



E-Budgeting and the Effectiveness of Pro-Poor Public Spending: An Institutional Governance Perspective from Local Government in Indonesia

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Abstract

Background: Despite continuous increases in local fiscal capacity and budget allocations, governance constraints—such as weak transparency, accountability, and coordination—often undermine the effectiveness of pro-poor public spending. From an institutional governance perspective, these constraints challenge not only policy performance but also the sustainability of poverty alleviation efforts.

Objective: This study examines the relationships among local government budget management quality, *e-budgeting* implementation, and the effectiveness of pro-poor public spending at the subnational level in Indonesia.

Methods: Drawing on survey data collected from officials in local government agencies in West Tanjung Jabung Regency, the study employs Partial Least Squares-Structural Equation Modeling (PLS-SEM) to analyze direct and indirect relationships among multidimensional governance constructs.

Results: The results indicate that the Regional Revenue and Expenditure Budget (APBD) does not have a significant direct effect on poverty reduction ($\beta = -0.036$, $p = 0.776$). However, APBD has a positive and significant effect on E-Budgeting implementation ($\beta = 0.667$, $p < 0.001$), while E-Budgeting significantly contributes to poverty reduction ($\beta = 0.673$, $p < 0.001$). These findings suggest that effective E-Budgeting implementation plays a crucial role in enhancing transparency, accountability, and budget efficiency, thereby supporting poverty reduction efforts in Tanjung Jabung Barat Regency.

Conclusion: By strengthening transparency, accountability, budget traceability, and interagency coordination, *e-budgeting* enhances consistency between budget planning and implementation processes and supports the sustainable effectiveness of pro-poor public spending in decentralized government systems. Theoretically, this study contributes to the public financial management and digital governance literature by positioning *e-budgeting* as an institutional mediating mechanism linking budget quality to sustainable policy implementation.

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INTRODUCTION

Poverty alleviation remains a major challenge in many developing countries. Poverty reduction constitutes a core dimension of social and economic sustainability, as persistent

poverty undermines long-term development outcomes and institutional stability. To address this challenge, numerous countries have promoted fiscal decentralization, positioning local governments as primary actors in public financial management and expenditure. Within this framework, local public spending constitutes a key policy instrument of subnational governments. However, extensive empirical evidence indicates that increases in fiscal capacity and expenditure allocations do not automatically translate into significant reductions in poverty. Pro-poor programs often fail due to targeting errors, politicization, weak coordination, and limited institutional capacity (Andrews, 2004; Crawford, 2008; Madduma Bandara, 2016; Yankson, 2007; Yossinomita et al., 2025).

These failures are not merely the result of budgetary constraints but stem primarily from governance problems and the limited capacity of implementing organizations. Corruption, weak accountability, and inadequate coordination across organizational units frequently prevent public spending from effectively reaching target groups (Nursini & Tawakkal, 2019; Olaoye et al., 2024; Tirtosuharto, 2022). In public financial management, the budget is understood as a policy implementation mechanism whose performance depends heavily on the quality of governance. From a sustainability perspective, ineffective budget governance not only weakens short-term policy outcomes but also threatens the long-term continuity and credibility of poverty alleviation efforts.

In line with the principles of good governance, transparency and accountability in budget management are essential prerequisites for the effectiveness of pro-poor public spending. Improvements in budget governance and institutional capacity are therefore critical to ensuring that public spending contributes to sustainable and inclusive development rather than producing temporary or fragmented impacts (Nurias et al., 2023; Purwanti & Nurhidayati, 2025; Putra, 2017).

Most existing studies on public spending and welfare continue to emphasize the direct relationship between the level or composition of public expenditure and indicators of poverty or well-being, particularly in sectors such as health, education, agriculture, and social protection (Asmawati et al., 2025; Guermazi & Gharbi, 2024; Gumede et al., 2024; Wahiba & Ahlem, 2022). This approach examines how variations in expenditure allocation affect poverty or quality of life at the national or regional levels, while paying limited attention to budget management and implementation processes (Kim & Ahn, 2020; Mogues et al., 2008; Mogues & Benin, 2012; Takeshima, 2024). Consequently, the quality of budget governance and policy implementation at the local government level has rarely been the central focus of empirical research (Asmawati et al., 2025; Mogues & Benin, 2012; Takeshima, 2024).

