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Financial Technology and Sustainable Development in ASEAN Region: Role of Income Inequality

(Teknologi Kewangan dan Pembangunan Mampan di Kawasan ASEAN: Peranan Ketaksamaan Pendapatan)

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ABSTRACT

This study explores the relationship between financial technology (FinTech), sustainable development, and the moderating role of income inequality in the Association of Southeast Asian Nations (ASEAN) countries. The study obtained data from 10 ASEAN countries from 2015 to 2022, employing a random-effects model to examine the interplay between FinTech, income inequality, and sustainable development. New findings suggest that FinTech adoption enhances environmental, economic, and social sustainability in ASEAN countries. However, this effect is enhanced by reducing the income inequality. Countries with better resource distribution employ FinTech responsibly and inclusively to improve their sustainable development. However, this study highlights the U-shaped relationship between FinTech acceptance and sustainable development. This study adds to the current body of research by emphasizing the complex impact of income inequality on the connection between FinTech and sustainable development. This finding provides a more thorough explanation of how economic disparities can shape this relationship. The findings highlight the need for policymakers and stakeholders in the financial industry to create inclusive financial ecosystems to reduce income inequality and enhance sustainable development. This includes promoting digital financial inclusion through improved internet and mobile access, enhancing financial literacy, developing robust regulatory frameworks, fostering public-private partnerships, offering targeted financial services for marginalized groups, and implementing measures to address income inequality.

Keywords: Financial technology; renewable energy; sustainable development; ASEAN; income inequality

ABSTRAK

Kajian ini meneroka hubungan antara teknologi kewangan (FinTech), pembangunan mampan, dan peranan pemoderasi ketidaksamaan pendapatan dalam negara-negara Persekutuan ASEAN (ASEAN). Kajian ini memperoleh data dari 10 negara ASEAN dari tahun 2015 hingga 2022, menggunakan model kesan rawak untuk mengkaji interaksi antara FinTech, ketaksamaan pendapatan, dan pembangunan mampan. Penemuan baru mencadangkan bahawa penerimaan FinTech meningkatkan kelestarian alam sekitar, ekonomi, dan sosial di negara-negara ASEAN. Walau bagaimanapun, kesan ini dipertingkatkan dengan mengurangkan ketaksamaan pendapatan. Negara dengan pengagihan sumber yang lebih baik menggunakan FinTech secara bertanggungjawab dan inklusif untuk memperbaiki pembangunan mampan mereka. Walau bagaimanapun, kajian ini menyerlahkan hubungan berbentuk U antara penerimaan FinTech dan pembangunan mampan. Kajian ini menambah kepada badan penyelidikan semasa dengan menekankan kesan kompleks ketaksamaan pendapatan terhadap hubungan antara FinTech dan pembangunan mampan. Penemuan ini memberikan penjelasan yang lebih mendalam mengenai bagaimana perbezaan ekonomi boleh membentuk hubungan ini. Penemuan ini menyerlahkan keperluan bagi penggubal dasar dan pemegang taruh dalam industri kewangan untuk mewujudkan ekosistem kewangan yang inklusif bagi mengurangkan ketidaksamaan pendapatan dan meningkatkan pembangunan mampan. Ini termasuk mempromosikan inklusi kewangan digital melalui peningkatan akses internet dan mudah alih, meningkatkan literasi kewangan, membangunkan rangka kerja pengawalseliaan yang kukuh, memupuk kerjasama awam-swasta, menawarkan perkhidmatan kewangan yang disasarkan untuk kumpulan terpinggir, dan melaksanakan langkah-langkah untuk menangani ketidaksamaan pendapatan.

Kata kunci: Teknologi kewangan; Tenaga boleh diperbaharui; Pembangunan mampan; ASEAN; Ketaksamaan pendapatan

JEL: Q5, Q8, O33, J1, G23, Q56
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INTRODUCTION

Financial Technology (FinTech) plays a significant role in transforming the financial service landscape of the Association Southeast Asian Nations (ASEAN). This region, consisting of diverse economies such as Indonesia, the Philippines, Vietnam, Thailand, Myanmar, Malaysia, Cambodia, Laos, Singapore, and Brunei Darussalam, provides a unique setting for exploring the interplay between FinTech, sustainable development, and income inequality. Despite their shared commitment to achieving the Sustainable Development Goals (SDGs), these countries face challenges related to wealth distribution disparities and limited access to financial services (Deng et al. 2019; Lisha et al. 2023; Taskin et al. 2022
). FinTech has the potential to address these obstacles (Wewege & Thomsett 2019).

When considering a reduction in income inequality, the central issue is how FinTech can potentially act as a catalyst for sustainable development. Although FinTech is frequently acknowledged for its potential to enhance financial inclusion, its benefits are not uniformly distributed. A comparison of the nearly universal adoption of FinTech in Singapore and Malaysia, with the comparatively lower rates observed in Cambodia and Myanmar, reveals a glaring disparity in digital financial access. This discrepancy is significantly correlated with other SDGs including SDG 1 (Poverty Eradication), SDG 8 (Promoting Decent Work and Economic Growth), and SDG 10 (Reduction of Inequalities) (United Nations 2015b)

Recent statistics indicate that the level of internet usage, which is vital for the advancement of FinTech, differs significantly between nations. For example, internet penetration rates in Brunei and Singapore surpass 80%, whereas they fall below 40% in Myanmar. This discrepancy significantly affects the accessibility and efficacy of digital financial services in fostering sustainable development. Additionally, Singapore exhibits a significant discrepancy in terms of income distribution according to the Gini coefficient (World Bank 2021). Singapore's Gini coefficient value of 45.9 signifies a considerable degree of inequality, whereas Laos's value of 36.4 indicates a more equitable income distribution. Economic disparities affect the efficacy of FinTech initiatives aimed at advancing equality and sustainable development (World Bank 2021).

