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Navigating Sustainable Development in Southeast Asia: The Interplay of Digital Technology, Trade Openness, and Institutional Quality

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Abstract

The objectives of United Nations Sustainable Development Goals (SDGs) underscore the significance of leveraging innovation and technology to tackle urgent global issues, including poverty, inequality, climate change, and sustainable economy. Southeast Asian Nations (ASEAN) exhibits notable GDP and digital economy advancements, although they also face considerable pollution. However, relatively few research has investigated ASEAN's sustainability. This paper is to examine the effects of digital technology (DT) and digital service trade (DST) on ASEAN's sustainable development, considering the moderating role of institutional quality (IQ). This study employs panel data from 10 ASEAN countries spanning 2005–2019 and utilizes feasible generalized least squares (FGLS) analysis and Panel generalized estimating equations (PGEE) analysis to evaluate the moderating influence of institutional quality on digital technology and digital service trade in influencing ASEAN's sustainable development. This study used population size and industrial value added as control variables. Empirical data showed the essential role of institutional quality in affecting sustainability. The findings demonstrate that digitalization alone is insufficient to achieve sustainability. Digital service trade can jeopardize sustainability unless it is tempered by strong intelligence, which reduces risks associated with cross-border data flows and digital inequality. The study indicates that institutional development is required before utilizing digital technologies and digital service trade for environmental and social advancement. Institutional quality and focused policy alignment are critical for transforming digital innovation and trade into equitable and long-term growth throughout ASEAN.

Keywords: *Institutional Quality; Digital Technology; Digital Service Trade; Sustainable Development; ASEAN.*

1. INTRODUCTION

South-East Asia holds a significant position in the global arena due to its economic, environmental, and social characteristics. The examination of sustainable development in the region is essential, since it encompasses an intricate interaction among swift economic expansion, environmental conservation, and social fairness (Feng et al., 2024). The transformative capacity of DT and digital service trade (DST) to advance sustainable development is garnering heightened worldwide focus, especially within the context of the United Nations SDGs. The objectives of SDGs underscore the significance of leveraging innovation and technology to tackle urgent global issues, including poverty, inequality, climate change, and sustainable economic development (Kwilinski et al., 2023; Romao et al., 2024). The region's extraordinary economic development in recent decades has elevated millions from

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poverty; yet, it has also presented substantial concerns, such as environmental degradation, resource depletion, and increasing social inequities.

From an economic perspective, Southeast Asia's contribution to the global economy underscores its importance in sustainable development. The Association of Southeast Asian Nations (ASEAN) is the fifth largest economy in the world. According to the Asian Development Bank, ASEAN accounted for 7.1 per cent of global GDP in 2023 and 8.5 per cent of global GDP growth over the past decade (WE, 2025). This trend demonstrates the region's economic resilience and growth potential. Meanwhile, ASEAN’s digital economy will continue to grow rapidly in 2024, with gross merchandise volume expected to reach US$263 billion, a 15 per cent year-on-year increase, underscoring the strong momentum of ASEAN's digital economy industry and the region's importance in the global digital economy landscape (Hoppe, Baijal, et al., 2024). However, sustaining this growth requires a balanced approach to environmental and economic challenges.

From an environmental perspective, ASEAN is highly vulnerable to climate change, with rising sea levels, extreme weather events and deforestation posing serious threats to livelihoods and ecosystems. The region accounts for about 5.3% of global carbon dioxide emissions in 2022, largely due to deforestation, peatland degradation and energy consumption (Chen et al., 2024; Statista, 2023). ASEAN has experienced a significant decline in forest cover, shedding approximately 15% from 1990-2019 (Turner & Snaddon, 2023). This demonstrates the urgent need for conservation and incorporation of biodiversity conservation into comprehensive policy frameworks (Z. Wang et al., 2024).

On the social front, the region has made significant progress in improving education, healthcare and financial inclusion through digital transformation. For example, more than 70 per cent of ASEAN 's population now has access to the internet, with mobile broadband penetration reaching 132% by 2022 (Shanahan & Bahia, 2023). Digital financial services such as e-wallets and mobile banking have provided financial inclusion to previously unbanked populations (Zhang, 2024). By 2022, nearly 400 million people in ASEAN used digital payment platforms (Hoppe, Chang, et al., 2024). These advances demonstrate the potential of DT to bridge social divides and promote equitable development.

The incorporation of DT is essential avenues for sustainable growth (Dodgson et al., 2018). The effectiveness of these pathways in achieving SDGs is contingent upon the quality of the governing institutional framework (Sun et al., 2025). Technological change spurring disruptive innovation can create whole new production functions in economic activity, significantly enhancing economic and social well-being (Liu et al., 2024). The DT of ASEAN is seeing rapid expansion, driven by enhanced internet accessibility, technological innovations, and a growing acceptance of digital services. However, relatively few research has investigated DT and sustainability in ASEAN. Ha and Chuah (2023) analyzed the effects of digital transformation on the economy and ecology of ASEAN, advocating for the establishment of more sustainable technical infrastructure to facilitate the SDGs. This paper expands upon this suggestion, to examine the penetration of DT on sustainable development.

According to the report of Google, Temasek, and Bain & Company, the DST of ASEAN would attain US$1 trillion by 2030, which highlights its significant contribution to economic development (Hoppe, Chang, et al., 2024). The swift expansion of e-commerce highlights the transformative influence on economic activity, environmental protection, and social welfare (Behera et al., 2024; Rakotondrazaka & Xu, 2024; Romao et al., 2024). Singapore distinguishes

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itself as a digital powerhouse due to its sophisticated infrastructure and robust policy environment that fosters innovation (USA.gov, 2024). Likewise, Malaysia's Blueprint seeks to enhance the nation's competitiveness (EPU, 2021). Vietnam has established itself as a leader in the digital startup ecosystem, but Indonesia's extensive market has significant prospects for digital commerce (Dewi & Lusikooy, 2024). Nevertheless, disparities persisted, as nations like Myanmar and Laos encountered obstacles in digital inclusion attributable to inadequate infrastructure and policy backing.

While the potential of DT and DST in advancing sustainable development is widely discussed, the role of IQ in shaping these outcomes remains underexplored. Numerous studies have shown that IQ significantly enhances environmental quality in industrialized countries, such as the European Union (Aydin et al., 2024) and the United States (Khan et al., 2021). Meanwhile, there have been many research on developing regions (Rehman et al., 2023; Zheng et al., 2024). However, a comprehensive analysis of how IQ moderates the relationship between DT, DST, and sustainable development in ASEAN is lacking. This gap underscores the need for research that examines these interlinkages within the region's unique socio-economic and institutional contexts.