Against this backdrop, advances in information technology have encouraged the adoption of digital governance in public financial management, including the implementation of e-budgeting systems. E-budgeting enables integrated and digitally documented processes for planning, budgeting, execution, and budgetary control, thereby enhancing traceability, consistency, and transparency in local budget management. In practice, e-budgeting functions not only as an administrative tool but also as an institutional mechanism with the potential to strengthen coordination across implementing units, enhance accountability in budget utilization, and support the effective implementation of pro-poor public spending. As a governance innovation, e-budgeting has increasingly been promoted as a sustainability tool that supports the long-term effectiveness and resilience of public spending systems.

Nevertheless, research on digital governance reveals a similar limitation. Digital budgeting systems, Financial Management Information Systems (FMIS), and e-budgeting are generally examined as instruments for improving transparency, accountability, and administrative efficiency in public financial management (Barani & Nemati, 2016; Khera & Patibandla, 2020; Matveeva et al., 2021; Suryanto, 2019; Yashina et al., 2024). These studies tend to position digital systems as tools that support managerial decision-making, financial oversight, and information disclosure rather than as institutional mechanisms that bridge budget planning and policy implementation. As a result, the role of e-budgeting as an institutional mechanism linking budget planning processes to the effectiveness of policy implementation—particularly in pro-poor public spending at the local government level—remains underexplored, limiting the current understanding of how digital governance reforms contribute to the sustainability of

poverty reduction policies.

These limitations highlight an important research gap. Theoretically, budgets are still predominantly understood as fiscal inputs rather than as mechanisms of policy implementation. Conceptually, e-budgeting is more often framed as an administrative tool than as an institutional mechanism connecting planning and implementation. Empirically, studies examining the relationship among budget management, digital governance, and spending effectiveness at the level of local government implementing organizations remain scarce.

In the Indonesian context, the effectiveness of public spending remains a critical issue in the era of fiscal decentralization. Although fiscal decentralization and central government transfers have contributed to poverty reduction, local government spending does not always have a significant impact on the quality of public services and welfare outcomes (Desdiani et al., 2022; Hardiwan et al., 2019; Nursini & Tawakkal, 2019; Siburian, 2020; Sudhipongpracha, 2017; Sudhipongpracha & Wongpredee, 2017). This mismatch raises concerns regarding the sustainability of poverty reduction achievements at the subnational level.

Various studies have identified poor planning quality, fragmented interagency coordination, limited bureaucratic capacity, and governance practices lacking transparency and accountability as major obstacles to the effectiveness of public spending at the local level. Tirtosuharto (2022) demonstrated that fiscal inefficiency significantly undermines poverty reduction outcomes in Indonesia, with institutional quality and geographical disparities playing a moderating role. However, the study focused primarily on provincial-level fiscal aggregates without examining the specific mechanisms through which spending inefficiencies emerge at the subnational level. Vidyattama (2022) attributed budget delays to weak local government capacity and political bargaining dynamics, but their analysis centered on procedural delays rather than on how coordination failures among agencies translate into suboptimal expenditure outcomes.

Miharja (2021) highlighted persistent interagency coordination deficits in metropolitan planning following two decades of decentralization while Wijaya (2016) documented the administrative burdens associated with the transition to accrual accounting, both of which point to systemic capacity constraints without empirically linking these constraints to spending performance. Farhan (2025) further underscored governance deficits in the context of decentralized foreign investment management, yet their governance analysis remained at the policy-framework level rather than operationalizing governance quality as a determinant of expenditure effectiveness. Collectively, these studies offer fragmented and sector-specific insights but have not systematically examined how the interaction among planning quality, coordination capacity, bureaucratic capability, and governance transparency jointly shapes local public spending effectiveness. This gap justifies the present study's integrative approach, which seeks to empirically assess these factors in combination rather than in isolation.

