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Access to Education in Indonesia's 3T Regions: Infrastructure Challenges and Technological Solutions

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ABSTRACT

Purpose: This study aims to identify educational barriers in Indonesia's Frontier, Outermost, and Disadvantaged (3T) regions and analyze technology-based strategies that may support educational equity.

Research Method: A qualitative library research approach with descriptive-analytical content analysis was employed. Data were collected from peer-reviewed articles, government reports, and policy documents published between 2021 and 2026 using predefined inclusion criteria to ensure source relevance and credibility.

Results and Discussion: The findings indicate that educational inequality in 3T regions is shaped by limited internet connectivity, inadequate electricity infrastructure, geographical isolation, restricted access to digital devices, and low digital literacy among educators. Technology-based interventions, including satellite internet, offline learning platforms, alternative energy systems, and teacher capacity-building programs, show potential to improve educational access; however, their effectiveness depends on contextual readiness, sustainability, and policy support.

Implications: Educational transformation in 3T regions requires integrated efforts that combine infrastructure development, human capacity strengthening, and responsive policy frameworks.

Originality: This study proposes an integrative perspective that positions infrastructure readiness, human capacity, and policy support as interconnected determinants of sustainable educational digitalization in 3T regions.

Keywords: 3T regions; educational equity; digital transformation; educational infrastructure; technology-based learning.

1. Introduction

Education is a fundamental human right guaranteed by the Indonesian constitution as a means of enhancing the nation's intellectual development. In the Golden Indonesia 2045 vision, the quality of human resources is a key pillar for lifting the country out of the middle-income trap. Nevertheless, educational opportunities remain unevenly distributed across Indonesia, particularly between developed urban areas and the Frontier, Outermost, and Disadvantaged (3T) regions. In the Indonesian context, 3T regions are areas characterized by geographical isolation, limited access to public services,

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and relatively low levels of socio-economic development. Consequently, educational disparities in these regions represent not only an administrative challenge but also an issue of social justice and equitable human capital development that requires urgent attention.

The current state of education in the 3T regions remains plagued by chronic limitations in physical infrastructure. Recent government reports and previous studies indicate that many schools in remote areas continue to face classroom shortages, inadequate library facilities, deteriorating school buildings, and limited access to basic educational resources (Africa, 2023). Severely damaged school buildings and extreme transportation difficulties to educational facilities keep net enrollment rates in these regions low (Wang, 2024). Indonesia's archipelagic geography creates massive logistical barriers, making conventional physical development often slow and expensive. These conditions demonstrate that geographical characteristics significantly influence the availability, accessibility, and quality of educational services in 3T regions. In addition to physical barriers, digital challenges are becoming a new barrier to students' potential in the 3T regions. In the context of educational digital transformation, access to internet connectivity and digital devices has increasingly become a prerequisite for ensuring equitable learning opportunities. Existing evidence suggests that substantial disparities persist between urban and remote areas in internet availability, digital device ownership, and opportunities to engage with technology-assisted learning environments. The lack of a stable internet signal and frequent power outages exacerbate their academic isolation. As a result, students in 3T regions may experience cumulative disadvantages that limit their participation in increasingly digitalized educational systems.

In response to these challenges, the Indonesian government has increasingly prioritized educational digitalization within its national education agenda. Several initiatives implemented during 2024 and 2025, accompanied by policy targets extending through 2026, emphasize expanding digital infrastructure, providing technology-assisted learning resources, and strengthening teachers' digital competencies (insert relevant citations). It should be noted that references to 2026 in this study reflect policy targets and planned interventions rather than completed implementation outcomes. This distinction is important to ensure clarity regarding the temporal scope of the analysis. However, implementing technology-based educational interventions in the Frontier, Outermost, and Disadvantaged (3T) regions presents substantial operational challenges. Previous studies have highlighted issues related to limited digital literacy among educators, inadequate technical support, and resistance to adopting new instructional approaches. Digital literacy, in this context, refers to educators' ability to access, evaluate, utilize, and integrate digital technologies effectively into pedagogical practices. Therefore, technological advancement alone cannot guarantee improvements in educational quality unless accompanied by adequate readiness of human resources and institutional support. Consequently, the educational challenge in 3T regions has evolved from limitations in conventional learning resources to broader concerns about technological readiness and the development of digital competencies.

