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Paradigm Shift Toward Just and Sustainable Welfare: How Financial Inclusion Shapes Inclusive Green Growth Under Digital Infrastructure

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Abstract: This study aims to examine the influence of financial inclusion dimensions accessibility (ACC), availability (AVA), and usability (USE) on the Inclusive Green Growth Index (IGGI) across all provinces in Indonesia, and to assess the moderating role of Digital Infrastructure (DIF) in strengthening this relationship. The study uses panel data from all provinces in Indonesia for the period 2019-2024 and employs three analytical approaches: Fixed Effects Model (FEM), Panel Vector Error Correction Model (PVECM), and moderation analysis using DIF. The findings reveal that in the FEM, ACC and USE have a positive and significant effect on IGGI, while AVA has a negative significant effect. The dynamic analysis using PVECM indicates that in the short term, ACC negatively affects IGGI, AVA and USE positively affect IGGI, whereas in the long term, ACC remains negative, USE remains positive, and AVA is no longer significant. The moderation analysis shows that DIF does not significantly moderate the effects of ACC and USE, while AVA is negatively significant, indicating that digital infrastructure has not fully enhanced the role of financial inclusion in promoting inclusive green growth. These results imply that policy strategies should focus on expanding equitable access to financial services, enhancing financial and digital literacy, strengthening regulatory support, and tailoring digital infrastructure development to regional and demographic conditions to foster sustainable inclusive green growth. The study's limitations include the use of quantitative DIF measures without assessing the quality of technology adoption. Future research is recommended to explore the impact of financial inclusion at the micro level, adopt more current indicators, and conduct analyses by demographic regions or cross-country comparisons to validate findings.

Keywords: Financial Inclusion; Digital Infrastructure; Inclusive Green Growth; Indonesia; PVECM

1. Introduction

The Climate change, declining environmental quality, and rising social inequality are pushing many countries to develop development approaches that are not only growth-oriented but also focused on sustainability and equity. The idea of inclusive green growth is important because it integrates economic, environmental, and social aspects simultaneously. However, a number of studies show that developing countries still face major challenges to achieve truly inclusive green growth, due to the dilemma between economic growth and environmental protection [1]. Avis [2] emphasized that the imbalance between inclusion and sustainability often occurs when the country's institutional capacity is inadequate, so the implementation of green growth tends to face structural obstacles.

Globally, the development of financial inclusion continues to show progress. The Global Findex Database 2025 report notes that 79% of the world's adult population had an account with a formal financial institution by 2024, a significant increase from 51% in 2011. Nevertheless, some 1.3 billion adults still remain unreachable for formal financial services. This gap is prevalent in low- and middle-income countries, especially in low-income groups, women, and people in remote areas. In addition, Global Findex 2025 also introduces a new indicator called the Digital Connectivity Tracker, which confirms that the gap in internet access and digital devices is a major inhibiting factor for digital financial inclusion in many developing countries [3].

In the context of inclusive development, financial inclusion plays an important role in providing access for people to participate in formal economic activities. Access to savings, credit, and other financial services allows households and small businesses to increase productive capacity, manage risk, and invest in activities that support long-term well-being [4,5]. However, some studies show that increased access to credit is not always in line with environmental sustainability as it can increase energy consumption and non-environmentally friendly goods [6]. Thus, the contribution of financial inclusion to green development depends on the support of other factors that can direct people's economic activities in a more sustainable direction.

Indonesia itself shows interesting and challenging dynamics of financial inclusion. The results of the 2025 National Survey on Financial Literacy and Inclusion (SNLIK) show that the national financial inclusion rate reached 80.51%, an increase from 75.02% in 2024, while financial literacy increased to 66.46% [7]. However, this achievement is not completely evenly distributed. Significant gaps were seen between urban (83.61%) and rural (75.70%) communities, as well as vulnerable groups such as low-educated people, farmers, fishermen, and residents of the archipelago. On the other hand, the use of digital financial services is still dominated by consumptive transactions, not productive financing or environmentally friendly investments. The limitations of digital infrastructure, ranging from the quality of the internet network, the availability of technological devices, to digital literacy, especially in areas outside Java, also hinders the optimization of digital financial inclusion. This condition shows that there is an inconsistency between the increasing level of financial inclusion and its contribution to greener, more inclusive, and sustainable development.

The development of digitalization then presents new opportunities through digital financial inclusion. The digitalization of financial services can expand service reach, lower transaction costs, and improve economic efficiency. Various studies show that digital financial inclusion has significant potential in driving green growth through increased innovation, resource efficiency, and information dissemination. The same is also seen in the ASEAN region, where digital financial inclusion has been proven to be related to economic and environmental performance [8]. On the other hand, green

finance contributes to expanding economic inclusion and supporting the achievement of sustainable development goals [9]. Support for digital innovation also strengthens the link between financial inclusion and sustainable development [10].

As a basic element in the digital ecosystem, digital infrastructure plays a role that cannot be ignored. Nie et al [11]. show that digital infrastructure plays an important role in increasing urban green innovation through economic agglomeration, strengthening digital inclusive finance, and increasing public attention to environmental issues. However, most previous research has only positioned digital infrastructure as an independent variable, not as a moderation variable in inclusive financial relations and inclusive green development.

Most of the research on financial inclusion and green growth has been conducted in certain countries, especially in China for example [12], [13]. Several studies have been conducted at the regional level such as South Asia [14]; MENA [15]; ASEAN [8]. In addition, multi-country research is developing, such as those conducted by Abbas et al. [16]; Ghaffar et al. [10]; Majeed et al. [6]; Thi and Oanh [5] to enrich the literature, although it does not examine the specific Indonesian context.

In the Indonesian context, Research by Az-zahra et al. [17] examines the relationship between financial inclusion and inclusive economic growth, but has not included the environmental dimension and has not examined the role of digital infrastructure. Similarly, Amaliah's [18] research examines digital financial inclusion and sustainable economic growth in Indonesia with indicators of GDP growth and CO₂ emissions. Although it makes an important contribution to the digital financial inclusion literature, the study does not include the concept of financial inclusion in a broader scope, has not implemented inclusive green growth indicators, and does not use digital infrastructure as a moderation variable. Thus, these studies have not been able to explain how the quality of digital infrastructure can strengthen or weaken the influence of financial inclusion on inclusive green development in Indonesia.

Although Al-Smadi [15] tested digital finance as a moderation variable in MENA countries, the study did not include digital infrastructure and did not focus on inclusive green growth. Thus, currently there is no research in both the Indonesian and global contexts that comprehensively integrates financial inclusion, digital infrastructure as moderation variables, and inclusive green growth in one empirical framework. In fact, the inequality in the quality of digital infrastructure in Indonesia is an important determinant that has the potential to affect the effectiveness of expanding financial access in encouraging inclusive green development. This empirical and theoretical gap emphasizes the urgency and contribution of the novelty of this research.

To address this gap, the present study goes beyond a mere integration of variables by developing a more structured conceptual linkage that explains the transmission mechanism between financial inclusion and inclusive green growth under varying levels of digital infrastructure. Prior studies have examined these relationships in a fragmented manner, focusing either on financial inclusion and green growth e.g. Dong et al. [4] or on digital infrastructure and green innovation e.g. Nie et al. [11], but have not simultaneously captured their interactive dynamics within a single framework.

This study therefore proposes a theoretically grounded model in which digital infrastructure functions not only as a supporting factor but also as a moderating mechanism that conditions the effectiveness of financial inclusion in driving sustainable outcomes. In line with endogenous growth theory and sustainable development perspectives, digital infrastructure enhances efficiency, connectivity, and information flows, which in turn influence how financial resources are accessed,

allocated, and utilized [19,20]. When effectively utilized, financial inclusion can channel funding toward productive and environmentally sustainable sectors, thereby fostering inclusive green growth [20], [21].

By explicitly articulating this mechanism, the study contributes not only empirically but also conceptually, offering a more integrated framework to understand the nexus between financial inclusion, digital transformation, and sustainable development, particularly in the context of developing countries such as Indonesia, where digital disparities remain significant.

2. Literature Review

2.1. Financial Inclusion

Financial inclusion is a condition when people have broad and easy access to formal financial services, such as banking, credit, and payment systems [16,19]. This concept includes three main aspects, namely access to financial services, the level of use by the community, and the quality of services that are able to meet the needs of users [22]. Financial inclusion is important because it can connect groups of people who were previously underserved by the formal financial system into more productive economic activities [20].