These challenges are empirically evident in West Tanjung Jabung Regency, Indonesia. During the period 2020–2022, the region experienced budget surpluses; however, from 2023 to 2024, its fiscal position shifted to deficits, reaching approximately IDR 237.9 billion in 2023 (Table 1). This shift indicates a tightening of fiscal space and highlights the increasing need for more effective management of the local government budget, particularly for poverty alleviation programs. At the same time, although realized local revenue and expenditure have increased over the past five years, the poverty rate declined only modestly, from approximately 10.75% in 2021 to 9.54% in 2024. Moreover, in 2024, West Tanjung Jabung Regency ranked second highest in poverty incidence within Jambi Province, well above the provincial average. This pattern suggests that increases in public spending have not been fully aligned with poverty reduction outcomes, indicating that the core issue lies in the quality of public expenditure management and implementation.

Table 1. Fiscal Dynamics and Poverty in West Tanjung Jabung Regency, 2020–2024

Year	Local Revenue (Million IDR)	Total Expenditure (Million IDR)	Surplus/Deficit (Million IDR)	Poverty Rate (%)
2020	1,421,415	1,390,379	31.036	10.29
2021	1,540,399	1,443,087	97.313	10.75
2022	1,665,017	1,580,801	84.216	10.00

2023	1,489,442	1,727,370	-237.928	9.79
2024	2,009,495	2,068,294	-58.799	9.54

Source: BPKAD West Tanjung Jabung Regency, 2024; BPS West Tanjung Jabung Regency, 2024

The urgency of this research is underscored by the real fiscal and social risks associated with governance inefficiency. If e-budgeting systems are not effectively implemented, local governments risk continued misalignment between budget planning and implementation, further limiting the poverty-reducing impact of public spending. For poor and vulnerable communities, this translates into reduced access to essential services such as health care, education, housing, and social protection. In the context of West Tanjung Jabung Regency, where poverty remains above the provincial average despite increasing public expenditure, the need to understand and strengthen institutional mechanisms for effective budget governance is both academically significant and urgently relevant to local financial governance reform.

In response to these conditions, the local government has implemented an e-budgeting system as part of public financial governance reform. The system is designed to enhance transparency, accountability, budget traceability, and coordination across local government agencies. However, the persistence of limited social outcomes suggests that the effectiveness of e-budgeting as an institutional mechanism for strengthening policy implementation requires further empirical examination.

Based on this background, this study analyzes the relationship between the quality of local government budget management, the implementation of e-budgeting, and the effectiveness of pro-poor public spending at the local government level. West Tanjung Jabung Regency was selected as the research context because it exhibits a combination of increasing fiscal pressure, relatively slow poverty reduction, and the adoption of e-budgeting as a budget governance reform strategy.

The novelty of this study lies in three interrelated dimensions. First, theoretically, this study advances beyond conventional fiscal-input frameworks by reconceptualizing e-budgeting as an institutional mediation mechanism, rather than merely an administrative tool, that links the quality of local budget management to the effectiveness of pro-poor public spending. Second, conceptually, the study integrates budget governance quality, digital governance, and spending effectiveness into a single analytical model, an approach that has not been systematically adopted in prior studies at the local government level in Indonesia. Third, empirically, this study examines these mechanisms at the level of implementing organizations within a single regency, providing micro-level evidence that complements existing macro-level or provincial analyses of fiscal decentralization and poverty reduction.

This study offers a conceptual contribution by positioning e-budgeting as an institutional mechanism that mediates the relationship between the quality of local government budget management and the effectiveness of pro-poor public spending. Unlike previous studies that emphasize direct links between spending and welfare outcomes, this research highlights policy implementation processes within local government agencies as a key determinant of pro-poor spending success. By doing so, the study contributes to the literature on sustainable public finance and governance by demonstrating how digital budgeting systems can support the long-term effectiveness of poverty-oriented public spending. It also extends the perspective of public financial management beyond budget allocation toward an institutional understanding of budget execution through governance mechanisms and digitalization.