The evidence base comprises recent studies that consistently identify educational inequality in 3T regions as a multidimensional phenomenon. Falah & Hadna (2022) identified six critical barriers, including limited internet access, parental economic constraints, inadequate facilities, insufficient educator quality, educator shortages, and poor road infrastructure. Ulfiaturrohmah & Diantoro (2021) similarly documented inadequate infrastructure and low teacher technological competency. Rabani *et al.,* (2023) found that technology implementation can improve learning quality and reduce regional educational disparities, provided that infrastructure development, teacher training, and collaboration among stakeholders are adequately addressed. Widiasanti *et al.,* (2023) demonstrated that Big Data

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applications in distance education can support student monitoring and facilitate more personalized learning experiences, although teacher preparedness remains a determining factor. More recent studies conducted during 2024–2025 continue to identify persistent challenges related to limited internet connectivity, inadequate digital devices, and disparities in educators' digital competencies across 3T regions (Harahap & Mahardhani, 2025; Nur Asyikin *et al.,* 2025; Tomasouw *et al.,* 2024). Collectively, these findings suggest that educational inequality in 3T areas cannot be attributed solely to geographical isolation but rather reflects the interaction of infrastructural, technological, socio-economic, and human resource factors.

Despite the growing body of literature, previous studies have generally examined educational infrastructure limitations, digital technology utilization, and teacher competency development as separate issues. Limited attention has been paid to understanding how physical infrastructure constraints and digital transformation initiatives interact amid Indonesia's ongoing educational policy transition during the 2024–2026 period. Furthermore, few studies critically assess the feasibility, sustainability, implementation risks, and contextual suitability of technology-based educational interventions in resource-constrained settings. Addressing this gap is important because technological solutions successful in one context may not apply to all 3T regions, given the diversity of geographical conditions, infrastructural capacities, and local community characteristics.

Therefore, this study aims to analyze the educational challenges experienced in the Frontier, Outermost, and Disadvantaged (3T) regions by examining both physical infrastructure limitations and emerging digital inequalities. Using a qualitative library research approach, this study synthesizes recent evidence to identify major educational barriers, critically analyzes the opportunities and limitations associated with technology-based interventions, and formulates strategic recommendations for policymakers. The originality of this study lies in its integrative perspective, which positions digital transformation not as a standalone solution but as part of a broader educational ecosystem requiring infrastructure readiness, educator capacity-building, and context-sensitive policy support to achieve more inclusive and equitable educational development.

The remainder of this paper is organized as follows. Section 2 provides a literature review and hypothesis development. Section 3 presents the research method and design. Section 4 provides the results and discussion. Section 5 is Concluding Remarks and Recommendations.

2. Literature Review and Hypothesis Development

2.1 Educational Inequality in Frontier, Outermost, and Disadvantaged (3T) Regions

Educational inequality remains one of the most persistent challenges facing Indonesia's efforts to achieve inclusive human capital development. Despite constitutional guarantees of equal educational opportunities, access to quality education remains highly variable across regions, particularly in Frontier, Outermost, and Disadvantaged (3T) areas. These regions are generally characterized by geographical isolation, limited transportation networks, inadequate educational infrastructure, shortages of qualified teachers, and restricted access to learning resources. The persistence of these barriers reflects that educational inequality in 3T areas extends beyond geographical constraints and is closely linked to broader socio-economic disparities. Sari *et al.,* (2024) emphasized that schools in 3T regions frequently face challenges, including inadequate facilities, limited learning support systems, and disparities in educational quality compared with urban areas. Similarly, Mathebula *et al.,* (2025) found that

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infrastructural deficiencies and insufficient teacher preparedness continue to hinder the implementation of effective learning processes in disadvantaged regions. These findings indicate that achieving educational equity requires comprehensive interventions that address both physical access and the quality dimensions of educational provision. Furthermore, Sui-Ni (2023) argued that realizing Indonesia Emas 2045 necessitates stronger coordination between central and local governments to ensure that educational policies effectively reach geographically marginalized communities.