From an economic development perspective, financial inclusion contributes to promoting more inclusive growth through expanding access to finance and increasing people's economic activities [23]. Financial access allows individuals and business actors to invest, develop businesses, and improve their well-being [20]. A number of studies have also shown that financial inclusion plays a role in reducing inequality and supporting sustainable development, as it promotes a more equitable and efficient distribution of the economy [24,25].

2.2. Digital Infrastructure

Digital infrastructure is a set of technologies and networks that enable digital connectivity, such as the internet, telecommunication systems, and data-based platforms [26]. This infrastructure is the backbone of modern economic development because it supports real-time information exchange and integration of various technology-based activities [25]. The main elements include network availability, access speed, and digital system capacity that is able to reach various regions and community groups [27].

The existence of digital infrastructure encourages changes in the way people and business actors carry out economic activities, including in terms of transactions, distribution, and service innovation [28]. This technology support also accelerates the adoption of digital financial services, thereby expanding the reach of financial services to people who previously had limited access [29]. A number of studies show that improving the quality of digital infrastructure is related to increasing economic efficiency and more inclusive growth opportunities through optimal use of technology [30–32].

2.3. Inclusive Green Growth Index

The Inclusive Green Growth Index (IGGI) is an indicator that measures development success that combines economic growth, social inclusion, and environmental sustainability [32]. This concept emphasizes that growth not only boosts the economy, but must also be evenly distributed and still protect the environment [33]. IGGI consists of three main dimensions, namely the economic

dimension (performance and efficiency), the social dimension (equity and welfare), and the environmental dimension (resource sustainability and environmental quality) [34].

In development, IGGI plays a role in supporting sustainable development by providing a comprehensive overview of the balance between these aspects. Previous research has shown that IGGI is influenced by factors such as government policies and governance (environmental regulations, government effectiveness, fiscal spending structure) [33,34], financial inclusion and financial stability [33,35], green investment and green finance [36,37], technological advances and digital economy [16,38], education and the quality of human resources [35,36], as well as income distribution and other dimensions of social equity [39].

2.4. Theoretical Framework

The basic concepts in this study depart from three main foundations, namely the theory of economic growth, sustainable development, and financial inclusion. Economic growth theory emphasizes the importance of the role of technology and capital as the main drivers of increased output and productivity [40]. On the other hand, sustainable development emphasizes a balance between economic, social, and environmental aspects so that the growth achieved does not come at the expense of future generations, as emphasized in the framework of Our Common Future and various recent studies related to sustainable development goals and the circular economy [41,42]. Meanwhile, financial inclusion emphasizes expanding access to financial services for all levels of society to create economic equity, reduce inequality, and support more inclusive and sustainable economic development [42].

In this study, the three concepts were operationalized through the variables used. Digital infrastructure is positioned as a representation of technological advances that are able to improve connectivity and economic efficiency [43]. Financial inclusion serves as a mechanism for distributing economic access that allows communities, including vulnerable groups, to participate in formal economic activities [44]. Inclusive green growth is the ultimate goal that reflects the achievement of economic growth that is not only socially inclusive but also environmentally sustainable [45].

The integration between concepts shows a mutually supportive linkage. The development of digital infrastructure encourages increased efficiency and expanded access to various services, including financial services [46]. This wider access then strengthens financial inclusion by opening up opportunities for people to obtain financing, make investments, and increase productivity [24]. Ultimately, such increased financial inclusion contributes to driving more inclusive and sustainable growth.

Based on this integration, the conceptual flow in this study illustrates that digital infrastructure has an effect on financial inclusion, which in turn has an impact on inclusive green growth. In addition, digital infrastructure also has a direct influence on inclusive green growth. Thus, the relationship between variables in this study is based on the integration of the theory of economic growth, financial inclusion, and sustainable development as a basis for explaining the mechanism that occurs.

3. Materials and Methods

3.1. Data Collection and Research Design

This study examines the impact of digital financial inclusion on inclusive green growth in Indonesia, specifically analyzing the moderating role of digital infrastructure. Using panel data from 32 provinces during the 2019–2024 period selected based on data completeness the sample includes Aceh, North Sumatra, West Sumatra, Riau, Riau Islands, Jambi, Bengkulu, South Sumatra, Bangka Belitung, Lampung, DKI Jakarta, West Java, Banten, Central Java, Special Region of Yogyakarta, East Java, Bali, West Nusa Tenggara, East Nusa Tenggara, West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan, North Sulawesi, Central Sulawesi, South Sulawesi, Southeast Sulawesi, Gorontalo, West Sulawesi, Maluku, North Maluku, and Papua. The study operationalizes digital financial inclusion through three dimensions: accessibility, availability, and usability, while inclusive green growth is conceptualized across economic, social, and environmental pillars. Digital infrastructure is employed as a moderating variable to assess how its availability strengthens the relationship between digital financial inclusion and inclusive green growth. Data obtained from OJK, Bank Indonesia, BPS, and KLHK are analyzed using panel regression models. This research offers new insights into the synergy between digital finance and sustainable development, highlighting the critical roles of accessibility, availability, and usability in fostering inclusive and environmentally sustainable economic growth.

Table 1. Variable Description.

Variable	Definition	Source
Dependent Variables		
Inclusive Green Growth Index (IGGI)	A composite index encompassing three pillars (economic, social, and environmental), reflecting sustainable and inclusive development outcomes at the provincial level.	Author's Calculation
Independent Variables		
Financial inclusion (FI)	A multidimensional index operationalized through accessibility, availability, and usability, representing the extent to which digital financial services are utilized by the population.	Author's Calculation
Moderating Variables		
Digital infrastructure (DIF)	The availability and quality of digital infrastructure that potentially moderates the relationship between digital financial inclusion and inclusive green growth.	Author's Calculation

Source: Author's calculation.

3.2. Calculation Method of Inclusive Green Growth Index (IGGI)

This study calculates the Inclusive Green Growth Index (IGGI) based on the framework developed by the Asian Development Bank [47]. Adjusted for data availability at the provincial level in Indonesia, the IGGI is constructed using 30 variables: 14 economic indicators, 10 social indicators, and 6 environmental indicators. Data were obtained from the Central Statistics Agency (BPS) and the Ministry of Environment and Forestry (KLHK), covering 32 provinces with complete datasets. The index is compiled through the following stages:

1. Normalize each variable using the min-max normalization method.
 - Normalization for variables with a positive effect on IGGI

$$Z = \frac{x - x_{min}}{x_{max} - x_{min}} + 1 \tag{1}$$

- Normalization for variables with a negative effect on IGGI

$$Z = \frac{x_{max} - x}{x_{max} - x_{min}} + 6 \tag{2}$$

2. Calculate the value of each pillar with the weighted average of the normalized indicator values with the formula:

$$Pillar\ to\ n = \frac{Z_1 + Z_2 + Z_3 + \dots + Z_i}{i} \tag{3}$$

i = The number of variables used on *the n* pillar.

3. Calculate the IGGI value with the formula:

$$IGGI = \frac{1}{3}(\text{Economy Pillar}) + \frac{1}{3}(\text{Social Pillar}) + \frac{1}{3}(\text{Environment Pillar}) \tag{4}$$

In addition to the standard IGGI, this study calculates the Balanced IGGI (BIGGI) to evaluate the equilibrium across the three dimensions. Achievement of inclusive green growth is significantly influenced by the balanced performance of economic, social, and environmental aspects. The BIGGI is calculated as follows:

1. Calculate the total absolute gap between the pillars with the formula:

$$\text{Total absolute gap} = |\text{Economic Pillar} - \text{Social Pillar}| + |\text{Social Pillar} - \text{Environmental Pillar}| + |\text{Environmental Pillar} - \text{Economic Pillar}| \tag{5}$$

2. Normalize the absolute total value with the formula:

$$CPBi = -5 \times \frac{(\text{Total gap} - \text{Minimum gap})}{\text{Maximum gap} - \text{Minimum gap}} + 6 \tag{6}$$

3. Calculating the BIGGI value with the formula:

$$BIGGI = \frac{3}{4}IGGI + \frac{1}{4}CPB \tag{7}$$

Table 2. Indicators of the Regional IGGI in Indonesia.