Unlike other determinants such as human capital or globalisation, income inequality directly affects an individual's ability to benefit from technological advancements in finance (Adjasi et al. 2023). Lower-income populations may face restricted access to technology in regions with high levels of inequality, limiting their potential to benefit from Fintech solutions. This study highlights the potential of mobile banking to deliver financial services to individuals in remote rural areas of countries such as the Philippines and Indonesia. However, economic inequality often hinders these groups' access to mobile technology and the Internet, which, in turn, affects their ability to utilized these resources effectively (World Bank Group 2022). To shed light on this issue, this study utilizes a dataset covering all ten ASEAN regions from 2015 to 2022 by employing econometric methods, specifically the random effects model, to examine the study variables.

This study examines the role of FinTech in creating inclusive digital financial ecosystems to address socioeconomic gaps in the ASEAN region. This study provides detailed recommendations for policymakers, financial institutions, and technology providers, suggesting that they should develop targeted interventions to promote FinTech adoption, enhance financial literacy, and improve digital infrastructure. These measures can drive inclusive economic growth and sustainable development by making financial services more accessible to marginalized populations, ensuring consumer protection through robust regulatory frameworks, and fostering public-private partnerships to innovate financial products tailored to the needs of low-income groups.

This study significantly contributes to the existing literature by providing empirical data on how economic inequality affects the relationship between FinTech and sustainable development, extending the work of previous studies that often assumed a direct positive relationship. Unlike previous studies that primarily focused on the benefits of FinTech in isolation, this study reveals that high levels of income inequality can hinder the positive effects of FinTech adoption. By doing so, it challenges the prevailing assumption of a direct positive relationship and underscores the importance of addressing income disparities to fully leverage the potential of FinTech for sustainable development. This study builds on and diverges from the study by Deng et al. (2019), who explored FinTech and sustainable development in China without considering the moderating effect of income inequality, thus providing a broader and more context-specific understanding of the dynamics in the ASEAN region.

This article begins with an introduction outlining the objectives and significance, followed by a literature review that identifies research gaps. Then, it presents the theoretical framework and hypotheses, details of the methodology used, and reports on the empirical findings. The discussion interprets these results in the context of existing literature concludes with key findings, policy recommendations, and suggestions for future research**

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

THEORETICAL FRAMEWORK

The theoretical framework of this study is based on two main theories: the diffusion of innovation (DOI) and financial inclusion theories. The DOI theory, developed by Rogers (1995), explains the adoption of new technologies through an S-shaped curve influenced by factors such as advantages over existing technologies, compatibility with existing systems, ease of use, trialability, and the observability of benefits. In the context of this study, the DOI theory helps understand the varying rates of FinTech adoption in different ASEAN populations, which can be attributed to wealth disparity (Lashitew et al. 2019). The financial inclusion theory emphasizes the importance of making financial services easily accessible to eliminate poverty and promote economic and social progress (Khan & Khan 2023). This theory aligns with SDGs such as No Poverty, Decent Work and Economic Growth, and Reduced Inequalities. This supports the exploration of how FinTech can bridge the gap between financially included and excluded populations, particularly in situations where income levels differ (Mhlanga 2022). By leveraging technology to enhance the availability of financial services, marginalized communities can improve their economic standing and contribute to a fairer society (Tao et al. 2022).

Income inequality plays a crucial role in the relationship between FinTech adoption and sustainable development (Khan & Khan 2023). Our theoretical framework considers how income differences affect FinTech adoption and its benefits. Higher economic disparity can hinder information dissemination and reduce the effectiveness of initiatives promoting financial inclusion, thus affecting progress towards the SDGs (Huang et al. 2024). By integrating these theories, the framework explains the diffusion and use of innovations in different economic contexts and highlights the importance of inclusive financial growth for sustainable development. It provides insights into the interconnected relationships among technology adoption, economic inequalities, and developmental outcomes. This comprehensive understanding enables the customization of policy interventions to maximize the positive effects of FinTech on reducing inequality and promoting sustainable development in ASEAN.

FINTECH AND SUSTAINABLE DEVELOPMENT

One example of how technological advances can significantly augment financial inclusion and economic empowerment is the integration of FinTech and sustainable development in the ASEAN region. Technological progress, including mobile money providers and financial institutions, digital loans, and enhanced internet accessibility, significantly contributes to the realization of SDGs. In addition to bolstering economic stability, these technologies deliver critical services, augmenting the general welfare of diverse populations across the ASEAN member states. Ongoing research has consistently underscored the favourable impact of increased internet usage on sustainable development. Surianshah (2021) found that the provision of improved internet connectivity in rural areas significantly enhanced agricultural productivity and income, consequently fostering economic progress. Similarly, the proliferation of internet access in Indonesia has significantly improved social welfare by expanding opportunities in the domains of education and healthcare (Ariansyah et al. 2023).

Despite these developments, the digital divide remains a significant obstacle. Strong policies are required to promote responsible and ethical technology use to preserve the benefits that technology offer, as the disparity in access impedes equitable development. The consensus is that the increasing availability of financial institutions and mobile money services is a significant driver of sustainable development. The availability of formal financial services promotes social sustainability and economic growth in the long term by encouraging the adoption of ethical financial practices and allowing communities to allocate funds to vital sectors such as healthcare, education, and renewable energy. The correlation between digital financial services and sustainable development is substantiated by empirical evidence that underscores the significant contribution of these services to the advancement of sustainability (Allen et al. 2016; World Bank Group 2022).

