrate that ASEAN's technology–energy landscape is characterized by structural heterogeneity rather than synchronized movement across infrastructure dimensions. Broadband infrastructure, renewable electricity, and economic growth capture different aspects of national development and therefore produce combinations that cannot be reduced to a single linear hierarchy. This result corresponds with the broader literature on digitalization and sustainability, which recognizes both the potential of digital technologies to facilitate cleaner energy systems and the environmental costs associated with digital infrastructure itself (Goldfarb & Tucker, 2019; Sadorsky, 2012; Zhao & Wang, 2022).

From a technology and innovation perspective, the principal empirical contribution of this profile is therefore the identification of coexisting rather than convergent infrastructure trajectories. The results indicate that renewable-intensive development can occur without extensive fixed broadband infrastructure, while advanced connectivity can develop alongside a comparatively low renewable electricity share. This interpretation is also compatible with research on innovation and green transition, which emphasizes the importance of complementary technological, institutional, and economic capabilities rather than assuming that one technological domain automatically generates transformation in another (Fu et al., 2018; Ding et al., 2022; Jiang et al., 2023). The three-profile structure consequently provides a descriptive baseline for examining whether these configurations persist, converge, or change when longer time-series and additional indicators such as mobile connectivity, R&D, energy intensity, electricity carbon intensity, and digital skills are incorporated.

Economic Growth and the Interpretation of Technology–Energy Profiles

The inclusion of GDP per capita growth provides an important contextual dimension for interpreting the technology–energy profiles because infrastructure characteristics do not operate independently from broader economic dynamics. The 2025 observations show considerable variation, ranging from 7.37% growth in Viet Nam to −2.64% in Myanmar, indicating that economies with relatively high renewable-electricity shares can experience substantially different short-run economic outcomes. This pattern cautions against interpreting renewable-energy penetration or broadband availability as direct determinants of annual economic growth. Previous research similarly indicates that the relationships among technological innovation, energy consumption, renewable energy, trade, and economic growth are multidirectional and conditioned by national economic structures (Shahbaz et al., 2015; Pradhan et al., 2018).

The contrast becomes particularly visible when the growth indicator is examined alongside renewable electricity. Laos records the highest renewable electricity share in the sample at 76.72%, but its GDP per capita growth is 3.17%, whereas Viet Nam combines a renewable share of 45.42% with 7.37% growth. Myanmar provides another contrasting case, recording 47.86% renewable electricity but −2.64% GDP per capita growth. These observations indicate that a high share of renewable electricity does not by itself translate into high contemporaneous economic growth because growth depends on broader factors including capital accumulation, productivity, trade, industrial structure, demographic dynamics, and macroeconomic conditions (Bhattacharya et al., 2016; Bekun et al., 2019).

Table 2. Comparative Interpretation of Economic Growth Within ASEAN Technology–Energy Profiles

Country	Broadband 2024	Renewable electricity 2025 (%)	GDP per capita growth 2025 (%)	Descriptive interpretation
Viet Nam	23.7	45.42	7.37	High connectivity, high renewable share, high growth
Indonesia	4.9	18.09	4.29	Lower connectivity, moderate renewable share, moderate growth
Cambodia	4.1	40.88	4.11	Low connectivity, high renewable share, moderate growth
Malaysia	13.5	20.65	3.94	Moderate connectivity and renewable share, moderate growth
Singapore	27.8	5.49	3.75	Very high connectivity, low renewable share, moderate growth
Philippines	7.1	23.31	3.56	Lower connectivity, moderate renewable share, moderate growth
Laos	2.7	76.72	3.17	Very low connectivity, very high renewable share, moderate growth
Thailand	14.9	16.57	2.51	Moderate-high connectivity, lower renewable share, lower growth
Brunei	21.2	0.18	-0.11	High connectivity, very low renewable share, near-zero growth
Myanmar	2.9	47.86	-2.64	Very low connectivity, high renewable share, negative growth

Source: compiled dataset used in this study.

Viet Nam represents the most pronounced case in which the three dimensions are simultaneously elevated. Its fixed broadband density of 23.7 subscriptions per 100 people is substantially higher than Indonesia's 4.9 and the Philippines' 7.1, while its renewable electricity share reaches 45.42% and GDP per capita growth reaches 7.37%. The combination is consistent with a development configuration in which infrastructure expansion, industrial transformation, and energy investment occur concurrently. Nevertheless, the observed co-occurrence should not be interpreted as evidence that broadband development caused renewable deployment or that either directly generated the recorded growth rate, because the present research design contains neither temporal identification nor controls for confounding factors (Ding et al., 2022; Li et al., 2023).