Theoretical Framework

Public Financial Management and the Effectiveness of Pro-Poor Public Spending

This study is grounded in the perspective of public financial management (PFM), which conceptualizes the public budget not merely as a fiscal instrument, but as an institutional mechanism that shapes the implementation of public policy. Within the PFM framework, budget management encompasses the planning, allocation, execution, control, and oversight of public resources to ensure that established policies are effectively translated into governmental actions (Rafiqi et al., 2021). Accordingly, the budget is understood as an institutional mechanism for policy implementation, whose performance is largely determined by the quality of the institutions

and processes that govern it.

A growing body of literature on PFM and governance demonstrates that the size of fiscal capacity or budget allocations does not automatically guarantee policy effectiveness. Numerous studies find that increases in public spending have significant impacts on poverty reduction and welfare improvement only in contexts characterized by high-quality governance; by contrast, under conditions of weak governance, such effects are limited or may even be counterproductive (Dankumo et al., 2023; Komarudin & Oak, 2020). Existing evidence further indicates that, in the absence of credible, transparent, and accountable budgetary institutions, increases in social spending often fail to reach target groups due to leakage, inefficiency, or political distortion (Ben Mimoun & Raies, 2022; Jindra & Vaz, 2019; Kwon & Kim, 2014). These findings reinforce the argument that the quality of budget management, rather than its magnitude alone, is the critical determinant of how public spending is translated into policy performance.

Within the PFM approach, concepts such as budget credibility, budget discipline, and the quality of budget execution are central to explaining why many governments fail to transform budgets into tangible policy outcomes. Budget credibility refers to the degree of alignment between planned budgets and actual expenditures. In contrast, budget execution quality reflects the bureaucracy's capacity to implement programs in a timely, targeted, and goal-consistent manner. Without sufficient credibility and execution capacity, budgets risk becoming mere administrative documents with limited effectiveness in implementing pro-poor policies.

At the local government level, policy implementation challenges become increasingly complex because budget execution involves multiple government agencies with diverse functions and interests. Institutional fragmentation, weak coordination, and limited technical capacity often lead to misalignment among planning, budgeting, and program implementation processes. In the absence of adequate institutional mechanisms, local government budget management is prone to inefficiency, overlapping activities, and weak oversight, ultimately undermining the effectiveness of pro-poor public spending (Nurias et al., 2023; Putra, 2017). Several studies show that misalignment between planning and budgeting processes at the local level frequently weakens the quality of basic public services, including health, education, and social protection (Dankumo et al., 2023; Mumuni & Mom Njong, 2023).

From a sustainability perspective, effective pro-poor public spending is not assessed solely by short-term outputs, but by the ability of budget institutions to consistently deliver social benefits over time. These findings underscore the view that, within the PFM framework, the effectiveness of pro-poor public spending is strongly influenced by the quality of local government budget management and by local governments' institutional capacity to coordinate, manage, and accountably implement budget processes. Budgets, therefore, constitute a necessary structural condition for pro-poor policies. However, they are not sufficient without institutional support that ensures budget plans are sustainably translated into programs and services that reach poor and vulnerable groups.

Based on these arguments, this study formulates the first hypothesis as follows:

H1: The quality of local government budget management has a positive effect on the effectiveness of pro-poor public spending.

Good Governance, Digital Governance, and the Implementation of E-Budgeting

In public administration theory, good governance is widely regarded as a normative and institutional prerequisite for the effective management of public resources. Principles such as transparency, accountability, effectiveness, responsiveness, and public oversight are crucial to ensuring that public budgets are allocated and used in accordance with policy objectives (Kaufmann et al., 2019). In the absence of good governance, public spending is vulnerable to leakage, misuse, political distortion, or allocation to less productive activities, thereby limiting its impact on societal welfare (Komarudin & Oak, 2020). A growing body of empirical research demonstrates that governance quality—reflected in dimensions such as government effectiveness, control of corruption, and the rule of law—moderates the relationship between public spending and social welfare outcomes, including poverty reduction and inequality (Balaji, 2025; Kaur et al., 2025; Setyarto et al., 2025).