Recent developments suggest that digital transformation has the potential to reduce educational disparities; however, unequal technological readiness may also create new forms of exclusion. Nthambeleni & Motadi (2025) demonstrated that regional disparities in digital development are associated with broader socio-economic inequalities, implying that students in less digitally connected areas face additional disadvantages in accessing educational opportunities. In the context of 3T regions, Setyanti *et al.,* (2025) reported that the adoption of digital technology can enhance educational accessibility when supported by adequate infrastructure and institutional commitment. Nevertheless, the benefits of technological interventions remain uneven because limited internet connectivity, inadequate digital devices, and varying levels of digital literacy continue to constrain their implementation. Asyikin *et al.,* (2025) emphasized that educational equity in 3T areas requires an integrated strategy encompassing infrastructure improvements, teacher capacity building, and responsive policy support. Moreover, Badaruddin *et al.,* (2025) highlighted that persistent digital educational inequalities may adversely affect young people's social mobility by restricting access to knowledge and future economic opportunities. Collectively, these studies suggest that addressing educational inequality in 3T regions requires a multidimensional approach that integrates infrastructural development, human resource strengthening, and sustainable digital transformation policies to ensure that no learner is left behind.

2.2. Digital Transformation and Technology-Based Learning in Remote Education Contexts

Digital transformation has increasingly become a strategic approach to expanding educational access and improving learning quality in geographically disadvantaged areas. In the context of Education 5.0, the integration of digital technologies into educational systems is no longer limited to adopting technological devices but also extends to transforming pedagogical practices, enhancing institutional readiness, and fostering learner engagement. Bernabei *et al.,* (2023) argued that emerging technologies, including artificial intelligence, learning analytics, and intelligent educational systems, have the potential to support more inclusive and adaptive learning experiences. Likewise, Bond *et al.,* (2021) demonstrated that technology-assisted learning environments can enhance instructional continuity and flexibility, particularly in situations where conventional face-to-face education is constrained. Technological innovations such as online learning platforms, immersive digital environments, and interactive learning applications are increasingly recognized as mechanisms for reducing barriers related to distance and limited educational resources. Tlili *et al.,* (2022) further suggested that advanced digital ecosystems may offer new opportunities for vulnerable populations and learners in underserved regions by facilitating greater interaction, collaboration, and access to educational content. Similarly, Li *et al.,* (2024) highlighted that technology-enhanced learning tools, including augmented reality applications, can increase student engagement and improve learning effectiveness by creating more contextualized and interactive educational experiences. Collectively, these studies indicate that digital transformation

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possesses considerable potential to strengthen educational inclusion and broaden learning opportunities in remote contexts.

Despite these promising developments, the effectiveness of technology-based learning remains contingent upon multiple contextual factors. Digital transformation should not be understood merely as the provision of technological infrastructure but rather as a systemic process requiring institutional preparedness, pedagogical adaptation, and equitable access. Bozkurt & Sharma (2023) emphasized that the successful implementation of remote learning depends on the development of flexible instructional designs that respond to diverse learner needs and local realities. From a critical perspective, Kwak & Pardos (2024) argued that educational technologies may inadvertently reinforce existing inequalities when issues of digital access, social exclusion, and unequal resource distribution are not adequately addressed. Furthermore, Zawacki-Richter *et al.,* (2019) noted that technological innovations can contribute meaningfully to educational improvement only when accompanied by investments in educators' competencies and supportive organizational environments. These findings suggest that technology should be positioned as an enabling instrument rather than a standalone solution to educational disparities. In remote educational contexts, particularly those characterized by infrastructural limitations and socio-economic vulnerabilities, the success of digital transformation depends on the interaction between technological readiness, teacher capacity, institutional commitment, and policy support. Consequently, efforts to promote technology-based learning should adopt a holistic and context-sensitive approach to ensure that digital innovations contribute to educational equity rather than exacerbate existing disparities.

