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# SMART VILLAGE ECOSYSTEMS: INTEGRATING IOT, FINTECH, AND DIGITAL LITERACY TO BOOST INCLUSIVE RURAL DEVELOPMENT

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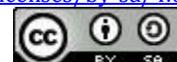aniindahsari160625@gmail.com

### Abstract

Rural communities face mounting development challenges, including poverty, limited access to infrastructure, and economic marginalization. At the same time, technological advances offer potential solutions through innovative village ecosystems integrating the Internet of Things (IoT), financial technology (fintech), and digital literacy initiatives. This research investigates how smart village ecosystems integrating IoT, fintech, and digital literacy can advance inclusive rural development, examining technology adoption patterns, digital capability development, financial inclusion mechanisms, and the factors that enable or constrain equitable participation. The study employed a qualitative exploratory case study design across two contrasting villages in the Cirebon district, West Java, Indonesia. Results reveal stark disparities between villages with advanced versus minimal ecosystem development. Setuapok village demonstrated functional IoT integration (agricultural sensors, village information systems, innovative governance platforms), diverse fintech adoption (mobile banking, digital payments, agricultural lending platforms), and systematic digital literacy programming reaching 68% of adults. In contrast, Karangsuwung village showed minimal IoT deployment, limited fintech access, and only 23% digital literacy coverage. However, even in the advanced village, inclusion remained highly uneven: while educated middle-aged males achieved comprehensive access to technology and benefits, marginalized groups faced persistent barriers. Women encountered gender-based constraints (cultural norms restricting mobility and technology use, domestic responsibilities limiting participation time, and male-dominated training environments). Elderly residents faced age-based exclusion (digital illiteracy, physical/cognitive limitations using interfaces, technology designs ignoring accessibility needs). Poor households experienced socioeconomic barriers (inability to afford devices, limited education constraining learning, livelihood pressures preventing training attendance).

**Keywords:** smart villages; digital inclusion; rural development; internet of things; financial technology; digital literacy

**INTRODUCTION**

The global trajectory toward sustainable development confronts a fundamental paradox: while technological innovation accelerates exponentially in urban centers and wealthy nations, rural communities, particularly in developing countries, face persistent development challenges, including poverty, limited access to infrastructure, inadequate public services, and economic marginalization. Innovative village concepts have emerged proposing that strategic deployment of digital technologies, particularly Internet of Things (IoT) systems, financial technology (fintech) platforms, and digital literacy initiatives, can address rural development constraints by improving agricultural productivity, expanding financial inclusion, enhancing governance transparency, and connecting remote communities to broader economic opportunities (Degada et al., 2021; Malik et al., 2022; Tosida et al., 2022). However, critical questions persist about whether technology-driven development interventions genuinely promote inclusive outcomes that benefit all rural residents across diverse social positions, or primarily advantage already-privileged groups while potentially exacerbating existing inequalities through differential access to and development of technology (Babin et al., 2022; Q. Wang et al., 2022).

Understanding technology adoption patterns requires analytical frameworks explaining why specific populations embrace digital innovations while others resist. Technology Acceptance Models (TAM and UTAUT) identify perceived usefulness, perceived ease of use, social influence, and facilitating conditions as critical adoption determinants (Amit et al., 2024; Malik et al., 2022; Q. Wang et al., 2022). In smart village contexts, these models illuminate how usability design, demonstrated benefits, peer effects, and infrastructure availability shape community adoption dynamics. However, acceptance models developed primarily for organizational and urban settings require adaptation for rural contexts, where collective decision-making, traditional authority structures, and subsistence livelihood pressures create distinctive adoption patterns that necessitate context-specific implementation approaches.

Indonesia's smart village development trajectory exemplifies both the promise and challenges of technology-driven rural transformation. Government policies, including the Village Law (UU No. 6/2014) and National Medium-Term Development Plan (RPJMN 2020-2024), explicitly prioritize village development and technology deployment, with significant budget allocations supporting infrastructure development and digital literacy programs. By 2024, over 5,000 villages nationwide had initiated innovative village programs incorporating various technology components. However, implementation quality varies dramatically, and systematic evidence regarding actual outcomes for diverse community members remains limited. While showcase villages demonstrate impressive technology arrays and receive substantial media attention, questions persist about whether these technological investments translate to meaningful improvements in villagers' lives, particularly for marginalized populations, including women, elderly residents, and economically disadvantaged households (Amit et al., 2024; Mukti et al., 2023; Ruhi et al., 2024).

This research investigates innovative village ecosystem functioning in practice within Indonesian rural contexts, examining how IoT technologies, fintech platforms, and digital literacy initiatives operate individually and collectively, which community segments successfully access and benefit from these technologies, what barriers prevent universal inclusion, and which implementation factors differentiate more inclusive from less inclusive outcomes. The study addresses critical knowledge gaps in the existing literature, which tend to emphasize technology deployment and functionality rather than examining actual usage patterns, differential access across social groups, and mechanisms that generate inclusion versus exclusion. Through a comparative case study of two contrasting villages in Cirebon district, West Java—one with advanced ecosystem development and one with minimal development—the research generates empirical evidence on the realities of smart village implementation and the practical implications for achieving genuinely inclusive technology-driven rural development.

The integration of IoT technologies into rural contexts creates unprecedented opportunities for data-driven agricultural management, environmental monitoring, infrastructure optimization, and public service delivery. (Widianingsih et al., 2025). Agricultural IoT applications, including soil moisture sensors, weather stations, crop monitoring systems, and livestock tracking devices, enable precision farming practices, improving productivity while reducing resource waste. Village infrastructure IoT, including innovative water management, electricity monitoring, and waste management systems, enhances resource efficiency and service quality (Dziembala et al., 2024; Pimenow et al., 2025). Governance IoT, incorporating digital information systems, participatory budgeting platforms, and service delivery monitoring tools, strengthens transparency and accountability. However, realizing these potentials requires not merely technology deployment but comprehensive ecosystem development, ensuring rural residents possess the necessary capabilities to access, understand, and effectively utilize IoT-generated information for improved decision-making.

Theoretical frameworks emphasizing capability development and digital equity offer essential perspectives for understanding the dynamics of smart village inclusion. The Capability Approach, as developed by Amartya Sen and Martha Nussbaum, emphasizes that development should expand people's capabilities—their fundamental freedoms to achieve valued functionings—rather than merely providing infrastructure. Applied to smart villages, this perspective highlights that technology access alone proves insufficient; meaningful inclusion requires developing capabilities to effectively utilize technologies for valued purposes, including digital literacy, financial literacy, critical evaluation skills, and adaptive learning capacities (Degada et al., 2021; Dziembala et al., 2024). Furthermore, capability development must address heterogeneity—different individuals and groups require different supports, suggesting one-size-fits-all technology deployment inevitably produces uneven outcomes. Digital Divide frameworks complement this perspective by analyzing how unequal technology access creates or exacerbates inequalities across multiple levels: first-level divides concern physical access (devices, connectivity); second-level divides concern digital skills and competencies; third-level divides concern the beneficial use of technology, translating access into tangible outcomes. Research demonstrates that infrastructure provision (first-level) proves insufficient

without capability building (second-level) and integration into livelihood practices generating benefits (third-level), explaining how villages with similar technology deployment exhibit vastly different inclusion outcomes based on capability development and effective usage promotion.