No.	Indicators	Operational Definition	Measurement Unit	Source
Economic Pillar				
1	Economy Growth (ECO)	Gross regional domestic product growth rate (%)	Percent	BPS
2	Trade Openness (TO)	Ratio of total exports and imports to GRDP, representing the degree of a province's economic openness to international trade	Percent	BPS
3	Primary Sector GDP (GRDP_PRIM)	The value of the primary sector's GDP contribution includes 1) the agriculture, forestry, and fisheries, and 2) the mining and quarrying sector	Million IDR	BPS
4	Secondary Sector GDP (GRDP_SEC)	Value of sector GDP contribution 1) processing industry, 2) procurement	Million IDR	BPS

		of electricity and gas, 3) water procurement, waste management, waste and recycling reconstruction, and 4) construction		
5	Tertiary Sector GDP (GRDP_TER)	The value of the sector's GDP contribution sectors other than the primary sector and secondary	Million IDR	BPS
6	Government expenditure on public service functions (GOV_PUB)	Government spending for public service functions	Million IDR	BPS
7	Government expenditure on order and security functions (GOV_SEC)	Government spending for order and security functions	Million IDR	BPS
8	Government expenditure on economic functions (GOV_ECO)	Government spending for economic functions	Million IDR	BPS
9	Government expenditure on environmental functions (GOV_ENV)	Government spending for service functions common	Million IDR	BPS
10	Government expenditure on housing and public facilities functions (GOV_HOU)	Government spending for environmental functions live	Million IDR	BPS
11	Government expenditure on health functions (GOV_HEA)	Government spending for health function	Million IDR	BPS
12	Government expenditure on tourism and culture functions (GOV_TOU)	Government spending for the function of tourism and culture	Million IDR	BPS
13	Government expenditure on education functions (GOV_EDU)	Government spending for educational functions	Million IDR	BPS
14	Government expenditure on social protection functions (GOV_SOC)	Government spending for protection function social	Million IDR	BPS
Social Pillar				
1	RT electricity users (ELECT)	Percentage of households (RT) that use PLN's electric lighting source (%)	Percent	BPS
2	Gini ratio (INEQ)	Inequality income	Percent	BPS
3	Life Expectancy (AHH)	Life expectancy at the moment Born (year)	Percent	BPS
4	Index Empowerment	Women's active participation in economic life	Percent	BPS

	gender (IDG)	and politics		
5	APS for elementary school (NER_PRIM)	School Participation Figures (APS) for ages 7-12 in Primary School and Equivalent	Percent	BPS
6	APS for junior high school (NER_SEC)	School Participation Figures (APS) for ages 13-15 in Junior High School and equivalent	Percent	BPS
7	APS for high school (NER_HIGH)	School Participation Figures (APS) for ages 7-12 in High School and Equivalent	Percent	BPS
8	Mean Years of Schooling (MYS)	Average years of formal education received by population aged 25+	Percent	BPS
9	Average Years of Schooling (AYS)	Average years of schooling completed by the population	Percent	BPS
10	Human Development Index (HDI)	Composite index of human development covering health, education, and income	Percent	BPS
Environmental Pillar				
1	Access to Clean Water (SANITATION)	Percentage of Households (RT) who gain access to Source of Decent Drinking Water (%)	Index	KLKH
2	Air Quality Index (AQI)	Level of air in an area at a certain period (%)	Index	KLKH
3	Water Quality Index (WQI)	Condition of water in an area at a particular time (%)	Index	KLKH
4	Marine Water Quality Index (IKAL)	A value that describes the status and condition of marine water quality in a specific location at a given time (%)	Index	KLKH
5	Land Cover Quality Index (IKTL)	A value that describes the status and condition of land cover in a specific location at a given time	Index	KLKH
6	GRDP Mining and Quarrying Sector Index (GRDP_MIN)	Development of the contribution of the mining and quarrying sector to provincial GRDP	Index	BPS

Note: GRDP – Gross Regional Domestic Product; IDR – Indonesia Rupiah; BPS - Central Bureau Statistics; and KLHK - Ministry of Environment and Forestry.

3.3. Financial Inclusion and Its Dimensions

Financial inclusion refers to the extent to which individuals and enterprises have access to formal financial services that are both useful and affordable, enabling them to participate effectively in economic activities. The measurement of financial inclusion in this study represents an extension of the indicators proposed by Sarma [48]; Sarma & Pais [49]; Rahman et al. [50]; Erlando et al. [51]. This

approach incorporates three key dimensions accessibility, availability, and utilization as presented in Table 3. Such a framework is intended to provide a comprehensive assessment of the extent to which financial services are accessible, available, and effectively utilized by the population within a given region. In this study, as summarized in Table 3. Accessibility is measured by the ratio of total deposit accounts (DPK) to the adult population, capturing the availability of financial services to the population. Availability is proxied by the ratio of total bank branches to the adult population, reflecting the physical infrastructure supporting access to banking services. Usability represents the degree to which financial services are actively utilized in economic activity, measured as the ratio of total financing to Gross Regional Domestic Product (GRDP). The data for these indicators are sourced from Bank Indonesia (BI), OJK, and BPS, providing a comprehensive and multidimensional perspective on the level of financial inclusion across Indonesian provinces.

Table 3. Operationalization of Financial Inclusion Indicators.

Variable	Indicator	Source
Accessibility	Amount of total deposit accounts / Number of adult population	Bank Indonesia (BI) & Statistics Indonesia (BPS)
Availability	Number of bank offices / Number of adult population	OJK & Statistics Indonesia (BPS)
Usability	Amount of financing / Gross regional domestic product	Bank Indonesia (BI) & Statistics Indonesia (BPS)

Source: Data processed by the author (2025).

3.4. Digital Infrastructure (DIF) Index Calculation Method

Until now, there has been no universally accepted standard for measuring the digital economy across studies, as many previous investigations have relied on single proxies such as financial technology, internet usage, or broader ICT adoption [52,53]. However, the use of a single indicator is insufficient to capture the multidimensional nature of digital economy development. To address this limitation, this study constructs a Digital infrastructure Index (DIF) as a composite measure of the digital economy for 32 Indonesian provinces over the 2019–2024 period. The index integrates multiple key indicators, including the percentage of mobile phone users (CELL), computer users (COMP), internet users (INTER), as well as the availability of card and e-money infrastructure (CARD_INFRA), regional e-money usage (E-MONEY), and RTGS transaction volume (RTGS), which collectively reflect the adoption and utilization of digital technology in society. This study applies the Z-Score standardization method to normalize and aggregate the indicators, providing a more transparent and robust assessment of digital infrastructure development. This approach allows for a comprehensive evaluation of the digital economy across all provinces and provides a solid empirical basis for policy formulation aimed at promoting inclusive and sustainable digital transformation in Indonesia.

$$\bar{x} = \frac{X - \bar{X}}{S} \tag{8}$$

Explanation:

\bar{x} = Standardized Value (Z-Score)

X = Sample Value

\bar{X} = Sampel Mean

S = Sample Standard Deviation

Table 4. Components of the Formation of Digital Infrastructure.

Variable	Indicator	Source
Mobile phone (CELL)	Percentage of the population owning a mobile or wireless phone (%)	Statistics Indonesia (BPS)
Computer (COMP)	Percentage of the population using a computer (PC, desktop, laptop, notebook, tablet) (%)	Statistics Indonesia (BPS)
Internet (INTER)	Percentage of population accessing the internet (%)	Statistics Indonesia (BPS)
Card & e-Money Infrastructure (CARD_INFRA)	Availability and capacity of electronic payment infrastructure, including ATMs, EDC, and card networks	Bank Indonesia (BI)
Regional e-Money Usage (E-MONEY)	Level of e-money utilization by the population in a region	Bank Indonesia (BI)
RTGS Transactions (RTGS)	Volume and value of real-time gross settlement transactions among banks	Bank Indonesia (BI)

Source: Data processed by the author (2025).