In addition to the literature gap, this study will address two more literature gaps. The influence of DT on sustainable development might be favorable, ambiguous, or detrimental. Certain researches indicate the beneficial impacts of DT on enhancing environmental quality, fostering social well-being, and stimulating economic development (Xiuxiang Li et al., 2024; C. Wang et al., 2024). Nonetheless, several research indicate that the influence of digital transformation on sustainable development is ambiguous or constrained (Che et al., 2024; Zhu et al., 2024). In addition, prior research has examined the influence of DT on sustainable development, it has done so from a singular standpoint, without integration (Ahmad et al., 2024; Chidambaram et al., 2024; Szalkowski & Johansen, 2024). Limited research has examined the fundamental proposition of the influence of DT on sustainable development of ASEAN comprehensively from environmental, economic, and social viewpoints.

On the other hand, most studies concentrate on the contributing variables, policy limitations and one-sided sustainable effects of DST (Jiang & Jia, 2022; Rakotondrazaka & Xu, 2024; Shah & Shah, 2024; Zhang & Wang, 2022). However, such one-sided studies may hinder the optimization of the benefits derived from DST. The outcomes of DST on sustainable development are conflicting; some findings indicate that DST positively enhances sustainable development, while others present opposite perspectives (Y. Li et al., 2024; Y. Wang et al., 2024). Consequently, this study will examine the influence of DST on sustainable development in ASEAN.

This study aims to address these gaps by investigating the following research questions:

1) Does digital technologies influence ASEAN's achievement of sustainable development?
2) What is the impact of digital service trade to sustainable development of ASEAN?
3) May institutional quality enhance the advancement of digital technologies to facilitate ASEAN's attainment of sustainable development?
4) What is the impact of institutional quality in augmenting the impact of digital service trade on sustainable development?

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This study aims to furnish policymakers, stakeholders, and scholars with actionable insights to leverage digitization for sustainable development in ASEAN by addressing these topics. The text varies in the following aspects: Initially, it concentrates on ASEAN. ASEAN exhibits notable GDP and digital economy advancements, although they also face considerable pollution and environmental challenges (Turner & Snaddon, 2023). However, relatively few research has investigated ASEAN's sustainability. In addition, this article selects a more comprehensive indicator as the dependent variable: the sustainable development index (Hickel, 2020). This index incorporates environmental, economic, and social sustainability, in contrast to earlier indices like CO2 emissions and deforestation rates (Chen et al., 2024; Xiuxiang Li et al., 2024). A comprehensive indicator measurement facilitates ASEAN in identifying the strengths and weaknesses of their SDGs, so enabling targeted development efforts. Second, this article examines the influence of DT on sustainability of ASEAN, considering the moderating role of IQ. The digital economy is regarded as a crucial mechanism for attaining the SDGs (Dodgson et al., 2018). Nevertheless, little attention has been devoted to the influence of DT on sustainable development of ASEAN, and this study will examine this issue. Third, this article examines the influence of IQ in augmenting the impact of DST on sustainable development of ASEAN. The outcomes of DST on sustainable development are conflicting (Y. Li et al., 2024; Y. Wang et al., 2024). Consequently, this study will examine the influence of DST on sustainable development in ASEAN. This study employed the feasible generalized least squares (FGLS) analysis and Panel generalized estimating equations (PGEE) analysis to evaluate the moderating influence of IQ on DT and DST in influencing ASEAN's long-term development. This study utilized population size and industrial value added as control variables to enhance precision, considering the demographic considerations and the importance of industrialization.

The subsequent sections of this work are organized as follows. Section 2 encompasses the literature review and identifies shortcomings. Section 3 delineates the materials and methodologies employed to achieve the study's objectives. Section 4 presents additional analysis and testing outcomes. Section 5 encapsulates the conclusions and recommendations derived from the research findings.

2. LITERATURE REVIEW

The effects of DT and digital services trade on advancing sustainable development has garnered significant scholarly interest in recent years. With the SDGs serving as the global framework for tackling urgent economic, social, and environmental issues, it is essential to comprehend the mechanisms by which these elements facilitate sustainable development. IQ, as a moderating variable, has become a crucial determinant in the effective realization of the promised benefits of digitalization. This section examines the current literature on DT, trade in digital services, and IQ within the framework of sustainable development, emphasizing Malaysia and other Southeast Asian nations.

2.1 Sustainable Development

Sustainable development (SD) is frequently characterized by Elkington's triple bottom line, which emphasizes the integration of the three essential dimensions: economics, environment, and society (Jeurissen, 2000). SD must be economically feasible, ecologically sound, and socially acceptable (Yang & Shahbaz, 2024). Assessing SD is a challenging endeavor. The selection of suitable factors for its measurement has been globally embraced (Yang & Shahbaz, 2024). Nonetheless, the methodology of choosing suitable factors to assess

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SD has been extensively implemented globally. These variables are referred regarded as 'indicators' (Shamsheer & Ismet, 2018). Numerous studies have opted to substitute SD with a singular economic, social or environmental metric (Han et al., 2024; Kwilinski et al., 2023; Q. Wang et al., 2024; Zhang, 2024). The selection of these factors is biassed. For instance. Romao et al. (2024) delineated the economic sustainable development index as encompassing Goal 1 (Eradicate Poverty), Goal 2 (Zero Hunger), Goal 8 (Decent Work and Economic Growth), and Goal 9 (Industry, Innovation, and Infrastructure).

This study selects the sustainable development index, assessed by Hickel (2020), which comprises a composite evaluation of economic, social, and environmental factors. This composite index can assess the intricate linkages among long-term sustainability variables. The computation of the SD is predicated on life expectancy, education, income, and consumption for human development in each nation, while considering the extent of ecological overshoot, carbon dioxide emissions, and physical footprint.

2.2 Digital Technology

Although the phrase 'digital technology' (DT) is prevalent, researchers have not reached a consensus on a definitive meaning. Selwyn et al. (2016) contends that DT includes technology related to digital devices such as tablets, smartphones, laptops, and social media platforms. Furthermore, accessing the internet from any location using a portable device might be regarded as an extension of employing DT (C. Wang et al., 2024).