Intersectionality frameworks, originating in feminist scholarship that examines how gender, race, class, and other social categories intersect to create distinctive experiences of privilege and oppression, are essential for understanding smart village inclusion dynamics (Sharma et al., 2023). Technology access and capability patterns reflect intersecting inequalities—poor older women face compounded disadvantages distinct from challenges experienced by poor older men, poor young women, or wealthy older women. Intersectionality directs analytical attention to how multiple marginalization axes intersect, requiring inclusion strategies that address specific intersectional positions rather than treating gender, age, and class as separate, independent factors amenable to isolated interventions. This perspective reveals why universal technology deployment fails to achieve universal inclusion, as barriers compound differently across social positions, necessitating differentiated support mechanisms.

Financial inclusion through fintech platforms addresses critical constraints on rural economic development, where traditional banking infrastructure remains limited and transaction costs are prohibitive for small-value activities typical of rural livelihoods. Mobile banking, digital payment systems, peer-to-peer lending platforms, and agricultural fintech applications theoretically enable rural households to access formal financial services, reduce transaction costs, build credit histories, and access capital for productive investments. (Das, 2025; W. Wang et al., 2025). Indonesian fintech expansion has been remarkable, with mobile banking users increasing from 15 million (2018) to over 150 million (2024), digital payment transaction values growing exponentially, and agricultural fintech platforms emerging specifically targeting smallholder farmers. However, questions remain about whether this fintech expansion genuinely reaches rural poor populations or primarily serves already-banked middle-class users, and whether rural residents possess digital literacy and financial capability to safely navigate fintech platforms without exposure to fraud, predatory lending, or inappropriate financial products.

Socio-Technical Systems perspectives are essential for understanding how technologies function within and co-evolve with social, institutional, and economic contexts rather than operate as independent, deterministic forces. Innovative village ecosystems constitute socio-technical systems where IoT sensors, fintech platforms, and digital literacy initiatives interact with existing agricultural practices, financial behaviors, governance institutions, social networks, and cultural norms (Baxter & Sommerville, 2011; Yu et al., 2023). This perspective recognizes that technologies designed for urban settings may require substantial adaptation for rural contexts, and that implementation approaches substantially shape whether technologies reinforce or transform existing power structures and inequalities. Understanding ecosystem functioning, therefore, requires analyzing both technical components and social embedding processes, examining how local institutions mediate technology adoption, how cultural norms shape usage patterns, and how power dynamics influence who benefits from technological interventions.

Digital literacy constitutes the foundational capability enabling rural populations to access and benefit from both IoT and fintech technologies, yet remains severely underdeveloped in Indonesian rural contexts (Cartile, 2020; Farias-Gaytan et al., 2022).

National statistics indicate that while 73% of urban Indonesians possess basic digital literacy, only 42% of rural residents demonstrate comparable capabilities, with stark disparities across age groups (elderly residents essentially digitally illiterate), gender (women significantly less digitally literate than men), and socioeconomic status (poor households lacking both devices and skills). Digital literacy encompasses not merely technical skills in operating devices but broader competencies, including information evaluation, online safety, digital citizenship, and adaptive learning, enabling individuals to navigate rapidly evolving technology landscapes. Systematic digital literacy programming targeting diverse rural populations represents an essential foundation for inclusive innovative village development, yet often receives inadequate attention in implementation initiatives emphasizing infrastructure deployment over capability building

Digital Divide frameworks analyze how unequal access to information and communication technologies creates or exacerbates social inequalities. First-level digital divides concern physical access to technology (devices, connectivity); second-level divides concern digital skills and competencies; third-level divides concern the beneficial use of technology, translating access into tangible outcomes. Research on digital divides demonstrates that providing infrastructure alone (first-level access) proves insufficient without capability building (second-level) and integration into livelihood practices generating benefits (third-level) (Degada et al., 2021; Dziembala et al., 2024). Applied to smart villages, these frameworks highlight how villages with similar technology deployments may exhibit vastly different inclusion outcomes based on capability development and effective use promotion.

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approaches substantially shape whether technologies reinforce or transform existing power structures and inequalities.

## RESEARCH METHOD

This study adopts a qualitative exploratory case study design to examine the functioning of innovative village ecosystems in Cirebon, West Java. The research aims to generate a deep contextual understanding of the factors influencing innovative village development, focusing on the complexities and diverse stakeholder perspectives that quantitative methods might overlook. Two villages were selected for comparison: Setupatok Village, which has implemented various digital technologies and IoT systems with substantial external support, and Karangsuwung Village, where minimal development has taken place. These villages were chosen to highlight contrasts in smart village progress despite similar economic and demographic profiles.

The research took place between June and August 2024, utilizing multiple data collection methods for comprehensive analysis. Primary data were gathered through 47 semi-structured interviews with participants from diverse backgrounds, including village leadership, technology providers, farmers, women's groups, elderly residents, and youth. Participant observation was also conducted at 12 technology deployment sites, including agricultural sensor installations, digital literacy training sessions, fintech service points, and government digital platforms, providing insights into technology interactions and service delivery. Document analysis of implementation records, policy documents, and secondary data from village reports and media coverage complemented these findings.

Data analysis followed an iterative thematic approach, starting with familiarization and initial coding of transcripts and field notes. Codes were organized into categories, and relationships between categories were examined to identify patterns across the two villages. A cross-case comparison was conducted to pinpoint differentiating factors, followed by the development of comprehensive thematic frameworks. Validation strategies, including triangulation of interviews, observations, and documents, member checking, and negative case analysis, were employed to enhance the reliability and quality of the findings.

This research adhered to rigorous ethical standards throughout data collection and analysis. Prior to data collection, ethical approval was obtained from the institutional review board, and formal permissions were secured from village authorities. All participants provided written informed consent after receiving comprehensive explanations about the research purpose, procedures, voluntary participation, and their right to withdraw at any time without consequences. To protect participant privacy and confidentiality, all interview recordings and transcripts were stored securely with password protection, personal identifiers were removed during transcription, and pseudonyms were assigned to all participants and villages in research outputs. Special care was taken to ensure that vulnerable populations, including women, elderly residents, and economically disadvantaged households, could participate safely without coercion, with interviews conducted in comfortable settings at times convenient to participants and in their preferred language (Indonesian or a local Sundanese dialect). Participants were

informed that declining to answer any question would not affect their relationship with village institutions or access to any services.