2.3 Integrative Framework: Infrastructure Readiness, Human Capacity, and Policy Support

The successful implementation of technology-based education depends not only on the availability of digital tools but also on the interaction between infrastructure readiness, human capacity, and policy support. Infrastructure readiness is the foundational dimension of educational digital transformation, as the effectiveness of technology-enhanced learning is inherently linked to reliable internet connectivity, electricity, digital devices, and supportive school facilities. However, physical infrastructure alone is insufficient to generate meaningful educational change. Cockerham *et al.,* (2021) argued that digitalization in educational settings should be understood as a complex process involving organizational transformation, leadership, and pedagogical adaptation rather than merely the adoption of technological innovations. Likewise, Howard *et al.,* (2021) emphasized that both institutional conditions and individual preparedness shape teachers' readiness to engage in online and technology-mediated instruction. Within this context, human capacity emerges as a critical determinant of educational transformation. Taajamo (2021) demonstrated that teachers' digital competence encompasses not only technical skills but also attitudes, knowledge, and the ability to integrate technology effectively into instructional practices. Similarly, Rani & Chu (2022) highlighted that collaborative professional development and institutional support mechanisms play important roles in strengthening educators' capacity to adopt and sustain technology integration initiatives. These findings collectively suggest that technological investments are unlikely to produce optimal outcomes unless accompanied by systematic efforts to enhance educator competencies and organizational readiness.

Beyond infrastructure and human resources, policy support functions as an enabling mechanism that shapes the sustainability and scalability of digital transformation initiatives. Effective educational policies establish strategic priorities, allocate resources, coordinate stakeholders, and create

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environments conducive to innovation and adaptation. Ifinedo *et al.,* (2020) found that organizational support and favorable institutional conditions significantly influence educators' willingness and ability to integrate technology into teaching practices. From a broader perspective, Rodegher *et al.,* (2024) argued that policy readiness and the development of digital competence should be addressed simultaneously to ensure equitable educational transformation across diverse contexts. Furthermore, Dexter & Richardson (2020) emphasized the importance of educational leadership in facilitating technology integration through vision-setting, capacity-building, and the establishment of supportive implementation structures. Taken together, these studies indicate that digital transformation should be conceptualized as an ecosystem rather than a technology-driven intervention. In remote educational settings characterized by infrastructural limitations and socio-economic vulnerabilities, sustainable educational improvement requires coordinated investments in infrastructure development, continuous enhancement of human capacity, and responsive policy frameworks. This integrative perspective provides a comprehensive foundation for understanding how educational equity can be pursued through context-sensitive strategies that recognize the interdependence of technological, institutional, and human dimensions.

3. Research Method

This research employed qualitative methods and a library-based approach to explore educational challenges and potential solutions in the Frontier, Outermost, and Disadvantaged (3T) regions of Indonesia. The study relied exclusively on documentary evidence obtained from academic publications and official government documents. Literature searches were conducted using several databases and repositories, including Scopus-indexed journals, Google Scholar, Garuda, and official publications issued by the Central Statistics Agency (BPS), the Ministry of Primary and Secondary Education, and other relevant governmental institutions. To ensure systematic identification of relevant studies, combinations of keywords were employed, including "3T education Indonesia," "educational inequality remote areas Indonesia," "digital transformation in education," "technology-based learning remote contexts," "educational infrastructure in 3T regions," and "digital literacy among teachers." The literature search focused primarily on publications issued between 2021 and 2026 to capture recent developments concerning educational digitalization and regional educational disparities. It should be noted that information relating to 2026 was treated as policy targets and strategic plans rather than completed implementation outcomes.

Predefined inclusion and exclusion criteria guided the selection of sources to enhance methodological transparency and replicability. Inclusion criteria comprised: (1) empirical studies or policy reports directly related to education in remote or disadvantaged regions; (2) publications discussing educational infrastructure, digital transformation, technology-based learning, teacher readiness, or educational policy support; (3) peer-reviewed journal articles published between 2021 and 2026; and (4) official reports issued by recognized governmental institutions. Exclusion criteria included duplicate publications, opinion articles lacking empirical or policy evidence, studies unrelated to educational contexts, and documents without identifiable sources. The screening process resulted in the inclusion of the most relevant literature to support the study's analytical framework. Source credibility was evaluated based on publication status, institutional authority, methodological clarity, and relevance to the research objectives.

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Data analysis employed descriptive-analytical content analysis to examine educational disparities objectively. The analytical process consisted of three stages. First, data reduction was conducted to identify information relevant to the themes of infrastructure readiness, human capacity, technological interventions, and policy support. Second, the selected evidence was organized into thematic categories to facilitate the interpretation of relationships among educational barriers and proposed solutions within the context of 3T regions. Third, interpretative synthesis was undertaken to formulate strategic recommendations by critically assessing not only the potential benefits of educational technologies but also their feasibility, sustainability, implementation risks, and contextual suitability. This approach was chosen to enable the research to produce a comprehensive synthesis between field realities and the national digital transformation policy framework.