This paper synthesizes the research findings of Sun and Wu (2023) and other scholars, incorporates the availability of pertinent data from Southeast Asian nations, and delivers a thorough assessment of the digital economy based on utilizes mobile cellular subscriptions rate. The United Nations and the International Telecommunication Union consistently compute and disseminate many DT indicators, including the Information and communications technology (ICT) Development Index, the e-Government Development Index, the e-Participation Index, and the Telecommunications Infrastructure Index (Akbari & Masiero, 2025). Sun and Wu (2023) chose the overall telecommunications sector, the quantity of Internet broadband access users, the count of mobile phone users, the workforce in the information transmission, computer services, and software industry, as well as the digital financial inclusion index for his analysis of the influence of DT on the environment. In Liu et al. (2024) study, DT was assessed utilizing a robot-mounted density measurement. This article utilizes mobile cellular subscriptions rate as the index, considering data availability. A mobile cellular telephone subscriber utilizes cellular technology to access public mobile telecommunication services (ITU, 2024). The total number of fixed telephone customers comprises the effective count of analogue fixed telephone lines, Voice over Internet Protocol subscribers, fixed wireless local loop subscribers, ISDN voice channel equivalents, and fixed public payphones (ITU, 2025).

2.3 Digital Service Trade

The definition of DST) is developing and encompasses all operations that enable information processing and communication (Zhang et al., 2024). DST encompasses the digitization of information, services, and products, facilitating the flow of information and technology across geographically dispersed firms on digital platforms and the establishment of virtual industry clusters (Y. Li et al., 2024).

Zhang et al. (2024) undertook a comprehensive analysis of DST, examining several dimensions including trade patterns, trade connections, and involved nations. The study's results indicate that the nation at the core of DST is progressively asserting dominance in the

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trade relationship. Sinha Roy et al. (2024) selected services export and import performance to quantify international trade flows. Prior research has examined gross national product, industrial output, and global demand for actual service imports (Sinha Roy et al., 2024).

However, there is widespread agreement among international bodies in the second version of Handbook on measuring DST that DST encompasses any international trade in which orders are placed digitally, delivered digitally or serviced digitally (Romao et al., 2024; World Trade et al., 2023). The DST engages in commerce involving six categories: telecommunications, computer and information services, financial services, insurance and pension services, intellectual property royalties, other commercial services, and personal, cultural, and recreational services (Sturgeon et al., 2015). These multinational organizations comprise the IMF, the OECD, the United Nations Conference on Trade and Development, and the World Trade Organization.

2.4 Digital Technology and Sustainable Development

DT is seen as a transformative force that may stimulate economic growth, improve social inclusion, and mitigate environmental deterioration. DT facilitate effective resource utilization, encourage renewable energy use, and assist sustainable urbanization within the framework of sustainable development (Dodgson et al., 2018). DT has a substantial and double-edged effect on environmental emissions. DT can exert substantial effects on environmental emissions (Ahmad et al., 2024; Kwilinski et al., 2023). Nonetheless, Addimulam (2024) discovered that digitalization exacerbates environmental risks. Wang et al. (2021) investigated the relationship between DT and green development, discussing the challenges and opportunities involved and highlighted the emission reduction impact of technical spillovers and the emission increase impact of DT, asserting that the influence of DT development on environmental enhancement in a country must be assessed based on its specific circumstances. Zhang and Liu (2022) have argued that the development of the digital economy may increase the carbon effect.

From the perspectives of social sustainability, the societal implications of DT are quite under-researched (Szalkowski & Johansen, 2024). Chidambaram et al. (2024) discovered that the influence of DT on social health is inherent in the design of artificial intelligence systems, mobile applications, telemedicine, digital health literacy, and other technological forms. There is a direct relationship between fintech and social sustainability (Hiew et al., 2024). The research of Bag et al. (2024) indicates that companies utilizing big data and predictive analytics are more inclined to disseminate information concerning the circular economy to stakeholders, hence enhancing trust and participation and fostering the social sustainability of the supply chain. It is evident that both DT and social sustainability currently adhere to a defined trajectory.

There has been literature related to DT and economic development. Uddin (2024) pointed out that the digital economy included communications technology, digital media and content as well as knowledge and tools. Affecting a broad spectrum of sectors, including banking, insurance, trade, agriculture, health, tourism and education, digital revolution is influencing economic growth. The studies conducted by Elfaki and Ahmed (2024) indicated that the implementation of DT had enhanced economic growth in Asia-Pacific nations. In Southeast Asia, the introduction of DT has been crucial in tackling developmental difficulties. Mobile technologies and Internet of Things applications have been utilized to enhance agricultural productivity and resource management in rural regions (ADB, 2022). Currently, few experts are concentrating on DT and sustainable development in ASEAN. Ha and Chuah (2023)

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analyzed the effects of digital transformation on the economy and ecology of ASEAN, advocating for the establishment of more sustainable technical infrastructure to facilitate the SDGs.

2.5 Digital Service Trade and Sustainable Development

DST is the exchange of services facilitated by digital platforms and technologies. This encompasses areas like information and communication technology services, digital financial services, and e-commerce (Sturgeon et al., 2015). The DST has expanded significantly in recent years, propelled by technological improvements and the rising digitization of global commerce (Qiu & Yu, 2023). DST is recognized as a vital catalyst for economic growth and innovation, especially in emerging nations (Qiu & Yu, 2023). Recent research indicated that DST facilitated efficiency improvements, lowered transaction costs, and broadened market access for enterprises. Digital platforms enable small and medium-sized firms to engage in international trade, thus democratizing economic opportunities (Xiaoli Li et al., 2024).

The relationship between DST and environmental sustainability has received heightened scrutiny in recent years. The swift expansion of digital services has led to an increase in electronic waste (Ramasamy et al., 2024). Romao et al. (2024) identified a statistically significant positive association between the progress of SDG goals and the expansion of DST, especially in the social and environmental sectors. (Han et al., 2024) contended that DST exhibits a good correlation with environmental sustainability. Xiuxiang Li et al. (2024) discovered that digital trade exerts a substantial low-carbon effect in 46 nations; however, its influence differs among countries with varying levels of development. The relationship between DST and environmental sustainability has received heightened scrutiny in recent years, regardless of its good or bad impacts. DST has created new opportunities for social sustainability. Yeerken and Deng (2023) discovered the variability in the effects of DST on income distribution, attributable to divergent policies regarding trade barriers in digital services among nations. Rakotondrazaka and Xu (2024) observed that the proliferation of digital delivery services may result in a decline in formal employment, while applying downward pressure on agricultural employment. Shah and Shah (2024) has determined that trust is essential for a sustainable digital economy. These findings underscore the dynamic interplay between DST, sector-specific labor markets, and public trust. Contemporary research is deficient in examining additional facets of social sustainability, especially in ASEAN. There is little scholarly consensus on the influence of DST on sustainable development in Southeast Asia.