In addition, the widespread adoption of mobile banking services has been instrumental in promoting financial inclusion and reducing poverty levels, thereby emphasizing the substantial influence that mobile technology has had on sustainable development. According to Dhahri et al. (2024), the use of mobile subscriptions facilitates access to vital information and enhances digital literacy. It provides essential financial services and educational opportunities, thereby empowering individuals and communities. Nevertheless, significant obstacles persist, including inequities in digital access and the imperative for conscientious technology utilisation. This underscores the significance of legislation promoting sustainable practices in mobile ecosystems and environmentally responsible data management.

THE MODERATING ROLE OF INCOME INEQUALITY

In the ASEAN region and other regions, income inequality plays a crucial role in shaping the relationship between FinTech and sustainable development. The rapid expansion of mobile money providers and financial institutions has highlighted their potential to drive sustainable development. Studies have shown that access to formal financial services promotes economic progress and fosters the long-term sustainability of communities by promoting economic stability and adaptability. By promoting responsible financial practices, these services empower communities to allocate resources to vital sectors such as

renewable energy, healthcare, and education. This aligns with the broader objectives and principles of sustainable development (Adjasi et al. 2023; World Bank 2021). However, the degree of economic disparity in a community can significantly impede the benefits of financial inclusion. Income inequality may impede the positive effects of financial technologies, such as online banking, on economic inclusion and social welfare, particularly for those with lower incomes who may face barriers due to limited technological access and digital literacy (Daqar et al. 2020). Income disparities within the ASEAN context could exacerbate this issue by creating unequal opportunities to utilize and benefit from digital financial services. To eliminate these disparities, economic inequality must be addressed by implementing targeted measures. This ensures that FinTech is equitably and unbiasedly accessible to all segments of society.

There is widespread acknowledgment of the importance of financial inclusion in efforts to address economic inequality and sustainable development. Demirgüç-Kunt and Klapper (2013) underscored the potential benefits of financial inclusion and stressed the importance of distributing these advantages across diverse socioeconomic groups. According to Huang et al. (2023), the degree to which different groups benefit from mobile technology, a critical component of FinTech that is anticipated to foster sustainable development, may be affected by wealth inequality. The potential exacerbation of preexisting disparities may arise from variations in the accessibility and utilization of mobile technology, thereby impeding the complete utilization of digital financial services by lower-income populations.

The proposition that income inequality affects the relationship between FinTech and sustainable development gains greater significance within this framework. Existing research supports the notion that economic inequality affects individuals' ability to fully benefit from widespread internet access and other FinTech tools. Mobile technology has positively affected social and economic development. However, the extent of its impact on different socioeconomic strata is not homogeneous (Khan & Khan 2023). The ASEAN region presents a unique challenge in its pursuit of sustainable and equitable development through FinTech utilization owing to its diverse economic environments and varying degrees of development. The disparities between income and digital accessibility underscore the critical nature of implementing policies that promote the adoption of FinTech and efficiently address income inequality (Yang et al. 2022). Implementing this approach will ensure that the transformative potential of FinTech positively impacts sustainable development in a manner that benefits all members of society, regardless of their socioeconomic status. By placing income inequality reduction at the forefront of the correlation between FinTech and sustainable development, stakeholders can formulate all-encompassing strategies that maximize the benefits of digital financial innovations for every individual in the ASEAN region.

This study fills gaps in the existing literature on FinTech and sustainable development by specifically focusing on the moderating effect of income inequality. The literature review reveals that previous research has primarily focused on the positive impacts of FinTech on economic inclusion and empowerment without adequately considering the nuanced effects on different socioeconomic groups in the ASEAN region (Rahayu et al. 2023). There is a lack of understanding of the distribution of FinTech benefits among various socioeconomic strata, particularly in environments with substantial income disparity. Additionally, the literature review highlights that the existing research has not sufficiently examined the potential negative consequences associated with FinTech, such as the accumulation of electronic waste and social exclusion. This study aims to address this knowledge gap by investigating the unintended consequences of FinTech deployments, specifically, its influence on social equity and environmental sustainability in the ASEAN region. Furthermore, the literature review reveals that FinTech adoption is often discussed without considering the diverse economic, cultural, and infrastructural contexts of the ASEAN countries. This approach provides more targeted observations of the potential of FinTech to facilitate sustainable development inclusively and efficiently. Overall, this study contributes to the existing body of knowledge by providing empirical evidence of the influence of income inequality, assessing the effects of FinTech, and offering a comprehensive understanding of how FinTech intersects countries under the unique conditions of the ASEAN region. The findings of this study contribute to scholarly research and provide valuable insights for policymakers and stakeholders in utilizing FinTech for sustainable development.

DATA AND METHODOLOGY

DATA AND VARIABLE DESCRIPTION

This study examines the effect of FinTech on sustainable development in ASEAN countries by employing datasets from the World Bank World Development Indicators and Global Findex databases from 2015 to 2022. The sustainable development index (SDI) was computed using six indicators. Principal Component Analysis (PCA) was used to compute the composite SDI. The study also incorporated a standard framework for measuring progress towards SDGs. This study applies a dual-index technique to assess the impact of FinTech on sustainable development in the ASEAN region. This study considers the sustainable development level of each country in ASEAN regions (SDI_{it}) as the explained variable per the indicators of sustainable development (Table 1). The independent variable $FinTech_{it}$ signifies the level of FinTech development. The indicators employed in the construction of the $FinTech_{it}$ index comprise three indicators: individuals using the internet (% of the population), number of ATMs per 1,000 $km^{2,}$ and mobile cellular subscriptions (per 100 people). These indicators were used as proxies for FinTech as they represent the level of technological innovation to promote access, penetration, and usage of financial services and products (Demirgüç-Kunt et al. 2022). As technological infrastructure is paramount for the

realization of the Fin Tech goal in Southeast Asian countries, the mobile cellular subscription (per 100 people) indicator was integrated into $FinTech_{it}$ to capture the level of infrastructure development for FinTech development in the region, representing a novelty to the current study.