Advances in information technology have given rise to digital governance as an approach

to strengthening the practical application of good governance principles. Digital governance refers to the use of information and communication technologies to enhance transparency, strengthen accountability, accelerate administrative processes, and expand public participation in decision-making (Balaji, 2025; Setyarto et al., 2025). In the domain of public financial management, one of the most prominent instruments of digital governance is e-budgeting, which refers to the use of integrated information systems to support digitized processes of budget planning, formulation, execution, and monitoring (Rafiqi et al., 2021).

From a governance perspective, the implementation of e-budgeting functions as an institutional mechanism that reinforces transparency and accountability in local budget management. E-budgeting systems enable the traceability of budget allocations and realizations, facilitate auditing and internal oversight, and improve information accessibility for stakeholders. As such, e-budgeting helps reduce information asymmetry and opportunities for deviation within the budgeting process (Prayoga & Yuhertiana, 2021). Empirical evidence from various countries indicates that digital budgeting systems and technology-based fiscal oversight significantly enhance fiscal transparency and public accountability, particularly in regions previously characterized by weak institutional capacity (Jin & Wang, 2025).

Beyond transparency and accountability, e-budgeting also enhances coordination and efficiency in budget management. The integration of budget information systems facilitates synchronization among planning, budgeting, and execution processes, thereby reducing institutional fragmentation and inter-unit inconsistencies. Numerous empirical studies show that the adoption of e-budgeting and digital financial systems is positively associated with improved resource allocation efficiency, higher-quality decision-making, and more effective internal controls at the local government level (Arianto et al., 2025; Dwibin Kannapadang et al., 2025). Evidence from developing countries further suggests that the digitalization of public financial systems can reduce administrative costs, accelerate procurement and payment processes, and enhance public trust in budget management (Bejarano-Murillo, 2024; Tariq, 2025).

In this sense, digital governance supports sustainability not by increasing expenditure levels, but by strengthening the institutional conditions required for durable policy implementation. In the context of pro-poor public spending, e-budgeting is particularly relevant because such programs typically involve multiple organizational actors and require cross-sectoral coordination. Food security, health, education, housing, and social protection programs are often managed by different local government agencies, and without adequate integration mechanisms, policy implementation risks fragmentation and ineffectiveness. By promoting consistency across planning, budgeting, and implementation, e-budgeting can enhance the effectiveness of public spending regardless of the size of the allocated budget. Several studies also indicate that the use of digital technologies in participatory budgeting and social program monitoring increases public engagement, improves targeting accuracy, and enhances service quality for vulnerable groups (Raghuvanshi & Dwivedi, 2025).

Nevertheless, the effectiveness of e-budgeting is highly contingent on organizational capacity, system maturity, and the quality of governance arrangements. Limitations in digital infrastructure, technological skills among public officials, organizational adaptability, and data governance can constrain the institutional performance of digital governance systems (Bejarano-Murillo, 2024; Hien et al., 2024). Consequently, strengthening e-budgeting must be accompanied by investments in technological infrastructure, human resource capacity-building, and organizational change management to fully realize the sustainability benefits of digital governance.

Based on these considerations, the second hypothesis of this study is formulated as follows:

H2: The implementation of e-budgeting has a positive effect on the effectiveness of pro-poor public spending.

E-Budgeting as a Mediating Mechanism in Policy Implementation

Within the frameworks of public financial management and digital governance, the relationship between budget management and policy performance is rarely direct. The impact of budgets on policy outcomes depends critically on the presence of institutional mechanisms that

bridge the gap between planning processes and implementation practices at the organizational level. In this context, e-budgeting can be conceptualized as a mediating mechanism linking the quality of local government budget management to the effectiveness of pro-poor public spending (Miranda Mustika et al., 2025). While high-quality budgeting constitutes a necessary condition for policy success, outcomes are ultimately shaped by institutional mechanisms governing execution, oversight, and coordination.