2.6 Moderating Role of Institutional Quality

Institutional quality is the efficacy and efficiency of a nation's institutions, such as its legal system, governance structure, regulatory framework, and the rule of law (Kaufmann & Kraay, 2002). IQ combines political, economic, and social interaction to establish a competitive and sustainable economy (North, 1991).

Scholars believe that efficient institutions and effective governance are essential for attaining development objectives (Entezari et al., 2023; Sun et al., 2025). Governments can establish effective frameworks to safeguard property rights while formulating and implementing ecologically friendly development policies. Zheng et al. (2024) found that superior IQ markedly decreases emissions, a phenomenon particularly evident in nations with robust institutions. Oussama and Abdellah (2024) acknowledged the beneficial effect of enhanced IQ on economic growth, emphasizing the significance of a transparent regulatory

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system. Ntow-Gyamfi et al. (2020) re-conceptualize the EKC as the economic market Environmental Kuznets Curve, which explains the relationship between economic development and sustainability by incorporating IQ as a moderator. The direct and moderating effects of IQ on environmental sustainability were analyzed (Kwakwa, 2023). Behera et al. (2024) observed that the utilization of ICT significantly enhances economic growth in 13 emerging economies; yet, there is an absence of synergy between ICT and IQ. Consequently, there is an absence of empirical evidence and theoretical frameworks to clarify the moderating influence of IQ on the relationship between DT, DST, and sustainable development in ASEAN.

2.7 Control variables

In recent years, academics have focused on the relationship between industrialization, population increase, and sustainable development, particularly in terms of environmental degradation, resource efficiency, and the green policy transition. Growing worries about climate change and environmental sustainability have led experts to reconsider classic development theories, particularly in emerging economies.

Several studies have emphasized the dual nature of industrialization. On the one hand, industrialization promotes economic growth and structural transformation; on the other, it degrades the environment by increasing emissions and resource extraction. Onwe et al. (2024) investigated the relationships between technical innovation, energy efficiency, and urbanization in key industrial economies. Their findings indicate that innovation and investment in clean energy can greatly mitigate the negative environmental repercussions of industrial activity, paving the path for green industrialization (Opoku & Yan, 2019). Despite advancements in renewable technologies, many industrialized countries continue to rely largely on fossil fuels to meet the energy demands of rapid industrialization (Onwe et al., 2024).

At the same time, demographic considerations complicate sustainability equation. Population expansion and urbanization increase the demand for resources like energy, water, and housing (Shakir Hanna, 2025). These demographic changes create both possibilities and risks (Ntom Udemba et al., 2024). In conclusion, the literature demonstrates a growing consensus that sustainable development necessitates a careful balance between industrial expansion and environmental preservation, with demographic dynamics serving as an important controller.

2.8 Gap in the Literature

This paper finds three inadequacies in literature based on the reviews. Initially, the influence of DT on sustainable development might be favorable, ambiguous, or detrimental. Certain researches indicate the beneficial impacts of DT on enhancing environmental quality, fostering social well-being, and stimulating economic development (Xiuxiang Li et al., 2024; C. Wang et al., 2024). Nonetheless, several research indicate that the influence of digital transformation on sustainable development is ambiguous or constrained (Che et al., 2024; Zhu et al., 2024). In addition, prior research has examined the influence of DT on sustainable development from a singular standpoint, without integration. Research has examined the effects of DT on the environment emissions (Ahmad et al., 2024; Kwilinski et al., 2023; Zhang & Liu, 2022). The relationship between DT and social development has been analyzed by Hiew et al. (2024) and Chidambaram et al. (2024). However, the societal implications of DT are quite under-researched (Szalkowski & Johansen, 2024). Elfaki and Ahmed (2024) indicated that the implementation of DT had enhanced. Consequently, limited research has examined the fundamental proposition of the influence of DT on sustainable development of ASEAN

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comprehensively from environmental, economic, and social viewpoints. Secondly, limited research has investigated the correlation between DST and sustainable development. On the one hand, the outcomes of DST on sustainable development are conflicting (Y. Li et al., 2024; Y. Wang et al., 2024). There have been lots of researches on the effects of DST on environment, societies and economy (Behera et al., 2024; Rakotondrazaka & Xu, 2024; Romao et al., 2024). However, such one-sided studies may have limits on the impact of DST on sustainable development, hence hindering the optimization of the benefits derived from digital services trade. On the other hand, most studies concentrate on the contributing variables, policy limitations of DST (Jiang & Jia, 2022; Shah & Shah, 2024; Zhang & Wang, 2022). Rare attention has been devoted to the influence of DT on sustainable development. Moreover, numerous research has examined the influence of IQ on the economy, environment, and other factors (Behera et al., 2024; Entezari et al., 2023; Sun et al., 2025). The direct and moderating effects of IQ were analyzed by Kwakwa (2023). Nonetheless, no research examines the influence of IQ as a moderating factor in the relationship between DT, DST, and sustainable development.

3. DATA DESIGN AND MODEL SPECIFICATIONS

The research utilizes quantitative and secondary data which are collected from published sources. Ten nations of ASEAN economy are all included in this paper, including Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam. Table 1 provides a complete description of research variables, including sustainable development index (SDI), mobile cellular subscriptions rate (DT), digital service trade openness (DST), and institutional quality indicator (IQ). Controlling variables are population (POP) and industrial value added (INV). Data availability for this research determines the period spanning from 2005 to 2020. The present study employs annual data from SDI, United Nations Trade and Development (UNCTAD) and World Bank (WDI) database. The sources are listed in Table 1.