The three-month research timeframe (June-August 2024) was purposefully designed to provide sufficient depth for qualitative exploratory research while remaining pragmatically feasible. This duration enabled multiple field visits to each village, allowing researchers to observe technology usage across different agricultural cycles, conduct follow-up interviews to clarify findings, and build rapport with community members. While longitudinal research tracking changes over multiple years would provide additional insights, the intensive engagement approach employed during this period—including 47 semi-structured interviews, observations at 12 technology deployment sites, and extensive document review—generated rich, contextually-grounded data adequate for addressing the research questions about current smart village ecosystem functioning and inclusion patterns.

## RESULT AND DISCUSSION
## 1. Smart Village Ecosystem Configuration and Technology Adoption Patterns

This research compares the innovative village ecosystems of Astanajapura and Karangsuwung villages in Cirebon, Indonesia, highlighting their different stages of development and resource availability. Astanajapura has advanced considerably in implementing innovative village technologies, including IoT agricultural sensors, solar power generation, and mobile money services, with significant community engagement and institutional support. These technologies, while successful in many areas, exhibit uneven adoption rates, especially among disadvantaged groups such as small farmers and older populations, due to costs, technical complexity, and a lack of ongoing support. Conversely, Karangsuwung's ecosystem is fragmented, with limited infrastructure and adoption of innovative technologies, mainly due to unreliable electricity, slow internet, and insufficient local technical support. These barriers, compounded by weak institutional capacity and political apathy, have hindered the village's ability to harness the benefits of smart villages.

In Astanajapura, the digital infrastructure and mobile money services have been widely adopted, with younger residents showing the most enthusiasm for digital transactions. At the same time, older generations and women face barriers related to trust, security concerns, and family dynamics. The solar power system in Astanajapura achieved broad adoption across socioeconomic strata, thanks to a community-managed, affordable model that eliminated individual investment and operational barriers. On the other hand, Karangsuwung faces persistent challenges with inconsistent electricity and limited internet connectivity, making it difficult for residents to access IoT or fintech services. Institutional gaps compound these infrastructure issues, as the village government lacks the technical expertise to facilitate or support technology adoption, and political elites show little interest in smart village initiatives due to their existing access to urban resources.

The study highlights the critical role of institutional capacity, leadership commitment, and tailored approaches in the successful implementation of innovative village initiatives. Astanajapura's success is attributed to strong local governance, external partnerships, and comprehensive digital literacy programs. In contrast, Karangsuwung's failure to implement similar initiatives is rooted in infrastructure deficits, institutional weakness,

and political resistance. The findings suggest that for smart villages to succeed, there must be a concerted effort to build local technical capacity, ensure equitable access to technologies, and foster inclusive decision-making processes. Additionally, the research demonstrates the importance of addressing both infrastructure and institutional barriers, as well as the need for context-specific strategies that account for local challenges and opportunities in digital transformation.
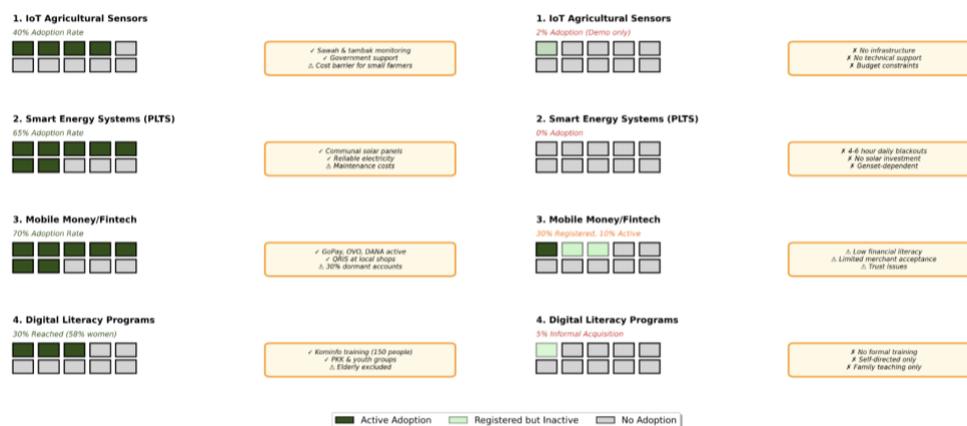


**Figure 1.** Technology Adoption Patterns Across Village Contexts - Description for Visualization

## 2. Digital Literacy Pathways and Capability Development

The development of digital literacy in two villages in Cirebon followed distinct paths influenced by available resources, institutional support, and social learning opportunities. In Astanajapura village, formal and informal learning channels, such as digital literacy training from BUMDes, supported residents in acquiring digital skills, with a focus on women through targeted recruitment. Despite these efforts, gaps in digital fluency remained, as the six-session training proved insufficient for building confidence and proficiency. Informal peer networks, especially within women's groups, played a crucial role, providing ongoing learning opportunities through WhatsApp groups and community support, fostering a continuous learning environment despite limited formal training.

In contrast, Karangsuwung village had limited formal training, with sporadic workshops on topics such as digital finance and online business, but lacked foundational skills. These workshops often failed because of assumed baseline knowledge, leaving many participants struggling with basic concepts and lacking adequate hands-on experience. The few residents with functional digital literacy primarily acquired skills through self-directed learning, encountering challenges with trial-and-error processes and occasional help from urban-dwelling relatives. The lack of consistent, accessible training opportunities led to gaps in critical digital competencies, particularly in information literacy and online safety.

The study highlighted significant gaps in content creation capabilities, particularly among women and older adults. While young, educated men demonstrated skills in digital marketing and content creation, the majority of residents remained passive consumers. This inequality proved economically significant for digital entrepreneurship, where a strong online presence was critical. Additionally, generational gaps in digital literacy left older residents vulnerable to exclusion from digital services, reinforcing their dependence on younger relatives for access to essential services. To address these challenges, the