High-quality local government budget management provides the structural prerequisites for policy implementation through sound planning and appropriate resource allocation. However, without the support of digital governance systems, this potential may not be fully realized in practice. Numerous studies show that gaps between budget plans and actual outcomes often arise due to weak traceability, inconsistent budget documentation, and poor coordination among implementing units. E-budgeting helps reduce these gaps by enhancing transparency in budget flows, enabling the traceability of budget changes, and synchronizing planning, budgeting, and execution processes (Dian Fathirah et al., 2024). Digital systems ensure that each stage of the budget cycle is systematically documented, thereby facilitating monitoring, auditing, and continuous policy adjustment.

From an institutional perspective, e-budgeting strengthens local government capacity through three primary mechanisms. First, traceability allows budget allocations and realizations to be tracked from planning to execution, reinforcing accountability and preventing deviations (Yashina et al., 2024). Second, coordination is enhanced through integrated information systems that connect multiple local government agencies and stakeholders, reducing institutional fragmentation and improving implementation consistency (Zhyber et al., 2024). Third, institutional capacity is strengthened as digital systems support procedural standardization, data integration, and stronger internal controls, ultimately improving bureaucratic capacity to implement programs effectively (Bisogno et al., 2022).

In this study, the effectiveness of pro-poor public spending is conceptualized as the performance of policy implementation processes carried out by local government agencies, as reflected in the ability of local budgets to sustainably support the provision of basic needs for poor communities in a coordinated, transparent, and policy-consistent manner. This approach distinguishes implementation effectiveness from direct economic outcomes, such as reductions in poverty rates, by focusing on institutional mechanisms and internal government processes. By positioning e-budgeting as a mediating variable, the study emphasizes that the quality of digital governance is a critical factor in strengthening the link between budget management and the performance of public policy implementation.

Empirical evidence from developing countries and decentralized governance systems suggests that budget digitalization does not directly improve welfare outcomes, but instead operates through improvements in institutional processes such as transparency, coordination, and organizational capacity (Bisogno et al., 2022; Yashina et al., 2024; Zhyber et al., 2024). Accordingly, e-budgeting should be understood not as a direct determinant of policy outcomes, but as an enabling mechanism that allows the quality of budget management to be more effectively translated into sustained and effective program implementation, including programs oriented toward poor and vulnerable groups.

Based on this theoretical framework, the third hypothesis is proposed as follows:

H3: The implementation of e-budgeting mediates the relationship between the quality of local government budget management and the effectiveness of pro-poor public spending.

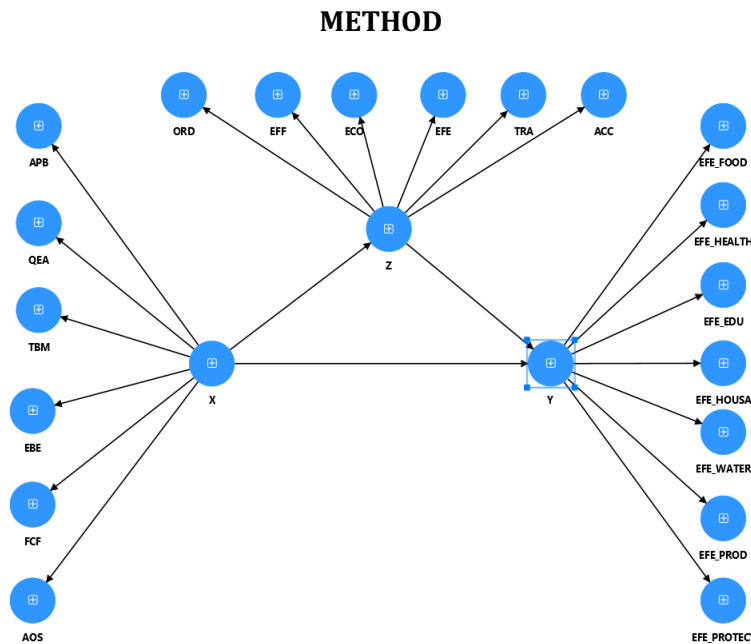


Figure 1. Conceptual Research Model. Descriptions of the variable codes used in the model are provided in Appendix Table A1.