This study also controls for a range of variables that might affect the level of sustainable development in a country. Thus, we control for the GDP per capita growth rate. Investing in growth increases sustainability. Energy transformation requires a robust investment climate, bolstered by economic expansion (Khan et al. 2022). Population density is a key indicator of population dispersion and regional environmental demands. Population intensification for economic growth has been accompanied by an increase in household waste, resource consumption, and environmental remediation difficulties. Thus, this study controlled for the population proxied by the population POP_{it} (annual growth%) (Grove et al. 2014). The education level of the labor force ($ELLF_{it}$) is a significant indicator of the degree of human capital, which is a crucial factor in the sustainable development of a country. Table 1 presents the measurement of the variables, their notations, and their sources.

TABLE 1. Measurement of variables in the models

Indicator	Notation	Measurement	Source
Sustainable Development Index (SDI)	REC	Renewable energy consumption (% of total final energy consumption	WDI
	RDE	Research and development expenditure (% of GDP)	WDI
	COEGF	CO2 emissions from gaseous fuel consumption (% of total)	WDI
	CRW	Combustible renewables and waste (% of total energy)	WDI
	EPRS	Electricity production from renewable sources, excluding hydroelectric (% of total)	WDI
	IND	Industry (including construction), value added (% of GDP)	WDI
Sustainable Development Goal Index	SDGI	A sustainable development goal scores rated on a scale of 0-100, a higher score indicates a better performance towards achieving the SDGs.	World Bank
Gini Index	Gini	A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality.	WDI
Fintech	INDUI	Individuals using the Internet (% of the population)	WDI
	AOFM	Account ownership at a financial institution or with a mobile money service provider (% of population ages 15+)	Findex
	MCS	Mobile cellular subscription (per 100 people)	WDI
GDP per Capita growth	GDPPCG	GDP per capita is gross domestic product divided by midyear population (GDP per capita growth (annual %)	WDI
Population	POP	Population (annual growth %)	WDI
Education Level of the labor force	ELLF	Literacy rate, adult total (% of people ages 15 and above)	WDI

TABLE 2. Summary of descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
SDI	76	-0.092	1.000	-2.505	2.483
SDGI	70	55.385	12.238	35.270	79.014
REC	80	23.456	24.288	0.000	85.770
RDE	76	1.202	1.087	0.050	4.006
COEGF	80	13.716	15.825	0.000	75.413
CREW	80	15.282	14.742	0.000	66.583
EPRS	80	3.295	2.961	0.000	17.235
IND	80	5.434	11.972	-34.671	54.547
FinTech	71	-0.141	1.000	-1.211	2.611
lnAOFM	80	4.312	0.418	2.349	4.605
lnMCS	71	3.808	1.292	-0.307	5.362
INDUI	78	28.359	26.467	0.000	83.700
Gini	80	38.379	1.811	32.000	43.000
GDPGPC	77	3.554	8.687	-7.475	65.387
PoPG	80	0.911	1.425	-4.905	4.166
ELLF	80	91.058	5.991	58.309	96.431

SDI: Sustainable development. SDGI: Sustainable development goal index. REC: renewable energy consumption. RDE: research and development expenditure. COEGF: CO2 emissions from gaseous fuel consumption. CRE: Combustible renewables and waste. EPRS: Electricity production from renewable sources, excluding hydroelectric. IND: Industry (including construction), value added. INDUI: Individuals using the Internet. lnAOFM: natural log of account ownership at a financial institution or with a mobile money service provider. lnMCS: Natural log mobile cellular subscription. Gini: gini index. GDPGPC: GDP growth per capita. PoPG: population growth. ELLF: Education level of labor force.

Table 2 of the descriptive data summarizes ASEAN-wide sustainable development measures and FinTech indicators. The average SDI was -0.092, indicating a neutral influence on sustainable development. However, the SDI ranges from -2.505 to 2.483, demonstrating a wide variation in sustainable initiative performance among countries. A mean SDG index (SDGI) score of 55.385 indicated moderate progress; however, nations' success levels varied from 35.270 to 79.014. This disparity shows how these countries are doing and what they face to achieve their SDGs. The regional adoption and effects of FinTech are stable and different, with a mean value of -0.141. Other measures, such as mobile cellular subscriptions and internet usage (average: 28.359%; maximum: 83.700%) show large variances in digital accessibility, which is crucial for financial inclusion and sustainable development. This vast data collection shows the complex interaction between technology, economic methods, and sustainability measures in ASEAN countries, emphasizing the need for specific policies to bridge the development-technology divide.

TABLE 3. Correlation matix

	SDI	SDGI	FinTech	lnAOFM	lnMCS	INDUI	Gini	GDPGPC	PoPG	ELLF
SDI	1									
SDGI	.301*	1								
FinTech	.538**	0.004	1							
lnAOFM	-0.002	-.295*	-0.046	1						
lnMCS	0.141	-0.069	.646**	-0.027	1					
INDUI	.529**	0.048	.947**	-0.024	.600**	1				
Gini	-.384**	-0.168	-.246*	0.191	-0.013	-0.205	1			
GDPGPC	0.003	-0.080	0.106	0.039	0.057	-0.016	-0.006	1		
PoPG	-.232*	-0.123	-0.147	-0.125	-0.129	-0.152	0.088	0.111	1	
ELLF	0.088	0.061	0.205	-0.026	0.061	0.198	0.049	-0.044	-0.154	1

*Note(s): ***,**, and *indicate significance at the 1 %, 5 %, and 10% levels, respectively. SD: sustainable development index. SDGI: sustainable development goal index. FinTech: financial technology index. lnAOFM: natural log of account ownership at a financial institution or with a mobile money service provider. lnMCS: Natural log mobile cellular subscription. Gini: gini index. GDPGPC: GDP growth per capita. PoPG: population growth. ELLF: Education level of labor force.*

PRINCIPAL COMPONENT ANALYSIS

PCA was used to measure the level of sustainable development in Southeast Asian countries based on six indicators (Table 1). The Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were conducted on the SD_{it} dimension. The KMO criteria were computed, and yield values ranging from 0 to 1 (values > 0.6) were employed to indicate that PCA could play a role in data reduction. The sampling adequacy was computed as follows:

$$MSA_j = \frac{\sum_{k \neq j} r_{jk}^2}{\sum_{k \neq j} r_{jk}^2 + \sum_{k \neq j} p_{jk}^2} \quad (1)$$

where MSA is a measure of sample adequacy, r_{jk} is the connection between the variables in the equation and another, and p_{jk} is the partial correlation.