4. Results and Discussion

4.1 Analysis Results

4.1.1 Infrastructure and Connectivity Constraints in Frontier, Outermost, and Disadvantaged (3T) Regions

The findings indicate that internet connectivity and electricity availability remain the most fundamental barriers to educational digitalization in Frontier, Outermost, and Disadvantaged (3T) regions. Many schools in remote areas of Papua, Maluku, and East Nusa Tenggara continue to experience limited access to stable internet services due to the absence of fiber-optic networks and inconsistent mobile signal coverage. As a result, teachers and students encounter difficulties in using online learning platforms and accessing digital educational resources, which have increasingly become integral to contemporary educational practices. These limitations limit opportunities for participation in technology-based learning activities and hinder the equitable implementation of digital education initiatives across Indonesia's regions.

The review further reveals that inadequate electricity infrastructure intensifies existing connectivity challenges. In several disadvantaged communities, electricity service remains unreliable, with some areas receiving only limited access at certain times of day. Such conditions constrain the operation of digital devices distributed through educational support programs, including computers, laptops, and interactive learning equipment. Consequently, schools often struggle to maximize the utilization of available technological resources within the teaching and learning process. The findings also suggest that inadequate internet and electricity infrastructure indirectly influence the development of digital competencies among educators and learners by limiting access to online training, digital learning environments, and technology-mediated educational experiences. Overall, these findings highlight that connectivity and energy infrastructure constitute essential prerequisites for supporting educational transformation in 3T regions.

4.1.2 Geographic Accessibility and Distribution Challenges

The findings demonstrate that geographical conditions represent another major obstacle to educational equity in Frontier, Outermost, and Disadvantaged (3T) regions. Indonesia's landscape, characterized by mountainous terrain, dense forests, and extensive archipelagic territory, poses substantial logistical challenges for the distribution of educational resources. Many schools in remote locations can only be reached by air or by river routes that are highly weather-dependent and involve considerable costs.

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Consequently, the delivery of textbooks, technological devices, and construction materials required for educational infrastructure development is frequently delayed compared with that for schools in urban centers. These circumstances contribute to disparities in the availability and quality of educational services experienced by communities in geographically isolated areas.

The review also finds that difficult geographic access directly affects educators' mobility and distribution. Teachers assigned to remote schools are often required to travel long distances through challenging terrain to reach their teaching destinations. Such circumstances contribute to uneven teacher distribution and may result in shortages of qualified personnel in disadvantaged regions. In several cases, educators are required to manage multiple classes simultaneously because of limited staffing capacity. Furthermore, geographic isolation complicates the maintenance of educational infrastructure and technological equipment, as repair services and technical support are often located far from remote communities. Consequently, damaged facilities or malfunctioning devices may remain unused for extended periods. These findings indicate that geographical barriers influence not only physical access to education but also the continuity and effectiveness of educational service provision in 3T regions.

4.1.3 Limited Availability of Digital Learning Devices

The findings reveal that limited access to digital learning devices remains a significant barrier to implementing technology-based education in Frontier, Outermost, and Disadvantaged (3T) regions. Although various educational assistance programs have sought to improve the availability of technological resources in remote schools, disparities in device ownership and utilization persist between urban and disadvantaged areas. In many schools in 3T regions, computers, laptops, tablets, and other digital devices are available only in limited numbers and are often concentrated in administrative offices or under-resourced computer laboratories. Consequently, students have limited opportunities to engage directly with digital technologies, thereby limiting the development of the fundamental digital competencies required in contemporary educational settings.

The review further indicates that the scarcity of digital devices affects the implementation of various national educational initiatives that rely on technological infrastructure. Limited availability of devices constrains students' participation in computer-based assessments and limits the adoption of hybrid or technology-supported instructional approaches. In addition, teachers encounter challenges in utilizing digital educational management systems and developing technology-enhanced learning materials due to inadequate access to appropriate equipment. The findings also suggest that disparities in digital device availability may contribute to unequal educational experiences and opportunities among students from different geographical contexts. Consequently, ensuring equitable access to educational technologies remains an important consideration in efforts to strengthen educational inclusion within 3T regions.