Unit of Analysis

The unit of analysis in this study comprised local government agencies operating within the Government of West Tanjung Jabung Regency that were directly involved in the planning, budgeting, implementation, and evaluation of poverty-oriented public programs. These agencies were selected as the unit of analysis because they functioned as the primary institutional actors responsible for translating local budget policies into the implementation of operational programs and public service activities.

Population and Sampling Technique

The study population comprised local government agencies in West Tanjung Jabung Regency involved in local government budget management and the implementation of poverty-alleviation-oriented programs. A purposive sampling technique was employed to ensure that the selected agencies were directly relevant to the study's objectives and were actively engaged in budget planning, execution, and digital budgeting.

Local government agencies were selected based on the following criteria: 1) Agencies that were directly involved in local government budget planning and budgeting processes. 2) Agencies responsible for implementing programs or activities oriented toward poor and vulnerable population groups, namely pro-poor programs. 3) Agencies that were institutionally connected to the implementation and operation of the e-budgeting system.

Based on these criteria, 25 local government agencies were selected as the research sample. From each agency, three key officials were surveyed: the agency head, the administrative secretary, and the head of the planning unit. These respondents were selected because of their strategic roles in budget formulation, coordination, and implementation.

For several agencies with central budget governance functions, the number of respondents was increased to obtain a more comprehensive understanding of their institutional roles. Specifically, additional respondents were drawn from agencies responsible for regional development planning, financial and asset management, and internal audit and oversight functions. These additional respondents included division heads, planning unit heads, assistant inspectors, and auditors, reflecting their direct involvement in budget coordination, control, and accountability processes. In total, 100 respondents participated in the survey.

Data Collection Techniques and Research Instruments

Research data were collected using a structured questionnaire. The research instrument was designed to measure three main latent constructs: 1) Quality of local government budget management, reflecting the quality of the planning, allocation, execution, and oversight processes of the local government budget. 2) Implementation of e-budgeting, representing the extent to which digital budgeting systems were used to support transparency, accountability, efficiency, and inter-agency coordination. 3) Effectiveness of pro-poor public spending, capturing the extent to which public spending aimed at meeting the basic needs of poor communities was implemented in a targeted, coordinated, and policy-consistent manner, as perceived by local government agencies.

All indicators were measured using a five-point Likert scale and were developed based on the public financial management literature, principles of good governance, and digital budget governance frameworks, with appropriate adjustments to the local government institutional context.

Research Ethics

This study was conducted in accordance with established principles of research ethics. Prior to data collection, respondents were informed of the research objectives and of their voluntary participation. Informed consent was obtained from all participants before survey distribution. Respondents' identities and institutional affiliations were kept strictly confidential and were not disclosed in any part of this article. The study received institutional support and cooperation from the local government of West Tanjung Jabung Regency. No identifying information was collected beyond respondents' roles. The research posed no foreseeable risk of harm to participants.

Data Analysis Techniques

Data analysis was conducted using Partial Least Squares–Structural Equation Modeling (PLS-SEM). The analysis followed two main stages: evaluation of the measurement model, or outer model, and evaluation of the structural model, or inner model.

Given the multidimensional nature of the key constructs, this study employed a hierarchical component model, namely a second-order construct, estimated using the repeated indicators approach. In this approach, all indicators of the first-order constructs, or dimensions, were assigned to their respective higher-order constructs and estimated simultaneously within a single PLS-SEM model. This specification allowed the higher-order constructs to capture the shared variance of their underlying dimensions while maintaining parsimony in the structural model.