Bartlett's test was performed to ascertain the suitability of the data for factor analysis. Bartlett's test was used to compare the null hypothesis, H_0, that all k population variances are identical to the alternative, which states that at least two are distinct. For instance, if there are samples with sizes n_i and sample variances S_i^2 then Bartlett's test statistics are

$$\chi^2 = \frac{(N-k)\ln(S_p^2) - \sum_{i=1}^{k}(n_i - 1)\ln(S_i^2)}{1 + \frac{1}{3(k-1)}\left(\sum_{i=1}^{k}\left(\frac{1}{n_i - 1}\right) - \frac{1}{N-k}\right)} \quad (2)$$

where $N = \sum_{i=1}^{k} n_i$ and $S_p^2 = \frac{1}{N-k}\sum_i (n_i - 1)S_i^2$ are the pooled estimates of variance. Thus, Bartlett's test of sphericity must be < 5% for factor analysis to be considered acceptable (Goni et al. 2020). Given that the indicators employed in the

construction of the SDI_{it} and $FinTech_{it}$ indices have different units and scales, transformation of the variables is desirable for the creation of composite variables using PCA. Therefore, we use *z*-transformation to standardize the variables under consideration for the indices (Le et al. 2019) and state as

$$\text{Standardized variable} = \frac{Q_i - \overline{Q}}{SD} \quad (3)$$

where, $\overline{Q}$ is the mean population, and SD is the standard deviation of the population.

The SDI uses reciprocal transformations to link metrics such as CO2 emissions to sustainability objectives. The SDI score decreases as CO2 emissions increase, making this transition crucial. PCA may yield negative results when the data points fall outside the mean of the transformed variables. This technique allows the SDI to assess the relative sustainability performance of entities or areas; negative values indicate performance below the sample mean.

TABLE 4. Principal component analysis for composite SD and fintech

	SD	Fintech	Proportion	Cumulative Proportion	Eigen Value
SDI:					
REC	-0.815		0.589	0.589	1.542
RDE	0.788				
COEGF	0.660				
CRW	0.824				
EPRS	-0.674				
IND	-0.790				
			KMO=0.629, Bartlett's test χ^2 =107.835***		
FinTech:					
INDUI		0.801	0.746	0.746	2.237
lnAOFM		0.836			
lnMCS		0.947			
			KMO=0.778, Bartlett's test χ^2 =167.175**		

*Note(s): ***,** denote significance at 1% and 5% respectively. KMO: Kaiser-Meyer-Olkin Measure of Sampling Adequacy. SD: sustainable development. REC: renewable energy consumption. RDE: research and development expenditure. COEGF: CO2 emissions from gaseous fuel consumption. CRE: Combustible renewables and waste. EPRS: Electricity production from renewable sources, excluding hydroelectric. IND: Industry (including construction), value added. INDUI: Individuals using the Internet. lnAOFM: natural log of account ownership at a financial institution or with a mobile money service provider. lnMCS: Natural log mobile cellular subscription.*

PCA indicates substantial relationships between ASEAN Sustainable Development and FinTech metrics. The investigation revealed significant component structures and adequate sampling (KMO > 0.6), confirming the findings of credible factor analysis. R&D investment relates positively to renewable energy consumption, and the "Renewable Energy & Development" component explains 58.9% of SD index variance. It inversely affects non-hydro-renewable electricity and CO2 emissions. Renewable energy and research boost sustainability scores. Higher CO2 emissions harm the environment and result in lower index scores. The sustainability index translates the negative effects of high CO2 levels into a structure that matches the positive CO2 emission trend of the SD index. Reciprocal transformations lower the sustainability index scores for higher CO2 emissions. Mobile cellular subscriptions, internet usage, and bank or mobile money account ownership influence "Digital Access & Inclusion" by 74.6%. Positive catalysts highlight how digital infrastructure fosters sustainable development through community and financial inclusion.

MODEL SPECIFICATIONS

Panel data are a vital use of econometric approaches because they involve collecting several observations over time from various entities, such as nations, corporations, and people. Random- and fixed-effects models are particularly useful in situations where there is a hierarchical structure and observable and unobserved factors influence the dependent variable. The fixed-effects model removes biases that are specific to each entity and remain constant over time, by accounting for all time-invariant variations across entities. It also addresses the issue of omitted variable bias when variables remain constant over time. The random-effects model is suitable when entity variations are random and not correlated with the predictors. This model considers within- and between-entity variations, allowing for generalization beyond the study sample. It assumes that the entity-specific effect is an uncorrelated random variable separate from the independent variables in the model. Both models are classified as "static" because they do not integrate the temporal dynamics of adjustment. Instead, they assess the levels or variations at each moment in time using observable and unobserved differences.