research recommended sustained, longitudinal training, peer mentoring, and family-based learning approaches to create a more inclusive and supportive digital literacy environment.
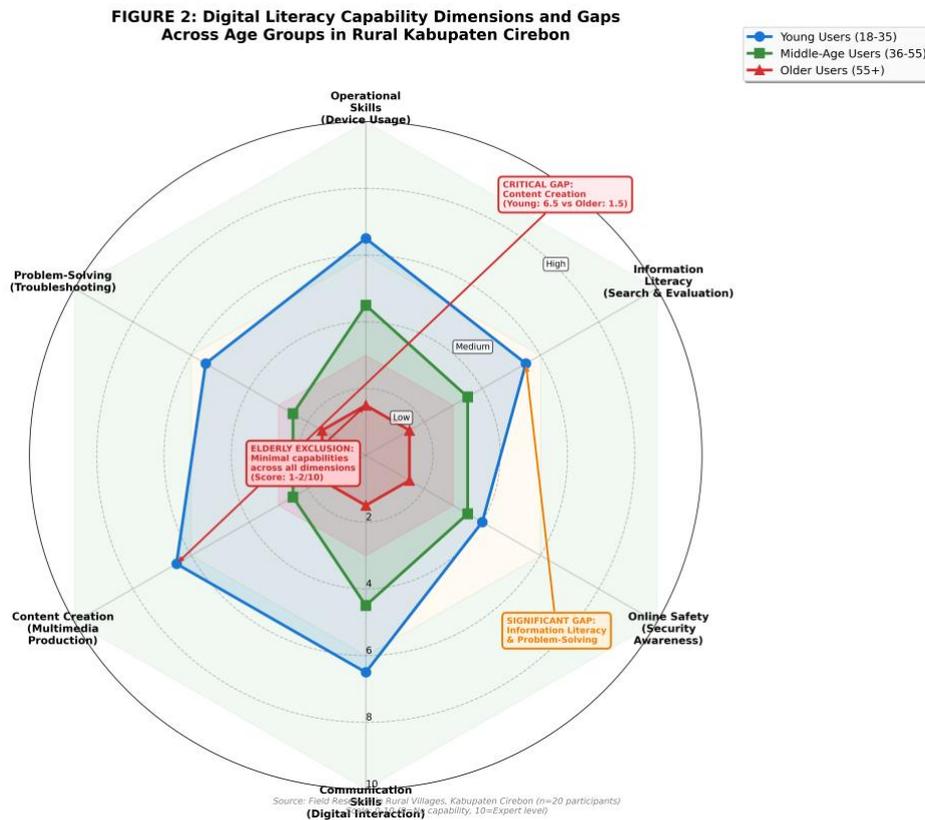


**Figure 2.** Digital Literacy Capability Dimensions and Gaps - Description for Visualization

### 3. Financial Inclusion Through Fintech Integration

The integration of financial technology into village ecosystems created new opportunities for financial inclusion while revealing persistent barriers limiting equitable access and meaningful use across the rural population of Cirebon Regency. In Astanajapura village, mobile money penetration of 70% represented substantial quantitative inclusion, yet a qualitative examination revealed that the depth and quality of financial service use varied dramatically across user segments. Active users, comprising approximately 40% of mobile money registrants, conducted multiple transactions weekly, including person-to-person transfers, bill payments, airtime purchases, and increasingly merchant payments as local shops adopted digital payment acceptance. These users described mobile money as transformatively convenient, eliminating needs to travel to distant bank branches for basic transactions, enabling instant money transfers to family members including urban-based children sending remittances to rural parents with unprecedented speed and lower cost than traditional remittance channels, and providing discrete financial management capabilities particularly valued by women conducting business activities or managing household finances with greater autonomy than joint traditional bank accounts permitted.

However, the 30% of Astanajapura village mobile money registrants whose accounts remained dormant or minimally used revealed important inclusion limitations beyond simple access metrics. Interviews with inactive users identified multiple constraining

factors including low financial literacy creating confusion about account management, fees, and appropriate usage contexts relative to cash transactions; limited merchant acceptance within the village requiring cash for most purchases except utility bills or specific shops that adopted digital payments, reducing practical utility for daily economic activities; persistent trust concerns about digital money's security and reliability, with several participants recounting hearing about others losing money through fraud, platform failures, or confusing transactions they did not authorize; and social-cultural norms where cash remained preferred for important transactions including ceremonial gift-giving, religious donations, and certain business dealings where physical money exchange held symbolic significance beyond mere financial value. These inactive users felt pressure to maintain accounts to receive remittances from urban relatives or participate in government programs increasingly disbursing payments digitally, but avoided proactive usage, immediately withdrawing any received funds to cash for comfort and control.

Digital credit products offered through mobile lending platforms presented more concerning inclusion patterns, with access concentration among already economically secure borrowers while excluding vulnerable populations who might benefit most from expanded credit access. The research identified approximately 15% of mobile money users in Astanajapura village who had borrowed through digital platforms, including operator-branded services and third-party fintech applications. These borrowers were disproportionately salaried employees, established business owners, and farmers with substantial landholdings. These precise populations already possessed access to formal bank credit, albeit through more cumbersome application processes. When asked why digital lending, these users emphasized convenience and speed, describing approval within minutes compared to days or weeks for bank loans, minimal documentation requirements, and the ability to borrow modest amounts for short-term needs without the social stigma or obligation they associated with borrowing from friends, family, or informal moneylenders. However, several also described problematic experiences, including unexpectedly high interest rates that were not clearly disclosed upfront, aggressive debt collection practices such as automated calls and SMS messages demanding immediate repayment, and damage to their digital credit scores from missing payments during temporary cash flow problems, which subsequently limited their access to better loan terms.

The exclusion of poor and economically marginalized households from access to digital credit, despite theoretical promises that alternative data would enable underserved, previously unbanked populations, represented a significant gap between fintech rhetoric and reality. Interviews revealed that platform algorithms prioritizing transaction history and patterns systematically disadvantaged poor users whose limited economic activity generated sparse digital footprints inadequate for credit scoring. Day laborers with irregular cash income rarely conduct enough mobile money transactions to establish creditworthiness signals. In contrast, smallholders with less than 0.5 hectares of land who sold most of their produce through informal cash markets similarly lacked transaction histories demonstrating regular income flows. Several participants described trying to borrow through digital platforms during genuine financial emergencies only to face rejection or be offered loan amounts of USD 5-10 too small to address their needs, forcing them back to informal lenders charging usurious rates. The cruel irony emerged that fintech's data-driven underwriting, while eliminating traditional documentation barriers, created new exclusionary mechanisms that privileged digitally active and economically

stable populations while marginalizing those most desperately in need of affordable credit access.

In Karangsuwung village, a more limited fintech landscape offered fewer services but potentially lower exclusion risks, as limited adoption meant few residents experienced financial exclusion from fintech per se. However, they remained generally excluded from formal financial services. The digital financial services agent operating from small shops served crucial functions, enabling cash-in and cash-out transactions for the 30% of the population with accounts. However, service quality varied considerably depending on agent cash and e-float management, with frequent instances in which agents lacked sufficient cash to process withdrawal requests or adequate e-float to accept deposits, forcing customers to return later or travel to alternative agents. No digital lending services operated in Karangsuwung village due to population size and transaction volumes falling below minimum thresholds, making platform entry commercially viable. This absence meant residents relied entirely on informal credit sources, including family borrowing, rotating savings and credit associations, and traditional moneylenders charging rates of 10-20% monthly, creating severe financial vulnerability yet also avoiding the predatory digital lending practices and credit score damages that concerned some Astanajapura village participants.