3.5. Specifications of Research Models and Stages of Analysis

This study employs a quantitative approach using panel econometric analysis to examine the influence of financial inclusion dimensions such as accessibility (ACC), availability (AVA), and usability (USE) on the Inclusive Green Growth Index (IGGI) across 32 provinces in Indonesia from 2019 to 2024. It also evaluates the role of Digital Infrastructure (DIF) as a moderating variable that shapes the strength of the relationship between financial inclusion and inclusive green growth. To achieve these objectives, the study applies two econometric models: panel regression and the Panel Vector Error Correction Model (PVECM). Panel regression is used to capture the structural and direct effects of financial inclusion, including the moderating effect of DIF, while PVECM is employed to identify short-run dynamics, long-run equilibrium relationships, and potential bidirectional causality that cannot be detected by static panel models. By integrating these two approaches, the study provides a more comprehensive and robust analysis of the mechanisms through which financial inclusion and digital infrastructure contribute to the formation of inclusive green growth in Indonesia.

The first analysis is conducted using panel data regression employing three estimation models, namely the Common Effect Model (CEM), the Fixed Effect Model (FEM), and the Random Effect Model (REM). The selection of the most appropriate model is determined through the Chow Test, the Hausman Test, and the Lagrange Multiplier Test [54]. The moderation model is constructed by incorporating interaction terms between the financial inclusion variables and digital infrastructure. Accordingly, the panel model used in this study is formulated as follows:

$$IGGI_{it} = \beta_0 + \beta_1 ACC_{it} + \beta_2 AVA_{it} + \beta_3 USA_{it} + \beta_4 ACC * DIF_{it} + \beta_5 AVA * DIF_{it} + \beta_6 USA * DIF_{it} + \varepsilon_{it} \quad (9)$$

Next, this study employs the Panel Vector Error Correction Model (PVECM) to capture the dynamic relationships among the variables [55]. The first step in the analysis is estimating the short-run model, which begins by assessing changes in the Inclusive Green Growth Index (IGGI) in

response to changes in Accessibility (ACC), Availability (AVA), Usability (USE), and Digital Infrastructure (DIF). The short-run model also incorporates the Error Correction Term (ECT), which reflects the system's adjustment process back toward long-run equilibrium following a disturbance. The short-run model is formulated as follows:

$$\Delta IGGI_{it} = \alpha ECT_{it} - 1 + \sum \gamma_1 \Delta ACC_{it} + \sum \gamma_2 \Delta AVL_{it} + \sum \gamma_3 \Delta USB_{it} + \sum \gamma_4 \Delta DIF_{it} + \varepsilon_{it} \quad (10)$$

In this context, $\Delta IGGI$ represents the change in IGGI, while the ECT captures the speed of adjustment toward long-run equilibrium, with the coefficients γ_1 to γ_4 measuring the impact of changes in each variable on changes in IGGI. A negative and statistically significant α coefficient indicates the presence of a correction mechanism toward long-run equilibrium. Furthermore, to capture the long-run relationships among the variables used in this study, the long-run model is estimated and formulated as follows:

$$IGGI_{it} = \beta_0 + \beta_1 ACC_{it} + \beta_2 AVA_{it} + \beta_3 USA_{it} + \beta_4 DIF_{it} + \varepsilon_{it} \quad (11)$$

In this long-run model, the relationships between IGGI and the variables of Accessibility, Availability, Usability, and Digital Infrastructure are explained without involving their short-term changes, focusing instead on the direct long-term effects of each variable on IGGI. The coefficients β_1 to β_4 indicate the long-run influence of each variable on IGGI. In addition, the Impulse Response Function (IRF) is employed to examine how shocks to Accessibility (ACC), Availability (AVA), Usability (USE), and Digital Infrastructure (DIF) affect IGGI over time, providing insights into both the short-run and long-run impacts of changes in these factors on inclusive green growth.

As the final stage of the analytical procedure, this study performs a Robustness Check using the Fully Modified Ordinary Least Squares (FMOLS) method [56]. The integration of FMOLS is intended to validate the consistency and reliability of the estimation results obtained from the Fixed Effect and PVECM models. This method is specifically selected for its ability to address potential endogeneity and serial correlation issues inherent in panel data, thereby providing optimal and unbiased long-run coefficients. By comparing the results across these diverse estimation techniques, the study ensures that the identified relationships between financial inclusion, digital infrastructure, and inclusive green growth are robust and not sensitive to variations in econometric specifications. This multi-staged approach ensures a comprehensive and rigorous analysis of the mechanisms driving inclusive green growth in Indonesia.

4. Results

4.1. Result

4.1.1. Descriptive Statistics

Table 5 shows the descriptive statistics depicting the inclusive green growth (IGGI) conditions in Indonesia. The average IGGI value at the provincial level is 2.77, with a minimum of 2.01, a maximum of 3.66, and a standard deviation of 0.29, indicating a moderate level of inclusive green growth, but with significant disparities across regions. Provinces with the lowest IGGI values are typically concentrated in Eastern Indonesia, such as Papua, East Nusa Tenggara, and West Sulawesi, which face structural challenges in economic development and the implementation of green growth policies. In contrast, more developed provinces such as DKI Jakarta, Bali, and the Riau Islands have

the highest IGGI values, reflecting better economic capacity and the availability of policies and infrastructure supporting green growth implementation.

The Digital Infrastructure variable has an average value of 31.66, with a wide range from -2.92 to 44.51, indicating a significant gap in access to and usage of digital financial services across provinces. Provinces with the highest Digital Infrastructure values, such as DKI Jakarta and Bali, reflect more advanced digital infrastructure and broader access to digital financial services, while Papua and several provinces in Kalimantan and Sulawesi show negative or very low values, indicating limited access to and adoption of digital technology, as well as low levels of digital financial literacy in these regions.

Table 5. Descriptive Statistics.

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
IGGI	2.772445	2.754692	3.658696	2.014746	0.287502	192
Accessibility	7.222966	7.177872	8.597678	6.720621	0.312823	192
Availability	2.107900	2.022608	5.796121	0.915981	0.889609	192
Usability	0.444713	0.404936	0.945942	0.193287	0.152354	192
DIF	31.66115	37.59000	44.51000	-2.920000	14.69684	192
Dig_Acc	229.3910	268.6527	382.6827	-21.30424	107.9567	192
Dig_Ava	66.19987	71.37596	250.7656	-5.766547	45.76764	192
Dig_Use	14.36131	14.39161	42.10389	-1.350177	8.838393	192

Source: Data processed by the author (2025).

Additionally, the Accessibility and Usability variables also show significant differences. The average Accessibility value is 7.22, with a range from 6.72 to 8.60, indicating relatively widespread access to financial services in Indonesia, although provinces in the eastern regions tend to fall below the average. Usability has an average value of 0.44 and a standard deviation of 0.89, reflecting uneven usage of financial services across provinces, particularly in regions with limited digital infrastructure and internet access. Provinces with the highest Usability values, such as DKI Jakarta and Bali, show better capabilities in utilizing available financial services, while regions with limited digital access, such as Papua and Nusa Tenggara, face challenges in effectively utilizing those services. Overall, disparities in digital financial access and usage create clear inequalities across provinces, necessitating more targeted policies to strengthen digital infrastructure, enhance digital financial literacy, and support the adoption of technology in underserved regions, particularly in Eastern Indonesia, to achieve a more equitable distribution of digital financial services.

4.1.2. Results of the Inclusive Green Growth Index (IGGI)

Figure 1 shows that the level of Inclusive Green Growth in Indonesia still varies significantly across provinces, reflecting disparities in regional capacities to manage environmentally friendly economic growth that is also socially inclusive. Provinces in the Sumatra, Java, and parts of the Kalimantan regions tend to fall within the medium to high categories, indicating that these areas possess relatively stronger economic capacity, better environmental governance, and more balanced social development [57]. East Kalimantan, in particular, appears in the highest category, indicating the region's success in integrating natural resource management with sustainable development practices. Meanwhile, several provinces in eastern Indonesia remain in the low to medium categories,

suggesting that challenges such as limited infrastructure, low institutional capacity, and dependence on primary sectors continue to hinder the achievement of truly inclusive green growth [58]. Overall, the map reinforces the need to prioritize the acceleration of green development in provinces with low performance, while simultaneously maintaining the momentum in regions that have already demonstrated strong outcomes. This approach is essential to achieving more equitable and balanced inclusive green growth across Indonesia.