The study adds a quadratic FinTech penetration variable ($FinTech^2$) to the econometric model to evaluate the nonlinear effects on sustainable development. This helps identify U-shaped or inverted U-shaped interactions in which FinTech may increase or decrease with new technology adoption. This definition is crucial for capturing the threshold effects, which are important in environments with rapid technological advancement and variable income disparity. This technique is supported by similar studies, such as Yan et al. (2023), who utilized quadratic terms to capture the nonlinear effects of ICT investment on industrial structure upgrading. The link between FinTech and the Gini index allows for a detailed investigation of how

income inequality affects these relationships. This highlights the complicated effects of FinTech on ASEAN's sustainable development. This technique supports our goal of understanding the immediate influence of technology adoption and the situations in which it may vary.

Owing to the panel nature of the data, which includes within and between-country differences across time, a random-effects model was used as the main analytical method. The decision is supported by extensive diagnostic testing, namely the Breusch-Pagan Lagrange Multiplier test. For instance, in the random-effects model (model 1), the test strongly rejected the use of the Pooled OLS model and instead favoured a panel method. The χ^2 value obtained from the test was 3.98, with a significance level of p =0.000. The Hausman test offers further validation by comparing the random-effects model with a fixed effects alternative. It examines the presence of relationships between entity-specific effects and regressors. Similarly, in Model 1, the findings indicate that the random-effects model is suitable for capturing larger implications by effectively addressing within- and between-entity variations. This was supported by a χ^2 of 5.81 with a p-value of 0.925.

Therefore, to analyze the effect of FinTech on sustainable development, the study builds an econometric model based on Allahham et al. (2024) as follows:

$$SDI_{it} = \alpha_0 + \alpha_1 FinTech_{it} + \alpha_2 FinTech_{it}^2 + \alpha_3 M_{it} + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

where SD_{it} signifies the sustainable development level of country *i* at time t, α_0 is the intercept term, and μ_i is the specific effects of countries that is constant over time, capturing all country-specific random variation. ε_{it} is the random error term. The random error term in the econometric model is assumed to have zero mean, constant variance (homoscedasticity), no autocorrelation, and no endogeneity with the independent variables. $FinTech_{it}$ is the FinTech index, and $FinTech_{it}^2$ is an independent variable that captures the U-shape with SDI_{it}; M_{it} is the moderation variable (Gini). X_{it} is the set of control variables, $\alpha_1 - \alpha_3$ is the coefficients of the independent variables, and γ is the coefficient vector of the control variables.

In this model, FinTech is expected to have a positive effect (+), as financial inclusion theory suggests that FinTech improves access to financial services, thereby enhancing sustainable development. FinTech² is also anticipated to have a positive effect (+), with benefits increasing at an accelerating rate due to network effects and economies of scale. Conversely, the Gini coefficient is expected to have a negative effect (−), as higher income inequality is likely to hinder sustainable development by limiting financial resource access for lower-income populations. However, the interaction term between FinTech and the Gini coefficient is projected to be positive (+), indicating that higher FinTech adoption may mitigate the adverse effects of income inequality on sustainable development.

RESULTS AND DISCUSSION

Table 5 presents the results of the random-effects model with SDI as the dependent variable, FinTech (INDUI, lnAOFM, lnMCS) and FinTech^2 as the main independent variable, and income inequality as the moderating variable. The model diagnostic tests show that the random-effects model is suitable and reliable for predicting the nexus between Fintech, income inequality, and sustainable development in ASEAN countries. To capture the total effect of FinTech on sustainable development in ASEAN countries, we computed net effects using conditional and unconditional effects. Conditional effects assess the influence of FinTech on sustainable development while keeping all factors constant. This clearly shows the influence of FinTech, while ignoring other factors. A detailed understanding of FinTech's unconditional effects helps explain its interaction with the real world, where many elements impact the results. It is also feasible to identify differences in FinTech benefits by examining their impact on various income levels and geographical regions. This approach demonstrates how FinTech promotes sustainable development in a region by addressing direct and indirect influences in different situations. For example, the net interaction between the FinTech index and the Gini index is 0.942([0.012×38.379] + [0.481], the mean of the Gini index is 38.379, the unconditional effect of FinTech is 0.481, and the conditional effect of the interaction between the FinTech index and Gini index is 0.014.

TABLE 5. Results of fintech, income inequality and sustainable development using random-effect model

	Dependent variable: Sustainable development (SDI)				
	(1)	(2)	(3)	(4)	(5)
Variable	FinTech	FinTech^2	INDUI	lnAOFM	lnMCS
FinTech	0.481***				
	(4.59)				
Gini	-0.166**	-0.157**	-0.268**	-0.218	-0.179***
	(-2.64)	(-2.70)	(-2.87)	(-3.61)	(-2.81)
FinTch×Gini	0.012 ***				
	(4.70)				
FinTech^2		0.018***			
		(4.96)			
FinTech^2×Gini		0.016***			

		(4.10)			
INDUI			-0.019***		
			(-5.43)		
INDUI×Gini			0.017 **		
			(4.62)		
lnAOFM				-0.215**	
				(-3.02)	
lnAOFM×Gini				0.203**	
				(2.79)	
lnMCS					-0.304***
					(-2.80)
lnMCS×Gini					0.228***
					(2.23)
GDPPCG	0.191**	0.044**	0.018***	0.199***	0.112**
	(3.08)	(5.86)	(4.77)	(3.23)	(2.02)
PoPG	0.135**	0.021***	0.129***	0.151**	0.025**
	(2.37)	(6.97)	(3.80)	(2.06)	(5.03)
ELLF	0.119**	0.163**	0.144**	0.159*	0.026***
	(2.08)	(2.86)	(2.62)	(2.20)	(5.12)
Net Effects	0.942	0.632	0.633	7.576	8.446
R^2	0.764	0.776	0.412	0.537	0.521
Wald χ^2	73.26***	76.41***	56.95***	68.91***	58.42***
B-P LM Test (Prob> χ^2)	0.000	0.001	0.003	0.000	0.000
Hausman Test (Prob> χ^2)	0.925	0.490	0.946	0.547	0.428
Countries	10	10	10	10	10
Obs.	65	65	71	73	65