Table 1: Variables Description

Variable	Abbr.	Description (Unit)	Source
Sustainable development index	SDI	SDI evaluates nation's human life expectancy, education, and income as the numerator, dividing it by its consumption-based carbon dioxide emissions and material footprint above the planetary threshold for equitable distribution. (score)	SDI database- https://www.sustainabledevelopmentindex.org/
Mobile cellular subscriptions	DT	Mobile cellular subscribers per 100 people denote the total count of individuals utilizing cellular technology to access public mobile telephone services, encompassing both post-paid subscribers and active pre-paid accounts. (%)	WTO database- https://data.worldbank.org/indicator/IT.CEL.SETS.P2
Digital service trade openness	DST	DST denote that international trade openness in ICT Services and ICT enabled Services. (%)	UNCTAD database- https://unctadstat.unctad.org/datacentre/
Institutional quality index	IQ	IQ is a composite governance metric that assesses Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. (score)	WTO database- https://databank.worldbank.org/reports.aspx?source=worldwide-governance-indicators

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Population	POP	Population indicators enumerate all residents in each region, irrespective of legal status or citizenship. (Numbers of people)	WTO database- https://data.worldbank.org.cn/indicator/SP.POP.TOTL
Industrial value added	INV	Industrial value added is the net production of a nation's industries, calculated by aggregating their outputs and deducting intermediate inputs, which encompass mining, manufacturing, construction, power, water, and gas. (% of GDP)	WTO database- https://data.worldbank.org/indicator/NV.IND.TOTL.ZS

Source: author calculation

As for the dependent variable, the sustainable development index can be served as a comprehensive indicator for evaluating the ecological efficiency of nations in facilitating human progress. This study selects the sustainable development index, assessed by Hickel (2020), which comprises a composite evaluation of economic, social, and environmental factors. The computation of the SDI is predicated on life expectancy, education, income, and consumption for human development in each nation, while considering the extent of ecological overshoot, carbon dioxide emissions, and physical footprint. The calculation of SDI is shown as following:

$$SDI = \frac{\sqrt[3]{LEI * EI * II}}{Ecological\ impact\ index} \quad (1)$$

In the equation 1, LEI refers to the life expectancy index. EI refers to the educational index, which is the average of the expected years of schooling index and the mean years of schooling index. II refers to the modified income index. Ecological impact index is calculated the extent to which the regional consumption-based carbon dioxide emissions and material footprint above the planetary threshold for equitable distribution. SDI refers to the sustainable development index.

As for the independent variables, mobile cellular subscriptions rate and digital service trade openness are designed as the indicator of DT and DST. Mobile cellular subscriptions rate utilizes cellular technology to access public mobile telecommunication services (ITU, 2024). DST is the proportion of the total amount of imported and exported digital services trade relative to gross domestic product (GDP). DST engages in commerce involving six categories: telecommunications, computer and information services, financial services, insurance and pension services, intellectual property royalties, other commercial services, and personal, cultural, and recreational services (Sturgeon et al., 2015). Sectoral classification criteria are based on the Extended Balance of Payments Services Classification (UN, 2012).

IQ index comprises the 6-point index of world governance indicators, including Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. Similar to past studies like Zheng et al. (2024) and Oussama and Abdellah (2024), this paper utilizes IQ index by taking the average of all indices, each receiving equal weight. Furthermore, the six indices are rated on a scale from 0 to 100. POP and INV are controlling variables in this paper, because of their influence on both dependent variable and independent variables.

Before empirical estimate, the data are subjected to log transformation to mitigate outliers, with the exception of IQ and SDI. IQ and SDI does not require log transformation in the dataset because both IQ and SDI are represented as scores percentages (Chan et al., 2024).

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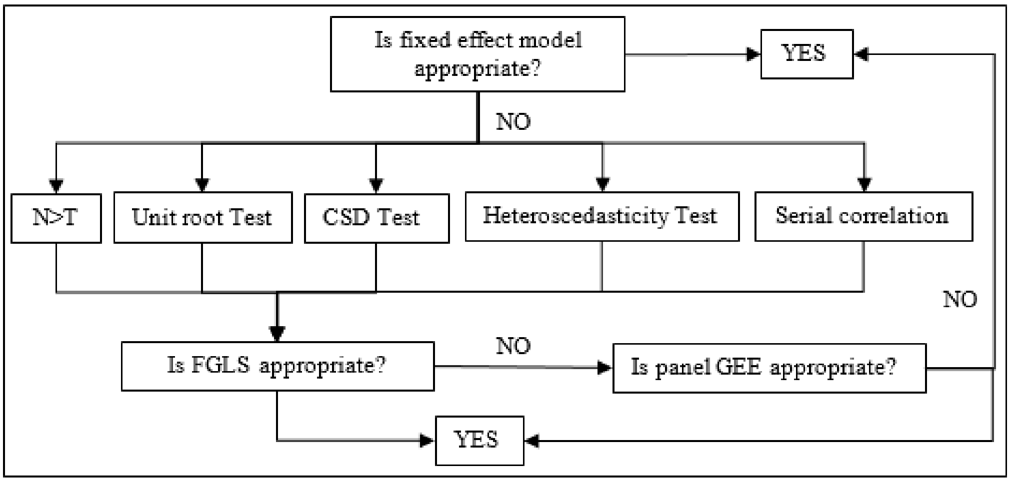
Given that the moderator variables are included in the same equation as the independent components, the IQ series are normalized to mitigate the elevated values of the variance inflation factor and to resolve the issue of multicollinearity.

3.1 Model Specification

This study examined the effects of digital technology (DT) and digital service trade openness (DST) on ASEAN's sustainable development (SD), considering the moderating role of institutional quality (IQ). The stepwise methodology employed in this investigation is illustrated in Fig. 1, which elucidates the rationale for using the FGLS test for this research.



Source: Dalei and Gupta (2024)

Figure 1: Research flow

The ASEAN group comprises 10 countries, and the time frame is from 2005 to 2020. Consequently, fixed effects are unsuitable as the time period (T) exceeds the number of countries (N), specifically T > N (Dalei & Gupta, 2024). Subsequently, we assessed cross-sectional dependency, heteroskedasticity, and serial correlation. The findings indicate an absence of cross-sectional dependency in the panel data over time; however, correlation and country-level heteroskedasticity are present. Conventional panel data estimators (OLS, fixed effects, random effects, and weighted least squares) encounter challenges in causal interpretations of the estimated coefficients when the error term's coefficient is non-unique and the variables are co-integrated (Abbas et al., 2024). To mitigate issues of heteroskedasticity and serial correlation in the panel data, this paper utilizes a non-spherical error structure to enhance inference and estimation through the application of a feasible generalized least squares (FGLS) estimator. The FGLS estimation procedure involves determining the heteroscedasticity structure based on the preceding OLS results. The general case of FGLS is as following:

$$\hat{\beta}_{fgls} = (X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y \qquad (2)$$

Where $\hat{\beta}_{fgls}$ refers to the coefficient of independent variables in FGLS estimation. X represents the matrix of explanatory variables, characterized by dimensions that are the product of the number of samples and the number of variables. y represents the vector of explanatory variables. Ω is the covariance matrix of the error terms, utilized to adjust for heteroskedasticity

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and autocorrelation. $\widehat{\Omega}^{-1}$ represents the inverse matrix of Ω, utilized in weighted least squares. $(X'\widehat{\Omega}^{-1}X)^{-1}$ signifies the covariance-adjusted component of the generalised least squares, which guarantees the estimator's optimality. $X'\widehat{\Omega}^{-1}y$ signifies the regression calculation subsequent to weighting the dependent variable y.