Agricultural fintech applications, theoretically promising transformative impacts for smallholder farmer financial inclusion, proved largely absent in both study villages, representing a significant gap between bright village visions and ground-level realities. Neither village had functional digital agricultural insurance products despite both locations facing weather variability and pest pressures that generated income risk. Participants expressed interest in affordable crop insurance when the concept was explained. However, no providers served their locations, with farmers surmising that their individual farms were too small and dispersed to justify insurance company operational costs. Supply chain financing, which the development literature frequently highlights as a fintech application enabling farmers to purchase quality inputs on credit, remained unavailable, with the few agricultural input suppliers operating in or near the villages dealing exclusively in cash due to their own capital constraints and risk aversion to credit without tangible collateral. Farmers continued purchasing inputs from whatever sources offered credit, often lower-quality products from informal suppliers charging implicit interest through inflated prices, perpetuating low productivity despite knowing better inputs would improve yields.

The integration or lack thereof between fintech and other innovative village ecosystem components revealed both missed opportunities and coordination challenges. In Astanajapura village, the lack of connectivity between agricultural IoT sensors for monitoring rice fields and ponds and digital financial services meant that the valuable production data generated by the sensors did not benefit farmers' creditworthiness assessments, representing a fundamental failure to leverage ecosystem synergies. Technology providers operated in silos, with IoT installers unaware of fintech platforms, fintech applications lacking interfaces to accept agricultural data inputs, and no intermediary organizations facilitating integration despite obvious mutual benefits. Several farmers noted that if their sensor data demonstrating consistent, proper farming practices and stable yield histories could inform credit decisions, they might access better loan terms than current platform algorithms, which are based solely on mobile money transactions and are largely disconnected from their primary agricultural livelihoods. The coordination challenges reflected both technical interoperability issues, where proprietary

systems lacked open data sharing capabilities, and institutional fragmentation, where government agriculture, ICT, and financial sector agencies each promoted separate initiatives without cross-sectoral coordination mechanisms.
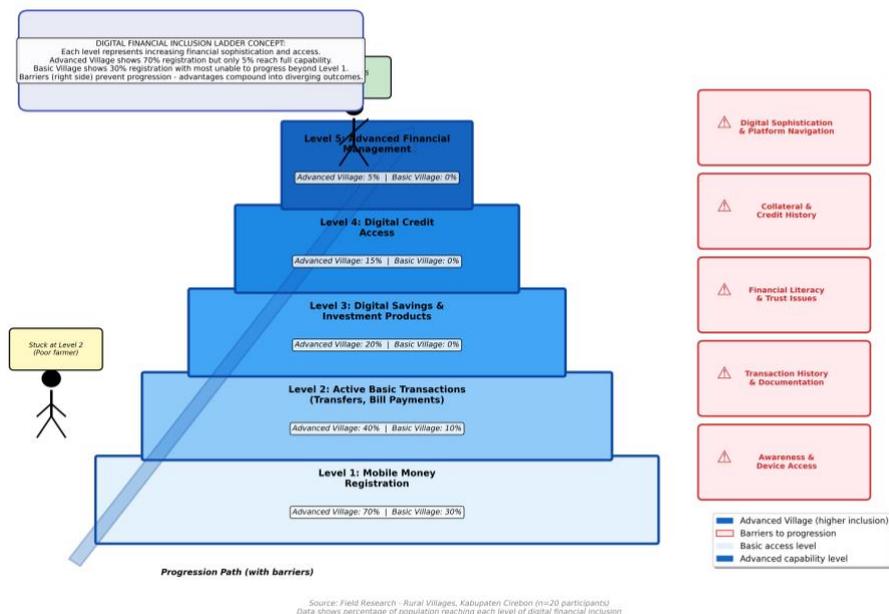


**Figure 3.** Fintech Usage Patterns and Digital Financial Inclusion Ladder - Description for Visualization

## 4. Inclusion and Exclusion Mechanisms Across Social Groups

The research uncovered complex, intersecting mechanisms that generate differential inclusion and exclusion patterns across multiple social identity dimensions, revealing that the benefits and burdens of the innovative village ecosystem are unevenly distributed rather than uniformly uplifting all community members. Gender emerged as a pervasive dimension structuring technology access, usage patterns, and outcome distributions in ways that simultaneously created new opportunities for women's economic participation while reproducing and sometimes intensifying existing gender inequalities. Women participants in Astanajapura village who successfully engaged with innovative technologies described how mobile money enabled business activities that traditional banking structures made difficult, citing the ability to receive customer payments instantly, maintain private business savings accounts without requiring husband co-signing, and conduct transactions discreetly without attracting family attention that might trigger expectations about contributing funds to household expenses or extended family requests. Several women entrepreneurs specifically emphasized how fintech platforms treating them as individual account holders rather than household representatives or male dependents provided dignity and autonomy previously absent in financial interactions.

However, these empowering experiences represented minority experiences within a broader landscape of persistent gender-based barriers that constrained women's participation in and ability to benefit from technology. Household-level technology access dynamics proved crucial, with women in both villages describing how shared family smartphones nominally belonged to husbands or sons who determined usage permissions, imposed implicit or explicit constraints on women's device time, and sometimes

monitored or questioned women's activities, generating inhibitions about extensive technology exploration. Digital literacy disparities reflected and reinforced these access patterns, with women typically having fewer opportunities for sustained technology learning due to household labor burdens, including childcare, cooking, cleaning, and agricultural work, which limit time available for training program participation or leisurely experimentation to build digital fluency. Several women described attempting to attend digital literacy workshops but facing family resistance framed through ostensibly reasonable concerns about neglecting household responsibilities, though similar concerns rarely constrained men's participation in development programs.

Cultural norms around appropriate feminine behavior created additional subtle constraints that interview participants struggled to articulate clearly but repeatedly gestured toward in discussions of technology discomfort. Women described feeling that extensive technology engagement, particularly for entertainment or social purposes rather than immediately productive applications, carried connotations of frivolity or time-wasting that did not apply equally to men, generating internalized guilt when spending time learning digital skills without clear, immediate returns. The mobile money platform's interfaces and marketing materials, predominantly featuring male imagery and business contexts, conveyed implicit messages about intended users that several women noted made them feel like outsiders appropriating tools designed for men rather than legitimate platform users in their own right. Online spaces, including social media and e-commerce platforms, could feel unwelcoming or even hostile, with several women recounting experiences of harassment, including unwanted advances, inappropriate comments on business pages, and generally dismissive or condescending treatment that created discomfort, deterring extensive engagement even when technically capable.