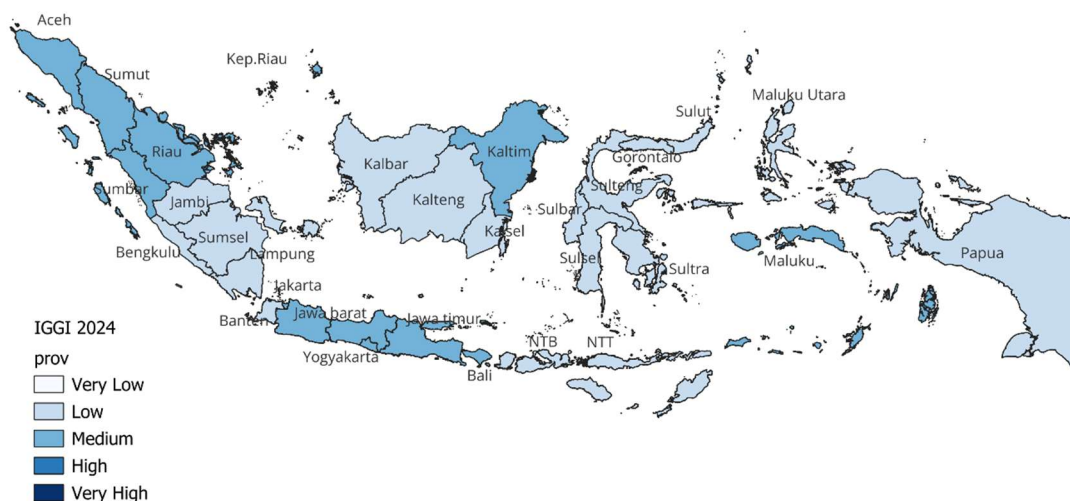


Figure 1. Map of Inclusive Green Growth Index (IGGI) by Province. Source: Data processed by the author (2025).

4.1.3. Calculation of the Inclusive Green Growth Index (IGGI) and Balanced Inclusive Green Growth Index (BIGGI)

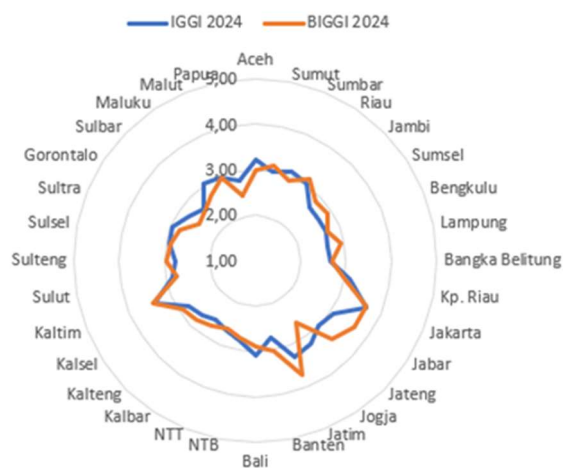


Figure 2. Comparison of the Inclusive Green Growth Index (IGGI) and Balanced Inclusive Green Growth Index (BIGGI) by Province, 2024. Source: Data processed by the author (2025).

Figure 2 illustrates a comparative pattern between the Inclusive Green Growth Index (IGGI) and the Basic Inclusive Green Growth Index (BIGGI) across 34 provinces in Indonesia in 2024. Overall, the two indices exhibit relatively similar trends; however, notable differences emerge in the achievement levels of individual provinces. IGGI, designed to measure inclusive green growth comprehensively through economic, social, and environmental dimensions [59], tends to show

higher values in provinces with strong economic capacity and governance, such as DKI Jakarta, East Java, West Java, and East Kalimantan. In these regions, the IGGI line appears wider compared to BIGGI, indicating that the integration of equity, environmental sustainability, and development quality has been more effectively realized [60].

Conversely, several provinces such as Yogyakarta, Gorontalo, Papua, and parts of eastern Indonesia display lower BIGGI values compared to IGGI. This suggests that when more basic indicators are used, shortcomings in foundational development and inclusiveness become more visible [61]. The graph also shows that provinces such as North Sumatra, Riau, Lampung, and South Kalimantan have slightly higher BIGGI scores than IGGI, indicating that although their basic development foundations are relatively strong, these achievements have not yet fully translated into comprehensive inclusive green growth [62].

The differences between IGGI and BIGGI across provinces reflect the extent to which basic development has progressed toward inclusive and sustainable green growth, aligning with international green growth frameworks that emphasize the integration of resource efficiency, social equity, and environmental protection. Provinces with small gaps between the two indices demonstrate development consistency, whereas provinces with large gaps require strengthened governance capacity, improved access equity, and better integration of environmental policy to achieve inclusive green growth.

4.1.4. Results of Estimating the Influence of the Financial Inclusion on Inclusive Green Growth

Table 6. Panel Data Estimation Results.

Variabel	Fixed Effect	Random Effect
C	0.028** (-3.005881)	0.001** (-3.256631)
ACC	0.000** (0.8506741)	0.000** (0.8479113)
AVA	0.000** (-0.3128338)	0.001** (-0.1433486)
USA	0.025** (0.6048807)	0.144** (0.3459582)
DIF	0.445 (0.0004007)	0.037 (0.0011685)
Chow Test	0.0000**	
Hausman Test		0.0000**
R-Squared	0.6854	0.6592
Prob F-Statistik	0.000**	0.000**
Observasi	192	192

Source: Secondary data processed by the author using Stata 17 (2025).

Table 6 shows estimation results from both the Fixed Effect Model (FEM) and the Random Effect Model (REM), the next step is to determine the most appropriate model using the Chow test and the Hausman test [63]. The results of both the Chow and Hausman tests indicate a probability value of < 0.05, leading to the rejection of the null hypothesis. Therefore, the FEM is selected as the most suitable

model for this study. Consequently, the Lagrange Multiplier (LM) test is no longer required, as the FEM has been confirmed as the preferred specification.

The FEM results reveal that accessibility and usability exert a positive and statistically significant effect on IGGI, whereas availability shows a significant negative effect. These findings indicate that improved access to and utilization of financial services effectively promotes inclusive green growth; however, the expansion of financial service facilities has not yet contributed in a consistent direction.

After obtaining the results from the model specification tests, the next step is to verify the suitability of the FEM with the assumptions of the Ordinary Least Squares (OLS) method. Therefore, classical assumption tests are conducted to ensure that the model satisfies the criteria of the Best Linear Unbiased Estimator (BLUE) [64]. In line with Basuki et al. [65], this study employs two classical assumption tests, namely the multicollinearity test to identify potential strong linear relationships among independent variables, and the heteroscedasticity test to confirm that the error variance remains constant across observations. These diagnostic checks are essential to ensure the reliability of the regression estimates and their validity for further interpretation.

Table 7. Results of Multicollinearity Test.

Variable	ACC	AVA	USA	DIF	DIF*ACC	DIF*AVA	DIF*USA
ACC	1.000	0.690	0.309	0.154	0.253	0.584	0.315
AVA	0.690	1.000	0.201	-0.041	0.031	0.628	0.104
USA	0.309	0.201	1.000	0.126	0.158	0.237	0.679
DIF	0.154	-0.041	0.126	1.000	0.794	0.687	0.776
DIF*ACC	0.253	0.031	0.158	0.794	1.000	0.742	0.797
DIF*AVA	0.584	0.628	0.237	0.687	0.742	1.000	0.654
DIF*USA	0.315	0.104	0.679	0.776	0.797	0.654	1.000

Source: Secondary data processed by the author using Stata 17 (2025).

Based on the correlation matrix presented in Table 7, none of the independent variables exhibit correlation values exceeding 0.80. Therefore, it can be concluded that the regression model does not suffer from multicollinearity issues, indicating that all independent variables are appropriate to be included in the estimation model.

Table 8. Results of Heteroskedasticity Test (Breusch–Pagan Test).

Statistic	Value
Chi-square	0.30
Prob > Chi2	0.5870

Source: Secondary data processed by the author using Stata 17 (2025).

As shown in Table 8, the probability value of the Breusch–Pagan test is 0.5870 (> 0.05), indicating that the null hypothesis cannot be rejected. This result confirms that the regression model does not exhibit heteroskedasticity, and the error variance remains constant across observations. Thus, the model satisfies the assumption of homoskedasticity.