This study examined the effects of DT and DST on ASEAN's sustainable development (SD), considering the moderating role of institutional quality (IQ). First, this paper proposed model A to analyze the effects of DT, DST and IQ on ASEAN's sustainable development, shown as Eq. 3. Models B and C incorporate interaction variables for IQ with DT and DST, respectively. Model B introduced the interacting effect of IQ and DT (IQ*DT) to identify the moderating role of IQ on sustainable effects of DT. In addition, model C the interacting effect of IQ and DST (IQ*DSY) to identify the moderating role of IQ on sustainable effects of DST. This method also circumvents reliance on a singular metric that employes a synthesis of components may yield misleading, distorted, or biassed outcomes (Abbas et al., 2024). By disaggregating the components and their attributes into distinct models, we mitigate the issue of multicollinearity. Many facets of globalization are significantly associated; thus, their inclusion in a singular model would result in variance inflation and consequently parameter bias. This paper uses panel FGLS models estimates the effects of DT and DST on ASEAN's SD, considering the moderating role of IQ. The model A, B and C are listed as following.

Model A: $$SDI_{it} = f(lndt, lndst, iq, lninv, lnpop) \quad (3)$$

Model B: $$SDI_{it} = f(lndt, \ln(mdt * iq), iq, lnpop) \quad (4)$$

Model C: $$SDI_{it} = f(lndst, ln(dst * iq), iq, lninv, lnpop) \quad (5)$$

where, SDI indicates sustainable development indicator; $lndt$ indicates the log transformation of mobile cellular subscription rate; $lndst$ indicates the log transformation of international trade openness in ICT Services and ICT enabled Services; 'iq' indicates normalized IQ indicator; $(dt * iq)$ indicates the log transformation of the interacting effect of mobile cellular subscription rate and institutional quality indicator; $(dst * iq)$ indicates the log transformation of the interacting effect of DST and IQ indicator; $lninv$ indicates the log transformation of industrial value added; $lnpop$ indicates the log transformation of population. Accordingly, 'it' represents country i for year t (i=1, 2, …, N, t=1, 2, …, T).

3.2 Econometric Methods

3.2.1 Pre-model estimation tests

In the contemporary age of globalization and heightened interaction among nations regarding economic, financial, political, and environmental goals, the dataset utilized in this work may exhibit cross-sectional dependence (CSD) and slope heterogeneity (SH) problems (Abbas et al., 2024; Chan et al., 2024). Panel data results will be biassed and unreliable in the presence CSD and SH. This paper performed a descriptive study to examine all variables, subsequently doing CSD statistics and SH analysis. Subsequently, cointegration, autocorrelation, and multicollinearity analysis within the data were conducted to investigate the long-term relationship among the variables. First, this paper employed the Pesaran (2015) test to assess cross-sectional dependence among the chosen ASEAN economy. This test accurately detects all combinations of N and T, as well as the presence of lagged values of the dependent variable in the panel (Pesaran, 2015). Equation (6) represents Pesaran's CSD test.

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$$CSD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{j=i+1}^{N} \gamma_{ij}\right)} \quad (6)$$

where cross-sectional units (N), time (T), and indices i and j denote error correlation among the sampled regions.

Then, this research subsequently employs the Pesaran & Yamagata (2008) slope heterogeneity test, which adeptly addresses heteroskedasticity and autocorrelation in the data (Hashem Pesaran & Yamagata, 2008). The failure to account for slope heterogeneity may result in inaccurate coefficients (Aydin et al., 2024; Dalei & Gupta, 2024). A crucial step prior to cointegration and error correction modelling is to assess the stationarity characteristics of the variables. In the absence of CSD difficulties in panel data, this research can utilize first-generation panel unit root tests, such as the Levin-Lin-Chu (LLC) test (Levin et al., 2002) and the Im-Pesaran-Shin (IPS) test (Im et al., 2003), to assess the stationarity of variables. This paper should employ second-generation panel unit root tests, such as CIPS and Pesaran's CADF test to address concerns like CSD in panel data (Pesaran, 2007; Pesaran et al., 2008).

Furthermore, this paper utilized Pedroni's panel cointegration test to examine the cointegration of variables (Pedroni, 2004). If the calculated statistic is considered statistically significant, the null hypothesis is rejected. This rejection signifies the presence of a cointegration relationship within the panel data. The next step is to assess autocorrelation through Wooldridge test (Wooldridge, 2016). The primary objective of autocorrelation testing is to verify the model's dependability and validity. Disregarding autocorrelation may result in erroneous findings or suboptimal judgements. Addressing autocorrelation through testing enables the development of more robust models, hence enhancing the scientific validity of studies and projections.

3.2.1 Post-model estimation tests

Panel generalized estimating equations (PGEE) analysis was utilized to assess the robustness (Ghisletta & Spini, 2004). These analytical tools yielded significant insights into the impact of IQ, DT, and DST on SD. PGEE models yield reliable parameter estimations despite individual heterogeneity and correlated observations (Dalei & Gupta, 2024). The model permits flexibility in defining the residual correlation structure and enhances inferential reliability via robust standard errors.

4. ANALYSIS AND RESULTS

This part starts with an assessment of the data qualities. Descriptive data are shown in Table 2, correlation analyses in Table 3, variance inflation factor (VIF) analysis in Table 4, CSD testing for cross-sectional dependency and slope heterogeneity tests in Table 5, panel unit root tests in Table 6, and Panel Cointegration tests in Table 7. To assure data consistency and dependability, descriptive statistics such as means, standard deviations, and minimum and maximum values are provided. To ensure data consistency and dependability, Table 2 includes descriptive statistics such as mean, standard deviation, minimum, and maximum values. In addition, the skewness and kurtosis statistics show that the test data are not normally distributed. IQ and SDI does not require log transformation in the dataset because both IQ and SDI are represented as scores or percentages (Chan et al., 2024). Other variables are transformed into natural logarithms.