4.1.4 Low Digital Literacy among Educators

The findings demonstrate that limited digital literacy among educators constitutes one of the most prominent non-physical barriers to educational digital transformation in Frontier, Outermost, and Disadvantaged (3T) regions. Teachers working in remote areas frequently encounter difficulties using digital devices and contemporary educational technologies in their instructional practices. These

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limitations are often associated with unequal access to professional development opportunities and the absence of continuous training programs tailored to the specific needs of educators in geographically isolated communities. As a result, educational technologies introduced through government initiatives may not be fully integrated into classroom activities, thereby reducing their potential contribution to improving teaching and learning processes.

The review also indicates that low levels of technological literacy may influence educators' confidence and willingness to adopt new instructional approaches. Teachers who have limited experience with digital technologies tend to rely on conventional teaching methods that emphasize printed materials and teacher-centered instruction. Consequently, students may have fewer opportunities to participate in interactive and technology-mediated learning experiences that support the development of higher-order thinking skills and digital competencies. Furthermore, the findings suggest that the provision of technological infrastructure alone is insufficient to ensure meaningful educational transformation unless accompanied by sustained efforts to strengthen educators' digital pedagogical capabilities. These findings highlight the importance of considering human capacity development as an integral component of educational digitalization strategies in 3T regions.

4.2 Discussion

4.2.1 Satellite Internet as a Context-Dependent Connectivity Strategy

The findings concerning limited internet connectivity suggest that conventional infrastructure expansion alone may be insufficient to address educational disparities in Frontier, Outermost, and Disadvantaged (3T) regions. Given Indonesia's geographical complexity, satellite internet technologies have increasingly been proposed as alternative solutions to extend connectivity to remote schools that remain beyond the reach of terrestrial networks. The use of satellite-based systems can facilitate access to online learning platforms, digital educational resources, and professional development opportunities for educators in geographically isolated communities. Through improved connectivity, schools may become more integrated into national educational initiatives and benefit from broader access to knowledge and instructional innovations.

Nevertheless, the implementation of satellite internet should not be regarded as a universally applicable solution. The sustainability of satellite-based educational connectivity depends upon several contextual factors, including the availability of reliable electricity, the affordability of subscription costs, and the presence of local technical support mechanisms capable of maintaining the infrastructure. In addition, variations in regional conditions imply that strategies effective in one location may not necessarily be transferable to other 3T settings. Consequently, efforts to promote satellite internet use require careful planning, long-term financing arrangements, and coordination among government agencies, private providers, and local communities. Without these supporting conditions, satellite connectivity initiatives risk becoming temporary interventions that fail to generate lasting improvements in educational equity.

4.2.2 Offline Learning Platforms and Their Sustainability Challenges

The findings related to unstable internet access highlight the importance of developing educational alternatives that are less dependent on continuous connectivity. In this context, offline learning platforms emerge as promising mechanisms to support instructional continuity in remote educational

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environments. The availability of locally stored educational resources, digital libraries, and offline learning management systems may enable teachers and students to access learning materials despite limitations in internet infrastructure. Such approaches offer flexibility and may reduce schools' dependence on external connectivity systems that are vulnerable to technical disruptions and geographical constraints.

However, the effectiveness of offline learning platforms extends beyond the mere provision of digital content. Their successful implementation requires regular updates to educational materials, alignment with evolving curriculum standards, and adequate teacher capacity to integrate these resources into pedagogical practice. Furthermore, maintaining local technological systems necessitates institutional commitment and clearly defined operational responsibilities at the school level. If these aspects are overlooked, offline platforms may gradually become obsolete and underutilized. Therefore, rather than being viewed solely as emergency responses to infrastructural deficiencies, offline learning systems should be incorporated into broader educational digitalization strategies that emphasize sustainability, adaptability, and responsiveness to the diverse realities experienced across 3T regions.

4.2.3 Strengthening Local Teacher Capacity for Digital Transformation

The findings on low digital literacy among educators underscore that human capacity is a critical determinant of successful educational digitalization. The provision of technological infrastructure alone does not automatically translate into improved learning outcomes if educators lack the competencies necessary to integrate technology effectively into pedagogical practices. Teachers in remote settings frequently face limited access to professional development opportunities, reducing their confidence and readiness to adopt technology-enhanced instructional approaches. Consequently, educational transformation initiatives that prioritize hardware distribution without corresponding investments in human resource development may generate suboptimal outcomes and contribute to the underutilization of available technological resources.