Based on the series of classical assumption tests that have been conducted, and considering that the model has passed the evaluation under the Fixed Effect Model (FEM) approach, the next stage of analysis involves performing a moderation regression test. This step aims to examine whether the

digital infrastructure variable is capable of strengthening or weakening the effect of financial inclusion on the dependent variable, Inclusive Green Growth (IGG).

Table 9. Results of Moderated Regression Analysis (MRA).

Model	Moderating Variable Coefficient	Moderating Variable Prob	Interaction Variable Coefficient	Interaction Variable Prob
IGGI = ACC + DIF	0.001487	0.017		
IGGI = ACC + DIF + ACC*DIF	0.018916	0.106	-0.002437	0.136
IGGI = AVA + DIF	0.002307	0.000		
Y = AVA + DIF + AVA*DIF	0.006205	0.000	-0.001804	0.000
Y = USA + DIF	0.002472	0.000		
Y = USA + DIF + X3*DIF	0.003629	0.021	-0.002836	0.433

Source: Secondary data processed by the author using Stata 17 (2025).

The moderation analysis reveals that the moderating variable (DIF) significantly influences only the relationship between Availability (AVA) and IGGI, as indicated by a significant negative coefficient of the AVA*DIF interaction term, implying that DIF weakens the positive effect of AVA on IGGI. In contrast, the interaction terms for Accessibility (ACC) and Usability (USE) with DIF are insignificant, demonstrating that DIF does not moderate their effects on IGGI. Thus, DIF only moderates one dimension of financial inclusion, while the others remain unaffected. Overall, the findings indicate two predictor-moderator models, where the moderator affects only the dependent variable, and one quasi-moderator model, where the moderator influences both the dependent variable and the relationship between the independent and dependent variables.

Table 10. Multicollinearity Test Results Using Variance Inflation Factor (VIF).

Variable	VIF	Tolerance
ACC	2.14	0.4678
AVA	1.99	0.5013
USE	1.11	0.8982
DIF	1.08	0.9284
Mean VIF	1.58	

Source: Secondary data processed by the author using Stata 17 (2025).

The results of the multicollinearity test using the Variance Inflation Factor (VIF) indicate that all independent variables have relatively low VIF values, well below the commonly accepted threshold of 10. The highest VIF value is observed for the *lacc* variable (2.14), followed by *availability* (1.99), while *usability* and *digital* exhibit lower VIF values of 1.11 and 1.08, respectively. No evidence of multicollinearity is detected, as all VIF values are below 10 and tolerance values exceed 0.1. The mean VIF of 1.58 indicates a low degree of correlation among the independent variables, suggesting that the model estimates are stable and reliable.

4.1.5. Estimated Results Panel Vector Error Correction Model (PVECM) and Impulse Response Function

The results of the Panel Vector Error Correction Model (PVECM) presented in Table 11 reveal that financial inclusion and digital infrastructure significantly influence the Inclusive Green Growth Index (IGGI) in both the short and long run. In the short run, the significant negative coefficient of accessibility ($D(ACC(-3)) = -1.478456$; $t = -4.30885$) indicates that delayed improvements in accessibility negatively impact inclusive green growth, suggesting that late adjustments in access may exacerbate social and economic disparities, hindering optimal IGGI outcomes [37]. Conversely, availability of financial services ($D(AVA(-3)) = 0.181648$; $t = 2.29031$) has a significant positive impact, reflecting that increased service availability leads to more rapid inclusive green growth [4]. Similarly, financial usage ($D(USA(-3)) = 0.983571$; $t = 2.14071$) and digital infrastructure ($D(DIF(-3)) = -0.002528$; $t = -3.00933$) both show significant effects, although the rapid expansion of digital infrastructure, if not accompanied by sufficient readiness among users, may create risks that weaken its positive impact on IGGI [66].

Table 11. Short-Term and Long-Term PVECM Results.

Variable	Coefficient Value	T-Statistics	Information
Short-Term Results			
CointEq1	-0.147082	[-6.46766]	
D(ACC(-3)) → IGGI	-1.478456	[-4.30885]	Significant
D(AVA(-3)) → IGGI	0.181648	[2.29031]	Significant
D(USA(-3)) → IGGI	0.983571	[2.14071]	Significant
D(DIF(-3)) → IGGI	-0.002528	[-3.00933]	Significant
Long-Term Results			
Financial Inclusion	1.000000	1.000000	
ACC → IGGI	-0.848283	[-2.46394]	Significant
AVA → IGGI	-0.140826	[-1.48581]	Not Significant
USA → IGGI	0.972604	[2.56716]	Significant
DIF → IGGI	-0.114819	[-2.30074]	Significant

Note: T-table ($\alpha = 0,05$) = 1,97287

Source: Data processed by the author (2025).

In the long run, accessibility ($ACC = -0.848283$; $t = -2.46394$) has a significant negative effect on IGGI, indicating that lower access to financial services is associated with a decline in inclusive green growth, while availability ($AVA = -0.140826$; $t = -1.48581$) shows a negative but not significant effect, meaning its influence is not statistically strong [5]. In contrast, financial usage ($USA = 0.972604$; $t = 2.56716$) has a significant positive effect, suggesting that increased utilization of financial services supports the improvement of IGGI, whereas digital infrastructure ($DIF = -0.114819$; $t = -2.30074$) exhibits a significant negative effect, implying that the current state of digital infrastructure may not yet effectively contribute to inclusive green growth, so overall the results highlight the importance of optimizing financial service usage while improving accessibility and the effectiveness of digital infrastructure to better support sustainable and inclusive development.

The Impulse Response Function (IRF) shown in Figure 3 illustrates the response of Inclusive Green Growth Index (IGGI), Accessibility, Availability, and Usability to one standard deviation shocks in the variables. The graph demonstrates that shocks to IGGI, accessibility, availability, and digital infrastructure (DIF) lead to both immediate and long-term responses. Notably, the response

of IGGI to innovations shows a gradual increase over time, with a clear upward trajectory, suggesting that improvements in green growth tend to have a persistent and lasting impact [37]. The response of Accessibility to innovations is more volatile, initially increasing, then stabilizing, indicating that changes in accessibility may take time to fully manifest in terms of green growth, but once adjusted, the effect is relatively stable. Similarly, the responses of Availability and Usability exhibit a more moderate adjustment, with Availability showing a steady positive change, while Usability initially fluctuates before stabilizing, highlighting that the effectiveness of financial services requires some time to align with changes in infrastructure and digital channels [14].

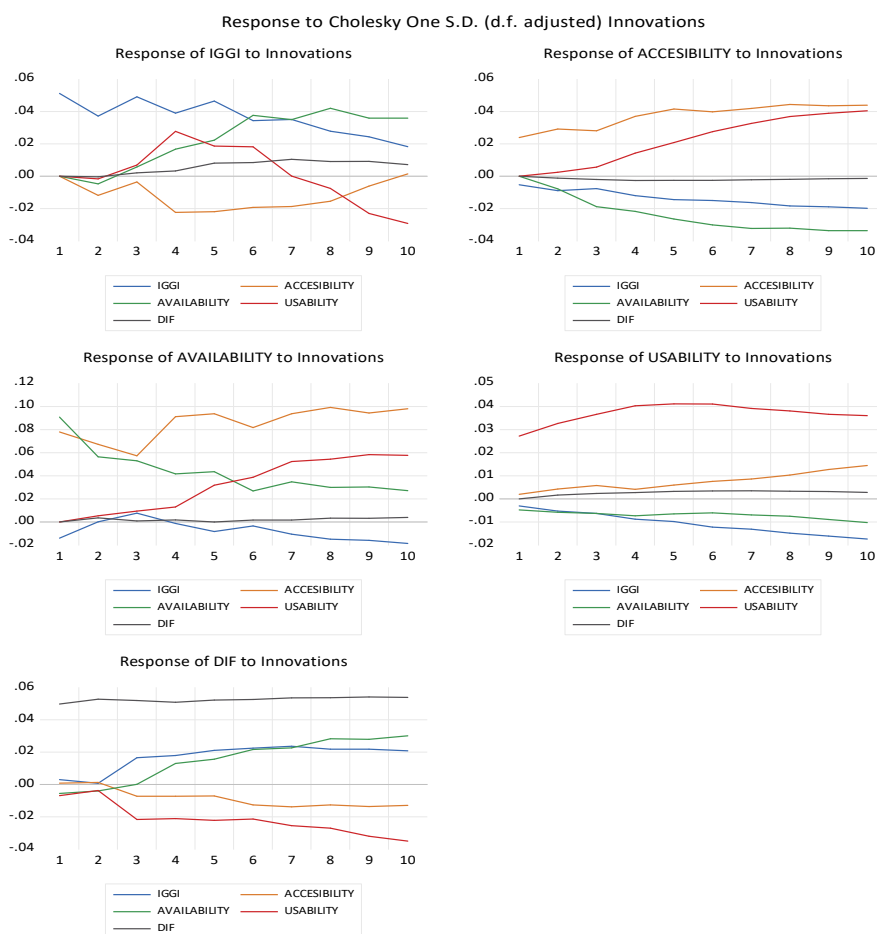


Figure 3. Impulse Response Function (IRF) Results for IGGI, Accessibility, Availability, Usability, and Digital Infrastructure (DIF). Source: Data processed by the author (2025).