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Table 2: Descriptive statistics

Variable	Obs	Mean	Std. dev	Min	Max	Skew	Kurt
SDI	150	0.589	0.187	0.133	0.813	-1.265	3.546
LNDT	150	1.902	0.468	-0.351	2.260	-3.198	13.751
LNDST	150	0.082	0.114	0.001	0.481	1.639	4.922
IQ	150	0.890	0.993	-1.755	2.062	0.493	2.516
LIINV	150	1.550	0.122	1.284	1.883	0.801	3.755
LNPOP	150	7.372	0.779	5.562	8.439	-0.902	3.140
Source: author calculation							

The correlation analysis in Table 3 revealed varying degrees of association among variables, ranging from -0.615 to 0.969. Most of them are not correlated.

Table 3: Correlation analysis

Variables	SDI	LNDST	LNDT	IQ	LNINV	LNPOP
SDI	1.000					
LNDST	-0.250*	1.000				
LNDT	0.019	-0.072	1.000			
IQ	-0.615*	-0.161*	0.543*	1.000		
LNINV	0.053	-0.464*	0.320*	0.264*	1.000	
LNPOP	0.686*	-0.381*	-0.062*	-0.448*	-0.310*	1.000
*Notes: * indicates significance at the 5% level. The definition of variables refers to Table 1.*						

Then, to determine multicollinearity, this article relies on the VIF and 1/VIF data presented in Table 4 (Shrestha, 2020). Results demonstrate that there are slight multicollinearities in three models. This paper began to prepare for the use of industrial value added and population level as instrumental variables in the three models, considering their impact on the article variables. However, due to the severe multicollinearities between industrial value added and the core independent variables, model B only considers population level as an instrumental variable. The covariance data for all three models showed that they might be used for further analysis. There is some association between the variables and other independent variables, but it does not contribute to unstable or incorrect regression coefficient estimations.

Table 4: Variance Inflation Factor (VIF) Test

DV: SDI	Model A		Model B		Model C	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
LNDST	3.370	0.266			6.310	0.158
LNDT	2.210	0.452	3.240	0.308		
IQ	2.980	0.336	2.760	0.362	3.160	0.316
LIINV	2.890	0.346			2.040	0.489
LNPOP	3.760	0.400	1.450	0.691	2.580	0.387
Mean VIF	3.040		2.870		3.880	
Note: The VIF value of 1 indicates no multicollinearity, values between 1 and 5 suggest moderate multicollinearity, and values of 5 or above indicate high multicollinearity. Correspondingly, the 1/VIF value of 1 also reflects no multicollinearity, values between 0 and 1 indicate moderate multicollinearity, and values approaching 0 signal severe multicollinearity.						

Table 6 shows the findings of Pesaran and Yamagata's (2008) slope heterogeneity test. The null hypothesis assumes that slope of coefficients are homogenous (Hashem Pesaran & Yamagata, 2008). This test calculated delta (Δ) and adjusted delta (Adjusted Δ) statistics to compare the alternative hypothesis of slope heterogeneity with the null hypothesis of slope homogeneity. At the 1% level of significance, the null hypothesis was rejected for all Model

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A, Model B, and Model C. As shown in Table 5, these findings give strong evidence of slope heterogeneity, implying that the estimated slope coefficients vary across cross-sectional units representing developing economies in ASEAN countries.

Table 5: Results of Slope Heterogeneity test

Tests	Model A		Model B		Model C	
	Result	P Value	Result	P Value	Result	P Value
Δ tilde	3.140	0.002	4.704	0.000	3.454	0.001
Δ tilde Adjusted	4.299	0.000	6.073	0.000	4.730	0.000

Source: author calculation

The paper then evaluates serial cross-sectional dependence (CSD) through the Pesaran's (2015) CSD test. Most serial cross-section tests reject the null hypothesis, indicating cross-section dependence. Given the presence of CSD for a significant number of variables in this study, this paper utilizes the Cross-sectionally Augmented IPS (CIPS) test to examine the panel unit root. CIPS test assumes that all series in the panel are non-stationary, whereas under the alternative hypothesis, a certain fraction of series in the panel are stationary. Table 6 indicates that the majority of panel unit root tests reject the null hypothesis for all series at first differencing, implying that they are stable. As a result, this paper performed first differencing on all variables in all model estimations.

Table 6: Results of Pesaran's (2015) CSD test and Panel Unit Root Tests

Variables	CSD	CIPS	CIPS after first difference
	Result	Result	Result
SDI	4.00***	-2.075	-6.061***
LNDT	22.67***	-2.392	-3.000**
LNDST	0.62	-2.431	-5.080***
IQ	11.78***	-2.295	-5.176***
LIINV	1.47	-2.585	-5.279***
LNPOP	25.68***	-1.294	-5.376***

*Source: author calculation *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.*

Then, this paper employed Westerlund and Edgerton (2008) test and Kao (2000) test to check the panel cointegration (Baltagi & Kao, 2000; Westerlund & Edgerton, 2008). Table 9 confirms the null hypothesis that there is no cointegration between the study variables in Model A, Model B, and Model C.

Table 7: Models Panel Cointegration tests

Tests	Model A	Model B	Model C
Westerlund and Edgerton test			
Variance ratio	-1.285	-1.270	-1.049
Kao test			
Modified Dickey–Fuller t	1.687	0.515	2.347*
Dickey–Fuller t	1.700	0.594	2.738*
Augmented Dickey–Fuller t	0.954	-0.247	2.207
Unadjusted modified Dickey–Fuller t	0.056	0.495	-0.532
Unadjusted Dickey–Fuller t	-0.001	0.577	-0.523

Notes: Results are the t statistic of each estimation. * indicates significance at the 10% level.