*Note(s): ***,**, and *indicate significance at the 1 %, 5 %, and 10% levels, respectively. The z-statistics are in parentheses. SDI: sustainable development index. Fintech: financial technology index. lnAOFM: natural log of account ownership at a financial institution or with a mobile money service provider. lnMCS: Natural log mobile cellular subscription. Gini: gini index. GDPGPC: GDP growth per capita. PoPG: population growth. ELLF: Education level of labor force. Mean of Gini index =38.379*

These findings showed evidence of FinTech's positive influence on sustainable development and validates its capability to enhance social, economic, and environmental sustainability by facilitating financial inclusion and service accessibility. This finding is consistent with existing studies that underscore FinTech's transformative potential to broaden the accessibility of financial services, thereby advancing sustainability across various domains (Allen et al. 2016; Dhahri et al. 2024). This study highlights the impact of income inequality on FinTech adoption and suggests that FinTech benefits are significantly magnified in more equitable economic environments. According to the financial inclusion hypothesis, inclusive financial institutions are crucial to guarantee broad-based economic progress and long-term viability (Khan & Khan 2023). A reduction in income inequality facilitates FinTech adoption, thereby enabling a more effective application of these technologies to promote sustainability. Empowering a larger segment of the population and fostering inclusive economic development, the data support the notion that equitable income distribution facilitates access to financial services and resources (Allen et al. 2016).

The findings revealed a U-shaped relationship between FinTech use and sustainable development. The Gini index influences the effect of FinTech on sustainable development, indicating a complex relationship between FinTech adoption, income inequality, and sustainable development outcomes. The study finds that, as income inequality increases, the effect of FinTech on sustainable development decreases; however, as FinTech spreads, its advantages for sustainable development increase. Research has also revealed that higher FinTech usage positively influences sustainable development (Pizzi et al. 2021). However, income inequality affects the impact of FinTech, suggesting that economic disparity can hinder its adoption. This is particularly concerning for lower-income populations who may have limited access to FinTech in unequal societies. Nevertheless, this study highlights that FinTech can minimize income inequality barriers and promote financial inclusion and accessibility, ultimately contributing to sustainable development. These findings emphasize the importance of policies that encourage FinTech usage, target and reduce economic inequality, and fully leverage its development potential (Ashenafi & Dong 2022).

Moreover, this study emphasized the adverse consequences of significant income inequality on the long-term sustainability of development initiatives. Afflictions marked by substantial income inequality frequently confront restricted access to financial resources and technology, thereby curtailing the potential benefits of FinTech. This finding aligns with the diffusion of innovation theory of Rogers (1995), which posits that the favorable reception and constructive effects of new technologies are more probable in contexts where they are readily accessible and compatible with the socioeconomic conditions of users. When income disparities are substantial, the restricted accessibility of critical technology and financial services can significantly impede the effectiveness of FinTech solutions, thereby impeding progress towards achieving development goals. According to previous studies (Adjasi et al. 2023; Huang et al. 2023; Huang et al. 2024), this may hinder innovation by restricting the availability of the capital and resources necessary for the adoption and progression of technology.

To understand the complex relationship between technology, economy, and sustainability, the model emphasizes the importance of control variables, including population expansion, GDP per capita growth, and education level. The relationship between economic prosperity, the availability of resources for sustainable technologies, and the growth of GDP per capita suggests that economic health is essential for fostering an environment conducive to FinTech and similar

innovations, thereby advancing sustainable development (Sachs et al. 2022). The pressure that population growth places on existing infrastructure and resources is a significant factor affecting sustainability. However, its influence extends to the efficacy and demand for FinTech solutions (United Nations 2015a). There is a significant correlation between one's level of education and enhanced comprehension and embracing of technological advancements. Academic pursuits at the tertiary level empower learners to more effectively understand and adopt advancements in FinTech (Khan & Khan 2023), thereby fostering prosperous and all-encompassing deployments. To effectively utilize FinTech to achieve sustainable development, these elements underscore the importance of sustaining consistent economic expansion, regulating population growth, and guaranteeing a highly educated population. In addition to income inequality, it is critical to resolve these concerns to ensure that technological advancements in ASEAN nations foster economic expansion and contribute to sustainable and equitable development.

SENSITIVITY ANALYSIS AND ROBUSTNESS TEST USING ALTERNATIVE SUSTAINABLE DEVELOPMENT MEASURE

We conducted a sensitivity analysis and a robustness test using the SDGI. The purpose of this analysis was to validate the reliability and consistency of the results obtained using the foundational model. By using the same random-effects model as the SDGI, any inconsistencies in the results could be attributed to changes in the measurement of sustainable development rather than the modelling approach. The SDGI is a comprehensive metric that integrates performance data from various development sectors such as poverty, health, education, gender equality, economic growth, and environmental sustainability (Sachs et al. 2022). This allowed a thorough assessment of the reliability of the model across different aspects of progress. The widespread acceptance and robust scientific foundation of the SDGI as a tool for monitoring progress towards universally recognized development goals justify its application in this study. This strengthens the theoretical basis of this study by linking it to the globally acknowledged development goals. Thus, this study analyzes the effect of FinTech on sustainable development using the SDG index (SDGI) as a dependent variable:

$$SDGI_{it} = \beta_0 + \varpi_1 FinTech_{it} + \beta_2 FinTech_{it}^2 + \beta_3 M_{it} + \lambda X_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

where $SDGI_{it}$ signifies the sustainable development goal level of country i in year t, β_0 is the intercept term, μ_i is the random effect for country i, which varies across countries but is constant over time, capturing all country-specific random variations; and ε_{it} is the random error term. The random error term in the econometric model is assumed to have zero mean, constant variance (homoscedasticity), no autocorrelation, and no endogeneity with the independent variables. $FinTech_{it}$ is the FinTech index, and $FinTech_{it}^2$ is an independent variable that captures the U-shape with $SDGI_{it}$, M_{it} is the moderation variable (Gini). X_{it} is the set of control variables, $\beta_1 - \beta_3$ is the coefficients of the independent variables, and λ connotes the coefficient vector on the control variables.