Indonesia illustrates a different configuration in which relatively moderate economic growth coexists with substantial infrastructure gaps. Its GDP per capita growth of 4.29% is higher than that of Malaysia, Singapore, Thailand, the Philippines, Laos, Brunei, and Myanmar, while its fixed broadband density remains only 4.9 subscriptions per 100 people and its renewable electricity share is 18.09%. The case suggests that short-run economic expansion can continue even when particular enabling infrastructures remain less developed than those observed in more connected economies. From an innovation perspective, this distinction is important because economic growth and technological capability are related but conceptually different dimensions, with productivity improvements depending on complementary skills, organizational capabilities, institutions, and innovation systems rather than connectivity alone (Fu et al., 2018; Goldfarb & Tucker, 2019).

The Singapore case further demonstrates the importance of separating digital infrastructure from energy-transition outcomes. Singapore has the highest broadband density in the sample at 27.8 subscriptions per 100 people, yet its renewable electricity share is only 5.49%, while GDP per capita growth reaches 3.75%. The configuration indicates that a highly developed digital economy can coexist with a relatively limited domestic renewable-electricity share, reflecting the importance of geographical constraints, energy-system structure, and resource availability in determining renewable deployment. Digital transformation can contribute to efficiency and sustainability through data-driven optimization and intelligent infrastructure, but such technological capabilities do not eliminate the physical and geographic constraints governing electricity generation (ElMassah & Mohieldin, 2020; OECD, 2024).

Malaysia and Thailand provide additional evidence that intermediate levels of digital infrastructure do not correspond mechanically to similar economic or energy outcomes. Malaysia records 13.5 broadband subscriptions, 20.65% renewable electricity, and 3.94% GDP per capita growth, whereas Thailand records 14.9 broadband subscriptions, 16.57% renewable electricity, and 2.51% growth. Their broadly comparable broadband levels therefore coexist with different renewable-electricity shares and growth outcomes. The difference reinforces the argument that technological development is embedded within wider economic and institutional systems, while renewable deployment is additionally shaped by resource conditions, investment incentives, energy policy, and electricity-market structures (Rennings, 2000; Cheng et al., 2019).

The renewable-intensive cases provide an important counterpoint to a digital-centered interpretation of economic modernization. Cambodia and Laos combine relatively low fixed broadband penetration with renewable electricity shares of 40.88% and 76.72%, respectively, while recording GDP per capita growth of 4.11% and 3.17%. Their profiles demonstrate that substantial renewable-electricity penetration can emerge from energy-resource characteristics and electricity-generation investment without requiring correspondingly high levels of fixed telecommunications infrastructure. This distinction is relevant to the concept of eco-innovation because environmental or energy-system transformation can emerge through technological changes in physical production systems even when digital connectivity remains comparatively limited (Rennings, 2000; Bhattacharya et al., 2016).

The relationship between digitalization and electricity demand also complicates the interpretation of these profiles. Digital infrastructure can facilitate energy efficiency, smart-grid management, renewable forecasting, and optimization, but expanding digital services simultaneously requires electricity for networks, computing, and data-processing activities. Earlier evidence on emerging economies indicates that information and communication technologies can be associated with increased electricity consumption, illustrating why digital expansion should not automatically be treated as environmentally beneficial (Sadorsky, 2012). More recent research similarly emphasizes that the sustainability consequences of digitalization depend on whether efficiency improvements and

technological substitution are sufficient to offset additional resource and energy demand (Sun et al., 2021; Zhao & Wang, 2022).

The growth observations also indicate why the present study avoids constructing a normative composite index from the three variables. Brunei's combination of 21.2 broadband subscriptions, only 0.18% renewable electricity, and −0.11% GDP per capita growth cannot reasonably be interpreted as a general measure of technological or developmental failure because each indicator captures a different phenomenon. Similarly, Myanmar's −2.64% growth does not negate the significance of its 47.86% renewable-electricity share, just as Laos's 76.72% renewable share does not establish that renewable electricity caused its 3.17% growth rate. A multidimensional profile is therefore preferable to an aggregated score when the theoretical relationships among indicators remain heterogeneous and potentially nonlinear (Ghazinoory et al., 2020; Ding et al., 2022).