The results of the three estimated models (A, B, and C), all of which use the Sustainable Development Index (SDI) as the dependent variable, provide several important insights into the role of DST, DT, IQ, and their interactions in promoting sustainability among developing

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ASEAN economies. Model A looks at the direct effects of DT, DST, and IQ on SDI. The results reveal that DT has a favorable and statistically significant impact on SDI in both the FGLS (0.118, $p < 0.01$) and PGEE (0.111, $p < 0.01$). This result is align with the research of Elfaki and Ahmed (2024). Similarly, IQ has a strong negative relationship on SDI, implying that higher IQ leads to weaker sustainability. This conclusion is contrary to the findings of Zheng et al. (2024) and Sun et al. (2025). Both industrial value added, and population are positively associated with SDI, implying that nations with stronger industrial capacity and larger populations outperform in sustainability measures. It is align with the findings of Onwe et al. (2024) and contract to the findings of Ntom Udemba et al. (2024). Notably, DST does not exhibit a statistically significant link in this A formulation. In contrast to this result, previous research by Romao et al. (2024) and Han et al. (2024) discovered positive long-term effects of DST.

Table 8: Estimates and Robustness test results

Tests	FGLS	P-VALUE	PGEE	P-VALUE
MODEL A				
LNDT	0.118	0.000	0.111	0.000
LNDST	-0.031	0.673	0.005	0.967
IQ	-0.133	0.000	-0.128	0.000
LIINV	0.364	0.000	0.380	0.000
LNPOP	0.146	0.003	0.156	0.000
MODEL B				
LNDT	-0.403	0.000	-0.349	0.001
IQ	-0.231	0.000	-0.212	0.000
IQDT	0.208	0.000	0.183	0.000
LNPOP	0.108	0.000	0.138	0.000
MODEL C				
LNDST	-1.100	0.000	-0.948	0.000
IQ	-0.159	0.000	-0.153	0.000
IQDST	0.086	0.000	0.074	0.000
LIINV	0.499	0.000	0.514	0.000
LNPOP	0.163	0.000	0.166	0.000

Model B introduces the interaction term ‘IQDT’, which represents the combined influence of DT and IQ, to account for IQ's moderating function in DT. The coefficient for LNDT becomes negative and remains substantial, whereas the interaction term IQDT has a positive and significant impact. This shows that IQ has a moderating effect, increasing the favorable influence of DT on sustainable development. This discovery builds on the prior research of Behera et al. (2024). Behera et al. (2024) primarily looked at the positive effects of DT on sustainable development, ignoring the importance of IQ. This research examines and demonstrates the moderate effect of IQ on DT.

In the absence of robust institutions, DT alone may not promote sustainability; nevertheless, with effective institutional frameworks, its benefits are magnified. Ha and Chuah (2023) advocated for the establishment of more sustainable technical infrastructure to facilitate the SDGs in ASEAN. This paper expands upon the suggestion of Ha and Chuah (2023), to examine the penetration of DT with IQ on sustainable development. LNPOP continues to exhibit significant effects in accordance with Model A.

Model C uses the IQDST term to assess the relationship of IQ and DST. The direct effect of DST is significantly negative and significant, showing that without effective institutions, DST may impair sustainable development, maybe due to environmental or regulatory flaws.

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This is contract to the findings of Romao et al. (2024) and Han et al. (2024), who discovered positive long-term effects of DST on sustainable development. However, the positive and significant coefficient of IQDST illustrates the complementing function of IQ in mitigating and reversing the negative externalities associated with DST. As in prior models, both industrial values added, and population continue to support SDI expansion.

5. DISCUSSION AND IMPLICATIONS

Empirical research of ten ASEAN member nations provides crucial insights into how digital technology, digital service trade, and institutional quality (IQ) interact to influence long-term development results. The continuous importance of IQ across all three models emphasises its essential role in digital technology and digital service trade, which drives ASEAN's sustainable development.

In Model A, the positive impact of digital technology on the Sustainability Development Index (SDI) indicates that ASEAN countries are starting to use digital innovations to improve environmental, social, and economic results. However, the insignificance of trade in digital services may indicate that trade liberalization in the digital sector does not always result in long-term development gains. This study supports worries that, without proper regulation and infrastructure, commerce in digital services may exacerbate inequality or environmental degradation through increased consumption, poorly managed e-waste, or data-driven energy demand.

Model B emphasises the moderating effect of IQ on digital technologies, highlighting a subtle dynamic: the positive impact of digital technologies is contingent on the quality of institutions. Specifically, the impact of digital technology on SDI is detrimental on its own, but favourable when combined with strong institutions. This shows that, in the absence of regulatory competence, digitalization may be ineffective in supporting sustainable development or may potentially exacerbate inequities or fail to achieve inclusive growth. However, effective governance institutions may employ digital tools to improve public services, e-government, green innovation, and universal digital access.

Mode C emphasises the relevance of IQ for ASEAN's sustainable development. DST has a detrimental influence on SDI, which could be attributed to regulatory inadequacies, environmental oversight concerns, or digital divide obstacles. However, the interaction term "IQDST" demonstrates how IQ might counteract these unfavourable effects. This emphasises the importance of a robust institutional framework in achieving environmental and social sustainability through research, technology, and innovation. Institutions can help to mitigate the risks associated with cross-border data flows, e-commerce externalities, and digital resource exploitation, as well as guarantee that trade openness aligns with ASEAN's environmental and social goals. ASEAN nations must prioritise IQ, including legal regulations, regulatory frameworks, and anti-corruption policies. Institutions were key enablers in transforming digital technologies and trade into beneficial and long-term development outcomes.

Furthermore, liberalizing trade in digital services without concomitant institutional development risks jeopardizing sustainability. ASEAN should continue to harmonize policies governing the trade of digital services through various initiatives. Tailoring digital trade policies to local capacities would help to reduce negative externalities. In addition, ASEAN should integrate digital advances into sustainable areas including smart agriculture, clean

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energy, digital banking, and education. Policies supporting open digital infrastructure, digital literacy, and inclusive innovation environments were critical. Regional collaboration is critical given ASEAN's disparities in institutional strength, digital readiness, and environmental capacity. ASEAN countries should pursue green industrial policies that encourage energy-efficient technology, digital manufacturing, and circular economy models. Countries with more sophisticated governance systems might exchange best practices, technical support, and collaborative monitoring platforms with less developed countries to help minimize inequalities.

In conclusion, the study emphasizes that digital technology and trade are not panaceas for ASEAN's sustainable development—they require strong institutions and well-aligned policies to produce positive environmental and social results. This conclusion not only emphasizes the significance of institutional development in the digital age, but it also provides a road map for ASEAN policymakers to navigate the complicated trade-offs of digital transformation while guaranteeing long-term viability.

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