In this regard, strengthening local teacher capacity should be considered a long-term investment rather than a one-time intervention. Continuous professional development programs, peer mentoring initiatives, and collaborative learning communities may enhance educators' digital pedagogical competencies while promoting locally relevant instructional innovations. However, the sustainability of such initiatives depends on institutional commitment, consistent funding mechanisms, and supportive leadership structures that encourage experimentation and continuous improvement. Furthermore, training programs should extend beyond technical operational skills to encompass instructional design, digital assessment practices, and strategies for fostering student engagement in technology-mediated learning environments. Therefore, teacher empowerment should be positioned as a central component of educational digital transformation policies in 3T regions, ensuring that technological innovations are supported by the human capabilities required for their effective implementation.

4.2.4 Alternative Energy Provision to Support Educational Digitalization

The findings concerning limited electricity availability suggest that educational digitalization in remote regions is fundamentally dependent on the reliability of supporting energy infrastructure. In communities where access to conventional electricity networks remains limited or unstable, alternative

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energy sources can strengthen the operational sustainability of technology-based educational initiatives. Renewable energy solutions, particularly solar energy systems, may provide schools with more consistent access to the electricity required to operate computers, digital learning devices, internet connectivity equipment, and other educational technologies. As such, alternative energy provision may serve as an enabling factor supporting broader efforts to reduce educational disparities in geographically isolated contexts.

Despite these potential benefits, implementing alternative energy systems presents several practical challenges that warrant careful consideration. Initial installation costs, battery replacement requirements, and limited local technical expertise may constrain the long-term viability of renewable energy initiatives in remote communities. Consequently, educational energy interventions should incorporate maintenance planning, technical training for local stakeholders, and sustainable financing arrangements to minimize dependency on external assistance. Furthermore, collaborative partnerships among government agencies, private-sector organizations, and local communities may enhance the effectiveness and ownership of renewable energy programs. These considerations indicate that alternative energy solutions should not be viewed solely as technological interventions but rather as integral components of comprehensive strategies designed to support equitable and sustainable educational development in 3T regions.

5. Concluding Remarks and Recommendation

Based on the findings and discussion, this study concludes that efforts to promote educational equity in Indonesia's Frontier, Outermost, and Disadvantaged (3T) regions continue to face multidimensional challenges across both the physical and digital dimensions of educational provision. The findings indicate that barriers to educational development extend beyond deteriorating school facilities to encompass limited internet connectivity, inadequate electricity infrastructure, geographical isolation, restricted access to digital learning devices, and insufficient digital competencies among educators. These interconnected constraints highlight that educational disparities in 3T regions cannot be adequately addressed through conventional infrastructure development alone. Furthermore, references to the 2024–2026 period in this study should be interpreted in the context of ongoing initiatives and policy targets aimed at strengthening educational digitalization, rather than as evidence of fully implemented outcomes.

This study also demonstrates that technology-based interventions, including satellite internet, offline learning platforms, alternative energy provision, and teacher capacity-building initiatives, possess considerable potential to support educational transformation in remote contexts. However, their effectiveness depends upon contextual factors such as financial sustainability, institutional readiness, local technical capacity, and responsiveness to regional variations. Therefore, technological innovation should not be viewed as a standalone solution but rather as one component within a broader educational ecosystem. The originality of this study lies in its integrative perspective, emphasizing that sustainable educational transformation in 3T regions requires the alignment of infrastructure readiness, human capacity development, and supportive policy frameworks. Strengthening collaboration among government institutions, educational stakeholders, local communities, and private sector actors is essential to ensure that future educational initiatives contribute meaningfully to more inclusive, equitable, and context-sensitive educational development across Indonesia.

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Volume 4, Issue 2 (2026). 43-55
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Statement of Use of Generative AI

During the preparation of this work, the author used generative artificial intelligence tools to support the scientific writing process. Grammarly was used to check grammar, refine writing style, and improve clarity in scientific writing. All interpretations, analyses, and conclusions presented in this study are the sole responsibility of the author.

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