The results have implications for how technology and innovation policy is conceptualized in ASEAN. Digital infrastructure, renewable electricity, and economic growth should be treated as potentially complementary but analytically distinct dimensions, because countries can display very different combinations of these characteristics. Research on digitalization and green innovation suggests that technological transformation can contribute to environmental and productivity outcomes through innovation, organizational change, and improved resource allocation, but these mechanisms depend on institutional and economic conditions (Jiang et al., 2023; Li et al., 2023). The present findings therefore support a differentiated research perspective in which infrastructure complementarities are investigated empirically rather than assumed from the simultaneous presence of digital and renewable technologies.

Finally, the observed profiles provide a foundation for extending the analysis from descriptive comparison toward longitudinal and causal research. A panel covering multiple years could examine whether changes in broadband infrastructure precede changes in renewable investment, whether renewable deployment affects digital infrastructure through electricity availability and reliability, or whether both are jointly driven by income, investment, institutional quality, and industrial transformation. Such research could also incorporate energy efficiency, carbon-emission performance, technological innovation, and resource productivity, building on previous work examining the relationships among energy, innovation, environmental performance, and economic development (Alam et al., 2016; Cheng et al., 2019; Zhou et al., 2010). In this sense, the present cross-sectional analysis is most useful as an empirical mapping exercise that identifies divergent ASEAN configurations and establishes a basis for more rigorous panel, spatial, or causal models.

Implications for Digital–Energy Transition and Technology Policy in ASEAN

The preceding profiles demonstrate that digital infrastructure and renewable electricity should be interpreted as interconnected but institutionally distinct components of technological transformation. Fixed broadband provides a foundation for digital communication, data-intensive services, and digitally enabled production, whereas renewable electricity represents a transformation in the technological composition of power generation. Their simultaneous expansion may generate complementarities through smart-grid applications, digital monitoring, automation, and improved information flows, but the two systems are subject to different investment cycles and physical constraints (ElMassah & Mohieldin, 2020; UNCTAD, 2024). The ASEAN evidence therefore supports an analytical framework in which digitalization and energy transition are examined jointly without assuming that one automatically determines the trajectory of the other.

The broadband results also require careful interpretation because fixed subscriptions are only one component of national digital connectivity. A low level of fixed broadband does not necessarily indicate that a country's population has limited access to the internet, particularly in economies where mobile networks constitute an important access channel. International telecommunications statistics distinguish between fixed and mobile connectivity, and the ITU's indicators are designed to measure specific telecommunications infrastructure characteristics rather than aggregate digital participation (ITU, 2026). Consequently, the present findings should be understood as a comparison of fixed-access infrastructure, while broader assessments of digital inclusion would require mobile broadband, affordability, network quality, and digital-skills indicators.

The distinction is particularly relevant for countries such as Indonesia, Cambodia, Laos, and Myanmar, where fixed broadband values are relatively low compared with Singapore and Viet Nam. Their lower fixed-subscription figures should not automatically be translated into an absence of digital

transformation because users may rely on mobile connectivity and other forms of access. Nevertheless, fixed infrastructure remains relevant for high-capacity applications requiring stable and reliable connections, including cloud computing, advanced enterprise services, industrial digitalization, and data-intensive public infrastructure. The digital-economy literature consequently treats connectivity as an enabling infrastructure whose economic significance depends on complementary technologies, capabilities, and institutional arrangements rather than on subscriptions alone (Goldfarb & Tucker, 2019; Koutroumpis, 2019).

The renewable-electricity dimension presents an equally important interpretive issue because a high renewable share can arise from different combinations of technologies. Hydropower can generate a large renewable contribution in resource-rich countries, while solar, wind, geothermal, and bioenergy may contribute differently depending on geography, investment, and grid conditions. The indicator used in this study therefore captures the share of electricity generated from renewable sources rather than the total scale of renewable-energy capacity or the carbon intensity of the electricity system. This distinction is consistent with international energy analysis emphasizing that renewable deployment must be evaluated alongside electricity demand, grid integration, investment, and the changing composition of energy systems (IEA, 2024).