Age-based exclusion patterns proved even more severe than gender, with older residents facing compounding disadvantages around digital technology access, literacy, and meaningful usage that created risks of systematic marginalization from increasingly digital service delivery and social interaction modalities. The research documented a stark generational divide: residents over 55 exhibited low technology adoption rates in both villages, with perhaps 20% possessing basic mobile phones used exclusively for voice calls and SMS, and fewer than 5% owning smartphones or engaging with internet-based services. Older participants consistently described feeling overwhelmed by digital technologies, using terms like "too complicated," "not for people like me," "meant for young people," that revealed not just capability deficits but identity-based perceptions that technology fundamentally belonged to different generations and ages seeking to engage, representing futile struggles against natural order.

The mechanisms generating age-based exclusion extended beyond digital illiteracy to encompass physical, cognitive, and social dimensions that intersected to create particularly severe barriers for elderly populations. Visual impairments common in older age created difficulties reading small smartphone screens and navigating interfaces with tiny buttons and subtle color distinctions, while declining fine motor control made precise touch interactions challenging and frustrating. Cognitive processing speed decrements made rapidly changing interfaces, multi-step processes requiring remembering sequences, and time-limited operations like one-time passwords expiring before users completed transactions, especially difficult. Social isolation is common among elderly residents, and limited access to family members or friends who might provide technology assistance. Living alone or with similarly aged spouses meant lacking household members who could

explain features, troubleshoot problems, or mediate access to digital services when self-service was not possible.

The inadequacy of bright village ecosystem designs for elderly users' needs represented a systematic failure to consider universal design principles that ensure technology accessibility across diverse capabilities. Default assumptions embedded in platform development processes clearly anticipated young, healthy, educated users with strong vision, fine motor control, digital familiarity, and social support networks assisting when needed, rather than designing for populations with sensory impairments, limited prior technology exposure, cognitive processing differences, and potential social isolation. The absence of accessible alternative interfaces offering larger text and buttons, simplified navigation paths, audio guidance, and extended time limits for completing operations created unnecessary exclusion of populations who could benefit substantially from financial inclusion, information access, and social connectivity, which digital technologies theoretically enabled. Several younger participants noted that their parents or grandparents expressed a desire to use mobile money for convenience but found the interfaces too confusing, suggesting that inclusive design, rather than inherent elderly technology resistance, explained substantial adoption gaps.

Socioeconomic status operated as a fundamental dimension structuring inclusion, with poverty creating compounding disadvantages spanning technology access, capability development, and the ability to capture benefits from ecosystem participation. Poor households faced immediate affordability barriers to purchasing smartphones, paying for mobile data plans, investing in IoT technologies, or even covering nominal fees for digital literacy training through Kominfo Digital Literacy Movement programs, which are theoretically available at subsidized rates. Beyond initial access costs, the ongoing sustainability of technology usage required maintaining devices, replacing broken components, purchasing data regularly, and paying transaction fees that accumulated to meaningful burdens for households operating on extremely tight budgets, where daily trade-offs between competing urgent needs meant technology expenses often lost to food, medicine, school fees, or other immediate necessities. The opportunity costs of time spent learning digital skills or attending training programs represented additional poverty-specific constraints, as poor households, depending on daily wage labor, could not afford the income loss from missing work days to attend workshops that wealthier households managed without immediate economic hardship.

The capability disadvantages associated with poverty extended beyond direct financial constraints to encompass deficits in educational and social capital that shaped the possibilities for technology engagement. Limited formal schooling, common among poor populations, created literacy and numeracy barriers that constrained digital literacy development, as text-heavy interfaces, numerical transaction confirmations, and written instructions assumed baseline educational competencies many poor users lacked. Weak social networks among marginalized populations meant limited access to peer-learning opportunities or informal technical support that better-connected residents used extensively for troubleshooting and skill development. The exclusion from formal digital literacy training through the Kominfo Digital Literacy Movement program programs ostensibly open to all but implicitly designed for educated populations proved particularly troubling, with poor, low-literacy residents attempting participation but finding themselves unable to follow instructions, embarrassed by their struggles relative to other participants, and ultimately dropping out without acquiring intended skills while perceiving their failures as personal inadequacies rather than program design failures.

The research revealed troubling patterns in which innovative village ecosystem development risked exacerbating rather than reducing existing inequalities, with benefits concentrating among already-advantaged populations with education, resources, social connections, and prior technology exposure, enabling effective ecosystem participation. At the same time, marginalized groups faced new forms of exclusion beyond traditional, persistent disadvantages. Several participants explicitly articulated concerns that innovative village development served elite interests, noting that village leadership and wealthier residents enthusiastically embraced technologies that offered personal benefits while expressing less interest in ensuring that these technologies served broader populations equitably. The absence of explicit inclusion mandates, accountability mechanisms, or targeted interventions addressing specific marginalization drivers meant that ecosystem development followed the path of least resistance, serving the easiest-to-reach populations while leaving the hardest-to-serve groups behind, thereby widening rather than narrowing social divides.



**Figure 4.** Intersectional Inclusion-Exclusion Matrix - Description for Visualization

## 5. Ecosystem Coordination, Sustainability, and Implementation Challenges

The coordination of multiple smart village ecosystem components across technology types, implementing organizations, and governance levels emerged as a critical challenge significantly undermining potential benefits and sustainability across both research sites. In Astanajapura village, despite relatively advanced technology deployment, the research documented systematic coordination failures, with different initiatives operating in parallel rather than synergistically, missing opportunities to integrate that could multiply the benefits of individual components. IoT agricultural sensor deployment was carried out through a government agriculture ministry pilot program.

The consequences of fragmented implementation manifested in multiple problematic ways, as participants described experiencing, even when they did not conceptualize problems as coordination failures. Farmers using IoT sensors manually transcribed and

analyzed data in notebooks because sensor systems could not interface with mobile apps or cloud platforms accessible via smartphones they already owned, representing a fundamental interoperability failure: closed, proprietary systems designed without coordination prevented the obviously beneficial mobility of data. Digital literacy training covered mobile money basics, but not IoT agricultural applications, because the trainers lacked agricultural technology knowledge. In contrast, agricultural extension workers promoting sensor adoption had limited digital literacy and could not effectively teach farmers to interpret sensor data displayed on smartphone interfaces.

Institutional fragmentation at the government level created downstream coordination challenges, as different sector ministries pursued separate innovative village initiatives guided by sectoral priorities and existing program structures rather than integrated rural development strategies. Agriculture ministry programs focused exclusively on production technology, including IoT sensors, fertilizer recommendations, and market price information systems, without considering digital literacy prerequisites or financial access constraints that determined whether farmers could actually utilize promoted technologies. ICT ministry initiatives emphasized connectivity infrastructure and digital skills training, but were disconnected from practical applications that could motivate learning and sustained technology use beyond novelty experimentation. Financial sector regulators promoted fintech expansion, but with limited attention to rural-specific challenges or coordination with other rural development programs that could create enabling conditions for meaningful financial service uptake. These vertical sector silos prevented holistic approaches to addressing interconnected challenges that require cross-sectoral coordination beyond any single ministry's mandate.