TABLE 6. Sensitivity and robustness test on results of fintech, income inequality and sustainable development goal index

	Dependent Variable: Sustainable Development Goal Index (SDGI)				
	(1)	(2)	(3)	(4)	(5)
Variable	FinTch	FinTech^2	INDUI	lnAOFM	lnMCS
FinTech	0.088***				
	(4.94)				
Gini	-0.167**	-1.177***	-0.017**	-0.118	-0.006**
	(-2.62)	(-4.02)	(-2.11)	(-5.15)	(-3.29)
FinTch×Gini	0.084***				
	(5.30)				
FinTech^2		0.015*			
		(1.95)			
FinTech^2×Gini		0.003**			
		(2.20)			
INDUI			-0.015**		
			(-2.22)		
INDUI×Gini			0.091**		
			(7.87)		
lnAOFM				-0.196	
				(-3.48)	
lnAOFM×Gini				0.046	
				(3.18)	
lnMCS					-0.008**
					(-2.40)
lnMCS×Gini					0.120**
					(5.42)
GDPPCG	0.012***	0.023***	0.006**	0.048**	0.204**
	(4.83)	(6.94)	(3.89)	(8.59)	(2.92)

PoPG	0.036***	0.039*	0.401***	0.373***	0.173**
	(19.75)	(1.80)	(18.22)	(8.16)	(2.54)
ELLF	0.012***	3.318	1.708***	0.068**	0.164**
	(4.83)	(4.91)	(3.02)	(4.08)	(2.82)
Net Effects	3.312	0.130	3.477	1.569	4.597
R^2	0.631	0.578	0.484	0.519	0.427
Wald χ^2	78.56***	77.86***	64.92***	68.29***	61.87***
B-P LM Test (Prob> χ^2)	0.000	0.001	0.000	0.000	0.000
Hausman Test (Prob> χ^2)	0.519	0.203	0.374	0.143	0.451
Countries	10	10	10	10	10
Obs.	61	77	78	68	68

*Note(s): ***,**, and *indicate significance at the 1 %, 5 %, and 10% levels, respectively. The z-statistics are in parentheses. SDGI: sustainable development goal index. Fintech: financial technology index. lnAOFM: natural log of account ownership at a financial institution or with a mobile money service provider. lnMCS: Natural log mobile cellular subscription. Gini: Gini index. GDPGPC: GDP growth per capita. PoPG: population growth. ELLF: Education level of labor force. The mean Gini index value was 38.379.*

The use of the SDG Index in conducting the sensitivity analysis strengthens the reliability and robustness of the study's findings. This study demonstrates that the positive impact of FinTech on sustainability is not influenced by specific measurement choices as consistent results are observed across different models and sustainable development indicators. This consistency provides a solid basis for verifying the genuine and reproducible advantages of FinTech in promoting sustainability. The study results were well-founded because of the rigorous methodology employed, including the use of the SDGI. This increases the confidence of policymakers and stakeholders in the suitability of the data for informed decision making. This thorough validation process underscores the importance of using comprehensive and multidimensional tools in research to capture the complex relationships between technological advancements and development goals. This further enhances the credibility of the findings in guiding future policy and strategic initiatives.

SUMMARY AND CONCLUSIONS

This study examines the relationship between FinTech, income inequality, and sustainable development in the 10 ASEAN countries from 2015 to 2022. This provides evidence that FinTech can contribute to environmental conservation, economic progress, and social welfare. However, this study also emphasizes the need for careful regulation and strategic policy frameworks to prevent excessive market saturation and ensure that FinTech benefits are accessible to a diverse range of individuals.

These findings suggest that nations with smaller economic disparities are better positioned to implement technological innovations efficiently and inclusively. This underscores the importance of prioritizing the reduction of economic disparities and the advancement of inclusive financial ecosystems. This study recommends adopting a strategic policy framework to maximize FinTech benefits while minimizing its potential negative impacts. Policymakers in ASEAN countries should focus on investing in digital infrastructure to increase internet penetration and mobile network coverage, especially in underserved areas, bridge the digital divide and provide equitable access to financial services. Governments in these countries must develop strong regulatory frameworks to ensure consumer protection, foster innovation, and promote competition within the FinTech sector, including data privacy, cybersecurity, and fair lending standards. Public-private partnerships can drive the development and deployment of FinTech solutions tailored to marginalized communities, enhancing financial literacy and digital skills. Additionally, financial institutions in these countries should offer targeted products for low-income groups such as microloans and accessible mobile banking services. Additionally, policies aimed at reducing income inequality, like progressive taxation and social welfare programs.

This study highlights the potential of FinTech to contribute to sustainable development objectives. However, it also emphasizes the need for careful regulation and strategic policy frameworks to ensure that Fintech benefits are accessible to all and do not exacerbate existing economic disparities. ASEAN governments can promote sustainable development by prioritizing inclusive financial ecosystems. This involves enhancing digital infrastructure, bridging the digital divide, and providing equitable access to financial services. Robust regulatory frameworks are essential to consumer protection, innovation, and competition in the FinTech sector. Public-private partnerships can drive FinTech solutions for marginalized communities, whereas targeted products for low-income groups and progressive taxation can reduce income inequality.Future researchers could study individual Southeast Asian nations to understand the impact of income inequality on the relationship between FinTech, sustainability, and access, using trends and regulatory frameworks, and tailoring their suggestions accordingly.

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