Table 3. Implications of ASEAN technology–energy configurations

Profile	Countries in dataset	Main empirical characteristic	Principal analytical implication
Profile 1	Malaysia, Singapore, Viet Nam	Relatively stronger fixed connectivity	Digital infrastructure can develop at different renewable intensities
Profile 2	Cambodia, Laos	High renewable electricity with low fixed broadband	Energy transition can be strongly resource- and infrastructure-driven
Profile 3	Indonesia, Thailand, Philippines, Myanmar, Brunei	Mixed or divergent combinations	No uniform relationship between connectivity, renewable electricity, and growth
Cross-profile case	Viet Nam	High broadband, high renewable share, highest growth	Illustrates simultaneous strength across the three observed dimensions
Cross-profile case	Laos	Lowest broadband, highest renewable share	Demonstrates divergence between digital and energy infrastructure
Cross-profile case	Singapore	Highest broadband, low renewable share	Demonstrates digital advancement without equivalent renewable penetration
Cross-profile case	Myanmar	Low broadband, high renewable share, negative growth	Shows that renewable penetration does not determine short-run growth

Source: author's calculation and interpretation based on Table 1.

The configurations also have implications for the concept of smart and sustainable infrastructure. Earlier research on smart cities emphasizes the role of information and communication technologies in improving infrastructure management, public services, and resource efficiency, but these benefits depend on the institutional and physical systems within which digital technologies are deployed (Caragliu et al., 2011). In the ASEAN context, renewable electricity could provide a lower-carbon energy base for expanding digital infrastructure, while digital systems could improve the monitoring and management of increasingly complex electricity networks. The potential complementarity therefore exists at the infrastructure-system level, even though the country-level indicators in this study do not establish whether such complementarities are already operating effectively.

The findings further suggest that technology policy should account for different starting configurations rather than applying an identical infrastructure pathway across ASEAN economies.

Countries with relatively low fixed connectivity and high renewable electricity, such as Laos and Cambodia, face a different combination of infrastructure conditions from highly connected economies such as Singapore. Economies with relatively moderate values across the indicators, including Indonesia, Thailand, and the Philippines, occupy yet another configuration in which improvements could occur simultaneously across multiple infrastructure dimensions. This differentiated perspective is consistent with the innovation-systems literature, which emphasizes that technological development depends on interactions among infrastructure, institutions, firms, knowledge, investment, and policy rather than on isolated technological inputs (Fu et al., 2018; Rennings, 2000).

A further implication concerns the relationship between digitalization and environmental sustainability. Digital technologies may facilitate energy efficiency and renewable integration through automated systems, forecasting, remote monitoring, and data-driven optimization, but the expansion of digital infrastructure also creates additional demand for electricity and physical equipment. Consequently, digitalization should not be treated as inherently sustainable without examining its net environmental effects. Research on information and communication technologies, digitalization, and energy efficiency similarly identifies this tension between potential efficiency improvements and additional energy requirements (Sadorsky, 2012; Sun et al., 2021; Zhao & Wang, 2022).

The descriptive profiles also point toward the importance of measuring digital infrastructure beyond simple access indicators. Future research could combine fixed broadband subscriptions with mobile broadband penetration, internet usage, affordability, network speed, cloud adoption, data-center capacity, and digital skills. These dimensions would provide a more comprehensive representation of digital readiness and would reduce the possibility that fixed broadband alone underrepresents digital activity in mobile-oriented economies. The broader digital-economy literature and international development assessments increasingly emphasize that connectivity must be accompanied by skills, productive capabilities, institutional frameworks, and inclusive access if digital technologies are to generate wider development effects (UNCTAD, 2024; OECD, 2024).

The same principle applies to renewable electricity measurement. Renewable generation share provides useful information about the composition of electricity supply, but it does not indicate the absolute amount of renewable capacity, investment intensity, electricity-system reliability, storage capacity, or carbon emissions per unit of electricity. A country may therefore record a high renewable share while still facing grid constraints or limited capacity to support rapidly expanding electricity demand. Incorporating additional measures such as renewable capacity per capita, electricity carbon intensity, energy intensity, storage deployment, and investment flows would allow future studies to distinguish between the quantity of renewable generation and the broader quality and resilience of energy transition (Cheng et al., 2019; IEA, 2024).

The economic dimension should likewise be expanded beyond annual GDP per capita growth when the objective is to evaluate technological transformation. The present growth indicator is useful for contextualizing the profiles, but a single-year observation is sensitive to temporary economic fluctuations and cannot capture structural productivity changes. Future studies could incorporate labor productivity, total factor productivity, GDP per unit of energy consumption, green total factor productivity, R&D expenditure, patent activity, and technology-oriented investment. Such measures would be more directly connected to innovation performance and would build upon research linking digital economy development, technological innovation, and green total factor productivity (Ding et al., 2022; Pradhan et al., 2018).