In contrast, the Digital Infrastructure (DIF) response is more complex, with an initial decline, followed by a gradual increase, suggesting that while the expansion of digital infrastructure may initially face challenges, it eventually strengthens the system, contributing to the enhancement of green growth. The Usability variable demonstrates a more dynamic response to innovations, with noticeable fluctuations that stabilize as the system adjusts. This pattern suggests that digital innovations have immediate effects, but their full impact depends on how well the users adapt and utilize these innovations over time [14,37]. Overall, the IRF results indicate that while traditional financial inclusion variables such as Availability respond more slowly, Usability and Digital Infrastructure exhibit quicker reactions, albeit with some initial volatility, reinforcing the idea that

digital finance serves as a fast transmission mechanism for changes in IGGI and financial inclusion conditions.

4.1.6. Robustness Check Using FMOLS

Table 12. Robustness Check Using PVECM and FMOLS.

Variable	Fixed Effect	PVECM		FMOLS
		Short-Term	Long-Term	
ACC	0.000** (0.8506741)	[-4.30885]** -1.478456	[-2.46394]** -0.848283	0.000** (0.8479113)
AVA	0.000** (-0.3128338)	[2.29031]** 0.181648**	[-1.48581] -0.140826	0.001** (-0.1433486)
USA	0.025** (0.6048807)	[2.14071]** 0.983571**	[2.56716]** 0.972604	0.144** (0.3459582)
DIF	0.445 (0.0004007)	[-3.00933] -0.002528**	[-2.30074]** -0.114819	0.037** (0.0011685)

Source: Data processed by the author (2025).

The FMOLS results generally confirm the robustness of the main findings. Accessibility (ACC) shows a consistent positive and significant effect in both FEM and FMOLS, despite negative dynamics in PVECM, indicating short-term adjustments. Availability (AVA) remains negative and significant in the long run, suggesting inefficiencies in financial service distribution, while usability (USE) is the most robust variable, consistently positive and significant across all models. In contrast, digital infrastructure (DIF) shows unstable results, being insignificant in FEM and FMOLS but negative in PVECM [55,56]. Overall, these findings indicate that the long-run relationships are robust and not sensitive to the estimation method.

4.2. Discussion

4.2.1. The Effect of Accessibility on the Inclusive Green Growth Index

The results show a divergence of findings between the static and dynamic model approaches. Under the static Fixed Effect Model (FEM), accessibility is found to have a positive and significant effect on the Inclusive Green Growth Index (IGGI). However, the dynamic analysis using the Panel Vector Error Correction Model (PVECM) presents contrasting results, where accessibility exhibits a negative influence on IGGI in both the short run and long run. These differences highlight the importance of incorporating temporal dynamics when assessing the relationship between financial inclusion and inclusive green growth. The dynamic model further suggests that the impact of accessibility is subject not only to immediate effects but also to structural adjustments toward sustainable development.

This condition can be interpreted as an indication of market unpreparedness and unequal quality of financial services across regions in supporting green development objectives. The expansion of financial access has not yet been sufficiently accompanied by a transition of financial services toward environmentally friendly and inclusive economic activities. Moreover, disparities in financial literacy and digital gaps across regions often lead to the use of financial services for

conventional and consumption-driven purposes, which may unintentionally intensify environmental pressure.

In the short term, broader financial accessibility is often used primarily for consumption and routine transactions; therefore, its direct contribution to sustainable development may remain limited [67]. In addition, financial inclusion tends to contribute more strongly to the economic and social dimensions of sustainability than to the environmental dimension [68,69]. Accordingly, the role of financial inclusion in supporting green and sustainable development depends not only on access to financial services, but also on whether such access is directed toward productive, inclusive, and environmentally responsible activities [67,69].

In the long run, the findings reaffirm previous studies suggesting that expanding financial access alone does not automatically enhance inclusive green growth. Accessibility serves as the primary gateway for individuals to participate in the financial system by enabling income creation, economic opportunities, and improved quality of life [51]. However, such access must be complemented by productive financial use [68]. and policy support geared toward sustainability. Thus, increasing financial penetration cannot be directly translated into improvements in IGGI unless financial access is directed toward green and sustainable sectors.

These findings are consistent with the literature asserting that the expansion of financial access often remains at a formal level rather than transforming into substantive inclusion that drives measurable improvements in social welfare and environmental sustainability [70]. Therefore, policy efforts should focus on expanding financial service coverage particularly in remote areas while enhancing financial literacy across all societal groups. Strengthening entrepreneurship through improved access to financial services and developing supportive financial infrastructure can ensure that financial accessibility contributes meaningfully to sustainable human development, provided that such access is utilized for productive purposes, such as educational investment or MSME development.

4.2.2. The Effect of Availability on the Inclusive Green Growth Index

The static estimation using the Fixed Effect Model (FEM) indicates that availability has a negative and significant effect on the Inclusive Green Growth Index (IGGI). In contrast, the dynamic analysis through the Panel Vector Error Correction Model (PVECM) shows that availability exerts a positive short-run effect but remains insignificant in the long run. These findings suggest that expanding financial service facilities initially enhances access and economic participation, yet the presence and distribution of financial institutions alone are insufficient to generate sustained improvements in inclusive green growth without effective implementation and long-term support mechanisms.

In the short run, the increase in the availability of financial services positively contributes to achieving inclusive green growth, as wider and easier access to financial products enables households and businesses to promptly utilize financial services for productive activities that support sustainable and equitable economic progress. This finding is consistent with prior evidence indicating that the expansion of financial facilities reduces transaction costs for low-income communities, thereby narrowing income disparities [71]. Moreover, existing studies confirm that financial inclusion exerts a positive and causal effect on green growth, with its benefits strengthening alongside improvements in financial infrastructure [72,73]. Financial inclusion also plays a crucial role in enhancing human

capital by facilitating access to financial support for health and education services, including in Indonesia, which ultimately improves public service quality and promotes inclusive economic development [74].

In the long run, the effect of financial service availability on inclusive green growth becomes insignificant, suggesting that without a consistent shift in financing toward environmentally friendly sectors, its contribution cannot be sustained. This aligns with Dong et al. [4], who argue that the expansion of financial service availability generates complex outcomes, including potential negative environmental pressures such as increased carbon emissions, despite simultaneously supporting green growth overall. Furthermore, Damrah et al. [75] emphasize that the environmental impact of financial inclusion is highly context dependent, shaped by socioeconomic conditions and regulatory structures across countries. In many developing economies, weak governance and limited oversight of environmentally risky financing hinder the ability of financial inclusion policies to produce long-term green development [76].

These findings indicate that, without proper regulation and oversight, the expansion of financial institutions may lead to financing allocations that deviate from green development objectives, potentially increasing natural resource exploitation and environmental pressures. Therefore, enhancing financial service availability remains crucial for promoting inclusive and sustainable green development in Indonesia. Policymakers and financial service providers particularly banks and other financial institutions must collaborate to expand infrastructure networks in remote areas and develop affordable financial products that support environmentally responsible economic activities. The government should ensure that the growing financial infrastructure is not only accessible but also effective in reaching and empowering all segments of society. Additionally, the equitable adoption of digital technologies is essential to further improve access to financial services nationwide.