The sustainability challenges facing innovative village initiatives in both research sites raised serious questions about the long-term viability of externally initiated technology deployments that lack adequate attention to local capacity building, maintenance systems, and economic models to ensure continued operation after initial project funding concludes. The IoT sensor pilot in Astanajapura village faced an uncertain future as the five-year project neared its conclusion, with no clear plans for ongoing technical support, sensor replacement when devices inevitably failed, or continued subsidies to enable farmers to afford maintenance costs and service fees beyond the pilot's free access period. Several farmers expressed concern that, while the pilot provided practical learning, they might abandon sensor use if post-project costs proved prohibitive or technical problems went unresolved without project staff providing troubleshooting. The village-scale solar power plant (PLTS) long-term viability depended on the village cooperative and BUMDes (Village-Owned Enterprises)'s capacity to manage increasingly complex technical and financial operations as the international donor phased out after three years, yet cooperative staff recognized their limited expertise and expressed anxiety about equipment failures they could not diagnose or repair without external technician assistance, requiring expensive travel costs.

In Karangsuwung village, with minimal innovative village development, paradoxically, fewer sustainability concerns emerged, but no pathway toward actual ecosystem emergence without external catalysts that existing village capacity could not generate independently. The village government, with the Village Head and Village Apparatus, stated smart village aspirations remained abstract because officials could not identify actionable entry points, translate general concepts into specific implementation steps, access technical expertise needed for system design and procurement, or mobilize financial resources beyond minimal regular budgets allocated for maintaining existing

basic infrastructure. The demonstration IoT sensors installed through the government pilot program faced maintenance challenges when minor technical issues emerged after the installation team departed, with neither the host farmers nor agricultural extension workers possessing the knowledge to diagnose problems or the confidence to attempt repairs, fearing they might damage expensive equipment. The installations gradually fell into disuse as mounting issues unresolved made sensor outputs unreliable, and farmers returned to conventional farming practices despite recognizing the theoretical sensor benefits they had witnessed when systems functioned properly.

The research revealed how critical local technical capacity development remained for innovative village sustainability, yet found systematic underinvestment in capacity building relative to technology hardware deployment across observed initiatives. The predominant implementation approach involved external technical teams, installing systems and providing brief user training, focusing on operational procedures, rather than deeper technical understanding, enabling troubleshooting and adaptive management. Astanajapura village's village-scale solar power plant (PLTS) installation included only 2 days of training for cooperative staff on basic system monitoring and meter reading, but no explanation of underlying technical principles, electrical system design, or systematic problem diagnosis to enable staff to address emerging issues independently. When system faults occurred, staff could only describe symptoms to external technicians who arrived days later, while suffering extended outages that eroded user satisfaction and cooperative credibility. Several staff members explicitly requested more technical training to build genuine system expertise. However, they found providers unwilling to invest time in comprehensive capacity building beyond minimal operational instruction, perhaps because deeper knowledge transfer threatened provider indispensability and ongoing maintenance service revenue.

The role of community ownership and governance in ecosystem sustainability emerged as a critical yet underdeveloped dimension across innovative village implementations. Astanajapura village's village-scale solar power plant (PLTS) demonstrated that collective ownership through the cooperative created stronger sustainability foundations than individually owned technologies like IoT sensors, as the cooperative possessed organizational continuity, collective resources for maintenance, and accountability to members, thereby generating pressure for sustained service delivery. However, cooperative governance of the microgrid remained relatively passive, with members paying fees but having minimal active engagement in system management decisions, oversight of financial sustainability, or strategic planning for system expansion or upgrading. The cooperative leadership expressed a desire for more active member participation but struggled to engage busy residents who viewed the microgrid as a utility service they consumed rather than a collectively owned asset they should actively govern. The tension between service delivery efficiency, which requires professional management, and democratic governance, which requires broad member engagement, remained unresolved, with cooperative leadership gravitating toward technocratic decision-making while occasionally feeling vulnerable to member criticism for decisions made without adequate consultation.
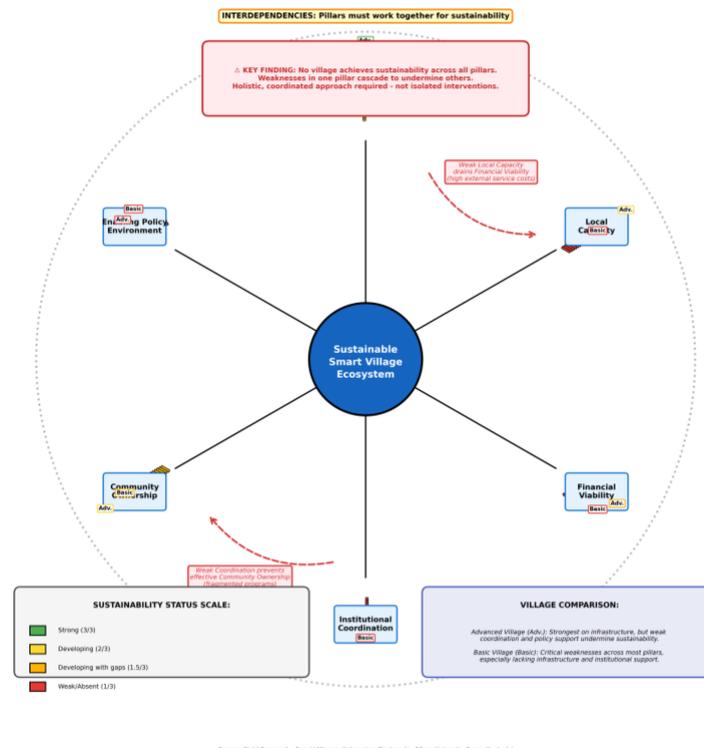
**Figure 5.** Smart Village Ecosystem Sustainability Framework - Description for Visualization

## Discussion

The findings of this research align with and extend existing scholarship on smart villages, rural digitalization, and inclusive development while revealing important contextual specificities and challenging some prevailing assumptions in the literature. The documented technology adoption patterns showing selective uptake concentrated among already-advantaged populations resonate with digital divide research, which demonstrates that technology access alone is insufficient for equitable participation when underlying capability, resource, and social capital inequalities remain unaddressed. (Degada et al., 2021; Lidén, 2016; Q. Wang et al., 2022). The finding that agricultural IoT sensors for rice field and pond monitoring attracted primarily progressive farmers with land ownership of more than 2 hectares and higher education rather than benefiting smallholders who might gain most from precision agriculture's efficiency improvements mirrors observations from precision agriculture studies in multiple contexts where cutting-edge technologies tend to concentrate among agricultural elites, widening rather than narrowing productivity gaps between large and small farmers. This pattern contradicts technology-optimist narratives suggesting that innovative agricultural technologies democratize access to productivity-enhancing tools, instead revealing how implementation approaches that fail to address affordability, capability, and support barriers enable elite capture of publicly funded innovations intended to benefit broad rural populations in Cirebon Regency.