Another important implication concerns the spatial and regional dimension of ASEAN development. Digital networks, electricity markets, supply chains, and investment flows increasingly cross national boundaries, meaning that national indicators may not fully capture regional interdependence. Renewable electricity generated in one location can potentially interact with regional electricity connectivity, while digital platforms and telecommunications systems can facilitate cross-border production and service integration. Future research could therefore extend the current descriptive framework using panel data and spatial or network methods to investigate whether infrastructure development in one ASEAN economy is associated with changes in neighboring economies (Li et al., 2023; Xu et al., 2024).

Overall, the results indicate that ASEAN's digital and renewable transitions should be understood as a set of differentiated infrastructure trajectories rather than as a single technological transformation. The empirical profiles demonstrate that high renewable penetration can coexist with limited fixed

broadband, while high connectivity can coexist with relatively low renewable electricity, and neither configuration guarantees a particular short-run economic growth outcome. This interpretation is consistent with evidence that technological innovation, energy transition, economic growth, and environmental performance interact through multiple mechanisms that cannot be adequately represented by a single indicator (Alam et al., 2016; Bekun et al., 2019; Raihan et al., 2022). The study therefore contributes a transparent descriptive baseline from which future research can examine the mechanisms linking digital infrastructure, renewable energy, innovation, and economic transformation over longer periods.

The policy relevance of these findings lies not in establishing a universal development sequence but in identifying the infrastructure combinations that characterize different ASEAN economies. Countries with strong renewable electricity but weak fixed connectivity may require different infrastructure priorities from economies with advanced digital networks but limited renewable generation, while economies displaying intermediate configurations may pursue coordinated investments across both systems. Such differentiation is compatible with the broader understanding of eco-innovation and sustainable technological change, where technological opportunities must be matched with institutional capacity, investment conditions, resource endowments, and system-level coordination (Rennings, 2000; Ghazinoory et al., 2020). Future longitudinal research can consequently test whether these configurations represent persistent structural characteristics or temporary stages in a broader process of digital and energy transition.

The final analytical implication is that the present profiling framework should be viewed as a starting point rather than a substitute for causal analysis. The three indicators successfully reveal substantial heterogeneity, but they cannot determine whether broadband expansion contributes to renewable deployment, whether renewable electricity facilitates digital infrastructure, or whether both are jointly associated with broader economic transformation. Establishing such mechanisms would require longer time periods, theoretically justified control variables, robustness tests, and appropriate econometric identification, potentially including panel, spatial, threshold, or dynamic models. The descriptive evidence nonetheless provides a useful empirical foundation for that next stage by showing precisely why a uniform assumption about the relationship between digital infrastructure, renewable electricity, and economic growth would be insufficient for understanding ASEAN's technology–energy transition.

CONCLUSION

The study demonstrates substantial heterogeneity in the technology–energy configurations of ten ASEAN economies based on fixed broadband subscriptions, renewable electricity generation, and GDP per capita growth. The standardized-distance profiling identifies three empirical configurations that illustrate different combinations of digital connectivity, renewable electricity penetration, and short-run economic dynamics. Viet Nam exhibits a comparatively integrated configuration, combining relatively high fixed broadband penetration, substantial renewable electricity generation, and the highest GDP per capita growth in the observed dataset, while Laos demonstrates the strongest renewable orientation alongside very limited fixed broadband infrastructure. Singapore and Brunei, in contrast, illustrate configurations in which relatively high fixed connectivity coexists with comparatively low renewable electricity penetration. These findings demonstrate that digital infrastructure and renewable electricity represent related but non-equivalent dimensions of technological transformation and should not be interpreted through a single linear development trajectory.

The study's principal contribution is methodological and empirical: it provides a transparent profile-based framework for comparing heterogeneous technology–energy configurations without imposing unsupported causal interpretations. The findings indicate that renewable electricity penetration cannot be assumed to result directly from digital connectivity, while short-run economic growth cannot be attributed to either infrastructure dimension based on the cross-sectional evidence. Future research should extend the dataset into a longitudinal panel incorporating mobile connectivity, renewable capacity, electricity carbon intensity, energy efficiency, R&D expenditure, digital skills, energy prices, institutional quality, and productivity indicators. Panel, spatial, and threshold approaches could subsequently test whether digital infrastructure and renewable-energy development reinforce one another, operate independently, or interact through specific economic and institutional mechanisms across ASEAN.

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