4.2.3. The Effect of Usability on the Inclusive Green Growth Index

The static analysis using the Fixed Effect Model (FEM) indicates that usability has a positive and significant effect on the Inclusive Green Growth Index (IGGI). Likewise, the dynamic analysis using the Panel Vector Error Correction Model (PVECM) confirms the same directional effect, showing that usability remains positively influential in both the short and long run. The consistency of these findings across both models reinforces the argument that usability is the most critical dimension of financial inclusion for promoting inclusive green growth, compared to merely expanding access or financial infrastructure. This consistency suggests that the effective utilization of financial services not only directly strengthens economic activities supporting the green transition but also sustains these effects over time as financial inclusion and literacy improve. In other words, the more optimally financial services are used, the greater the likelihood that financing is allocated to environmentally sustainable and socially equitable sectors in the long term.

Based on the short-run analysis, financial inclusion policies should focus on enhancing the quality of financial service utilization both Islamic and conventional through improved financial literacy, the provision of green financial products, and incentives for sustainable investments to maximize their impact on the Inclusive Green Growth Index (IGGI). This aligns with Chen et al. [68], who found that increased utilization of financial services, reflected in higher credit allocation and greater use of cashless payment instruments, supports productive economic activities, accelerates fund circulation, and promotes inclusive, sustainability-oriented growth. Furthermore, deeper

engagement with digital financial inclusion can stimulate green innovation by reducing capital misallocation and improving financial efficiency [77].

In the long run, the positive effect of usability on the Inclusive Green Growth Index (IGGI) becomes even stronger. Sustained use of financial services not only expands the economic inclusion base but also enhances the banking sector's intermediation capacity to channel financing toward productive sectors that support green development. This indicates that consistent utilization of financial services can generate a multiplier effect on sustainable economic growth while simultaneously strengthening social inclusion and environmental management over time [66,78]. Other studies show that digital financial inclusion (DFI) significantly reduces CO₂ emissions in the long run, although its short-term impact remains limited due to low digitalization levels [79]. These findings align with the literature emphasizing that the effective use of financial services is a critical stage in the financial inclusion process, as it is during this phase that the benefits of access and availability are internalized into productive economic activities [80].

Thus, usability can be regarded as the primary driver of inclusive green growth, as the effectiveness of financial inclusion is realized only when access and availability of services are actively and productively utilized. Accordingly, policymakers and financial institutions must create an environment in which credit flows can be optimally used to support sustainable development in Indonesia. Policies should promote responsible credit usage, including education on debt management and oversight of financial institutions. Additionally, special attention should be given to cashless payment instruments to facilitate productive and environmentally friendly sectors, ensuring that financial inclusion meaningfully contributes to inclusive green growth.

4.2.4. The Effect of Digital Infrastructure on the Inclusive Green Growth Index

The consistently negative effect of Digital Infrastructure (DIF) across the FEM, short-run PVECM, and long-run PVECM models indicates that digital expansion has not yet strengthened inclusive green growth in Indonesia. Early stages of digital infrastructure development often produce transition costs such as increased fiscal burdens, rising maintenance needs, and the reallocation of public resources away from environmental programs. These adjustment pressures can temporarily suppress green and inclusive outcomes, which aligns with evidence showing that digital infrastructure tends to produce delayed or non-linear effects on sustainability indicators [81].

The negative relationship may also reflect regional disparities in digital access that weaken the inclusiveness component of IGGI. Digitalization frequently benefits urban and economically advanced provinces more rapidly than rural or disadvantaged regions. This uneven distribution can intensify social inequality and limit the inclusive impact of green development. Prior studies emphasize that digital progress may reinforce existing structural gaps when accessibility and digital capability are not equally distributed across regions, leading to what scholars describe as adverse digital incorporation [82].

In addition, short run and long run PVECM results suggest that digitalization in its current form may be misaligned with green and inclusive development strategies. Rapid digital expansion can disrupt traditional sectors and increase energy consumption, which reduces environmental performance before the system stabilizes. Long term negative coefficients indicate that digital economic activities remain dependent on energy intensive processes and insufficiently supported by green oriented policies. Research shows that digitalization contributes positively to green growth

only when strong environmental governance and low carbon digital technologies are in place [83]. The consistent negative pattern therefore suggests that digital infrastructure has not yet been integrated effectively into sustainable and inclusive development pathways.

4.2.5. The Moderating Role of Digital Infrastructure in the Relationship between the Three Dimensions of Financial Inclusion and the Inclusive Green Growth Index

This study provides new insights into the role of Digital Financial Infrastructure (DIF) in supporting the contribution of financial inclusion to inclusive green growth in Indonesia. The findings for the Availability (AVA) dimension suggest that the rapid digitalization of financial systems can shift the role of physical bank branches. As digital services expand, the presence of brick-and-mortar offices is no longer a primary driver of sustainable economic activity, as people increasingly rely on more efficient and accessible digital channels [84,85]. These results are also supported by Basnayake et al. [86], who note that the impact of DIF on economic growth varies by country income level. In high- and upper-middle-income countries, DIF promotes growth in line with established financial inclusion, whereas in lower-middle- and low-income countries, increased DIF has yet to yield positive effects on inclusive green development. This highlights a transformation challenge, where the expansion of digital infrastructure is not yet fully matched by the capacity of communities to utilize it optimally for inclusive and environmentally friendly growth.

In contrast, for the Accessibility (ACC) and Usability (USE) dimensions, the presence of DIF does not affect their relationships with the Inclusive Green Growth Index (IGGI). This suggests that the mobilization of Third-Party Funds (DPK) and credit distribution continue to play a strong role in promoting sustainable economic and social activities, independently of digital development. Consequently, the utilization of digital financial services has not yet been fully integrated into financial intermediation processes that support sustainable development. These findings are supported by Xin et al. [87], who note that the impact of digital infrastructure is uneven and highly influenced by regional differences in technology adoption, implicitly highlighting the limitations of digital tools in moderating these relationships due to persistent digital gaps. Similarly, Mo et al. [66] argue that the moderating role of digital infrastructure is less effective because regional disparities result in unequal access to and utilization of technology for promoting green growth.

Overall, these findings indicate that financial digitalization has not yet evenly strengthened the contribution of financial inclusion to inclusive green growth. Its role is mainly observed in substituting physical financial services but has not fully enhanced financial intermediation. Therefore, policy directions should emphasize the equitable use of financial technology, improvement of digital literacy, and the development of a robust digital ecosystem to ensure that economic, social, and environmental benefits are realized across all regions of Indonesia.

5. Conclusions

This study aims to analyze the impact of financial inclusion dimensions namely accessibility (ACC), availability (AVA), and usability (USE) on the Inclusive Green Growth Index (IGGI) across all provinces in Indonesia, as well as to evaluate the moderating role of Digital Infrastructure (DIF) in strengthening these effects. Using panel FEM, panel VECM, and DIF moderation models, the findings reveal that the influence of financial inclusion dimensions on IGGI varies. The panel FEM results indicate that ACC and USE have a positive and significant effect, whereas AVA exerts a

negative and significant influence. The panel VECM analysis highlights both short-term and long-term dynamics, where ACC has a negative and significant effect in both periods, USE exhibits a positive and significant effect, and AVA is only positively significant in the short term. The DIF moderation analysis shows that ACC and USE are not significant, while AVA has a significant negative effect, suggesting that digital infrastructure has not yet uniformly strengthened the role of financial inclusion dimensions. These findings underscore the need for more comprehensive policy strategies, such as expanding equitable access to financial services through the development of both physical and digital networks, enhancing financial and digital literacy among the population, and strengthening regulations and incentives for financial institutions to improve inclusive intermediation functions. Moreover, digital infrastructure development should be tailored to regional and demographic conditions to support equitable and sustainable green growth. Future research is recommended to explore the impact of financial inclusion at the micro level, assess the effectiveness of digital infrastructure adoption, employ indicators that better reflect current conditions, and conduct observations by segmenting regions based on demographics or coverage areas to test the consistency of findings.

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Conflicts of Interest: The authors declare that there are no commercial or financial relationships that could be construed as potential conflicts of interest. The research was conducted independently, and no external influence affected the study design, data collection, analysis, interpretation, or the decision to publish these findings.

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