The research findings on digital literacy emphasizing the multidimensional nature of digital competencies and persistent gaps even among active technology users contribute to growing scholarly recognition that digital skills encompass far more than operational device usage, extending to critical evaluation, online safety, content creation, and

problem-solving capabilities distributed very unevenly across populations (Mmari et al., 2024; Pant & Agarwal, 2023). The documented generational digital literacy divide, in which older residents faced systematic exclusion from digital technologies designed for younger users, validates age-stratified digital inequality research while providing granular insight into the specific mechanisms that generate elderly exclusion. The finding that formal digital literacy training through the Kominfo Digital Literacy Movement program achieved limited effectiveness due to insufficient duration, lack of follow-up support, and inadequate differentiation for diverse learner needs echoes critiques of one-size-fits-all technology training approaches that fail to recognize heterogeneous baseline capabilities, learning styles, and practical constraints facing different population segments. The research extends existing literature by documenting the crucial role of informal peer learning and family-based knowledge transfer in digital literacy development. It suggests that effective capacity-building strategies should leverage and strengthen these organic learning networks rather than relying exclusively on formal training delivered by external experts.

The fintech findings revealing how mobile money created meaningful financial inclusion for some users while leaving others excluded, despite registration, and how digital credit platforms systematically privileged already-creditworthy borrowers while excluding people with low incomes who most need affordable credit access, contribute to emerging critical fintech scholarship questioning celebratory narratives about digital financial inclusion. The research validates concerns that alternative data credit scoring, while eliminating traditional documentation barriers, creates new exclusion mechanisms favoring digitally active populations who generate transaction histories demonstrating regular income flows, while marginalizing day laborers, smallholders with less than 0.5 hectares of land, and others whose livelihood patterns generate sparse digital footprints inadequate for algorithmic underwriting. The findings support arguments that fintech's promises to serve previously unbanked populations often fail to materialize at scale, as profit-seeking platforms target lower-risk borrowers accessible through conventional means while avoiding genuinely marginalized populations whose credit risk cannot be adequately assessed or mitigated with available data.

However, the research findings challenge some prevailing assumptions in imaginative village literature while revealing important context-dependent variations. The relative success of Astanajapura village solar power plants (PLTs) at the village scale, achieving broad adoption across socioeconomic strata, contrasts with the literature that emphasizes persistent energy access inequalities, suggesting that collective ownership and management through cooperatives can overcome individual affordability barriers and achieve more equitable outcomes than household-level technology adoption models. The finding that Karangsuwung village's minimal technology adoption reflected not only infrastructure deficits but also institutional capacity gaps, political economy dynamics favoring elite interests, and the absence of coordinating mechanisms challenges technology-deterministic narratives suggesting that infrastructure deployment automatically catalyzes ecosystem development. The research reveals that appropriate institutions, governance arrangements, and implementation strategies are equally, if not more, important than technology availability in determining whether innovative village initiatives generate inclusive outcomes or reproduce existing inequalities.

The documented coordination failures and sustainability challenges extend the literature recognizing fragmentation as a persistent problem in rural development programming, while providing specific evidence of how sectoral silos, institutional

fragmentation, and project-based implementation undermine smart village ecosystem integration. The finding that different ecosystem components operated in parallel without interoperability, data sharing, or complementary capacity-building reveals a gap between theoretical, innovative village frameworks emphasizing systemic integration and ground-level realities in which pragmatic implementation follows existing institutional structures and funding streams that reinforce rather than overcome fragmentation. The research findings on sustainability challenges validate concerns that externally initiated technology deployments that lack adequate attention to local capacity building, maintenance systems, and financial models to ensure continued operation face high failure rates once external support phases conclude. The research provides empirical grounding for the argument that sustainable, innovative village development requires fundamental shifts from project-based technology delivery toward long-term investments in local human capacity, institutional strengthening, and governance systems that enable communities to manage technology evolution independently.

The findings offer several actionable insights for stakeholders aiming to design and sustain inclusive, innovative village ecosystems. For local government leaders, the research underscores the need for coordinated efforts to integrate technology initiatives, ensuring that digital capacity building is part of a broader, integrated strategy rather than isolated projects. Village leaders should advocate for holistic planning that addresses technology, institutional arrangements, and sustainability from the outset. Technology providers and implementing organizations are urged to prioritize user-centered design, focusing on rural needs and ensuring accessibility for diverse users, especially the elderly and low-literacy populations. Moreover, local capacity building is essential, with a focus on training local technicians and ensuring the long-term sustainability of innovative village systems. For development agencies, infrastructure investments are crucial, but they must be paired with comprehensive, sustained digital literacy programs that foster ongoing learning ecosystems. Lastly, inclusive mandates should be incorporated into policies, ensuring that marginalized groups are not left behind and that interventions are tailored to specific barriers faced by different population segments.

Despite providing valuable insights, the research has several limitations that restrict its generalizability and scope. The small sample size and purposive sampling strategy limit the ability to draw broader conclusions about innovative village ecosystems, particularly regarding populations that are excluded from participation. The research was constrained by its three-month timeframe, which hindered the assessment of long-term sustainability and development impacts. Additionally, reliance on self-reported interview data introduces potential biases and limits objective verification of technology usage patterns. Future studies should consider larger, more diverse samples and employ longitudinal designs to track the evolution of innovative village ecosystems. Furthermore, the study's focus on village-level dynamics neglected broader macro-level forces, such as policy and investment decisions, which influence innovative village development. Cross-national and multi-scalar comparative studies are needed to understand better how different contexts shape the success of these initiatives.

## CONCLUSION

This research examining innovative village ecosystems in Cirebon, Indonesia, reveals that technology-driven development benefits concentrate among educated, digitally literate populations while systematically excluding marginalized groups—poor households, elderly residents, and women—facing intersecting barriers of affordability, capability constraints, and socio-cultural restrictions. Critical challenges include persistent infrastructure deficits, fragmented institutional coordination in which IoT, fintech, and digital literacy initiatives operate in silos, inadequate capability development that leaves users vulnerable to online safety risks, and financial inclusion gaps as digital platforms privilege creditworthy borrowers while excluding vulnerable populations.

Technology-deterministic approaches assuming infrastructure deployment automatically generates inclusive outcomes prove fundamentally inadequate. Achieving inclusive, innovative village development requires holistic strategies simultaneously addressing connectivity infrastructure, systematic digital literacy programming, universal accessibility standards, local capacity building, prioritizing community ownership, cross-sectoral coordination mechanisms, and explicit inclusion mandates with accountability for equitable outcomes. Future research should employ longitudinal designs, larger comparative studies, and political economy analyses to examine the power relations that shape the interests that innovative village development ultimately serves.

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