The measurement model evaluation assessed the validity and reliability of the latent constructs. Convergent validity was examined using outer loading values and Average Variance Extracted (AVE), while construct reliability was assessed using Cronbach's alpha, Composite Reliability, and rho_A. Discriminant validity was also evaluated to ensure adequate empirical distinction among the constructs in the model.

The structural model evaluation was conducted to test the research hypotheses. This analysis involved examining path coefficients, assessing their statistical significance using t-statistics and p-values obtained through bootstrapping, and evaluating the coefficient of determination (R^2) to assess the model's explanatory power.

The mediating role of e-budgeting was analyzed by testing both the direct and indirect effects between local government budget management quality and the effectiveness of pro-poor public spending, following established procedures for mediation analysis in PLS-SEM.

Regarding sample adequacy, a sample size of 100 respondents satisfied the minimum requirements for PLS-SEM, which recommend at least ten times the maximum number of arrows pointing at any latent variable in the model (Hair et al., 2019). In this study, the maximum number was six paths, making a minimum sample of 60 sufficient; therefore, 100 respondents provided an adequate margin. The bootstrapping procedure was conducted using 5,000 subsamples with bias-corrected and accelerated (BCa) confidence intervals to assess the statistical significance of path coefficients and indirect effects. To address common method bias, Harman's single-factor

test was performed. The results showed that no single factor accounted for more than 50% of the variance in the data, providing initial evidence that common method bias was not a serious concern in this study.

Operational Definition of Variables

The operational definitions of variables were formulated to translate latent constructs into empirically measurable indicators using a perception-based questionnaire administered to respondents. Detailed conceptual definitions, indicators, and measurement items are presented in the appendix.

RESULTS AND DISCUSSION

Results

This study employs Structural Equation Modeling (SEM) to analyze the impact of the Regional Budget (APBD) on poverty levels in Tanjung Jabung Barat Regency, both directly and through the mediating role of E-Budgeting optimization. This analysis aims to assess the extent to which the APBD, as the primary instrument for regional development financing, can contribute to reducing poverty, as well as to test whether the optimization of E-Budgeting can enhance transparency, accountability, and the effectiveness of budget management, thereby strengthening the APBD's impact on poverty reduction.

Results of the Measurement Model Testing (Outer Model)

1. Convergent Validity

At this stage, convergent validity testing was conducted to assess the alignment between the indicators and the constructs being measured. The evaluation was based on outer loading values, where an indicator is considered to have good validity if the outer loading value is greater than 0.70. However, values between 0.50 and 0.60 are still acceptable as they are deemed sufficient to represent the measured construct. The final convergent analysis results were then used to determine the suitability of the indicators in the research model.

Table 2. Outer loading values

Latent Variable	Indicator	Loading Factor	Model Evaluation
Regional Revenue and Expenditure Budget (APBD)	X1.1	0.711	Valid
	X1.2	0.733	Valid
	X1.3	0.732	Valid
	X1.4	0.723	Valid
	X1.5	0.724	Valid
	X1.6	0.798	Valid
	X1.7	0.790	Valid
	X1.8	0.803	Valid
	X1.9	0.811	Valid
	X1.10	0.721	Valid
	X1.11	0.706	Valid
	X1.12	0.739	Valid
E-Budgeting	Z1.1	0.722	Valid
	Z1.2	0.721	Valid
	Z1.3	0.737	Valid
	Z1.4	0.704	Valid
	Z1.5	0.755	Valid
	Z1.6	0.769	Valid
	Z1.7	0.773	Valid
	Z1.8	0.715	Valid
	Z1.9	0.735	Valid
	Z1.10	0.722	Valid

	Z1.11	0.711	Valid
	Z1.12	0.754	Valid
	Z1.13	0.756	Valid
	Z1.14	0.728	Valid
	Z1.15	0.719	Valid
	Z1.16	0.777	Valid
Poverty Reduction	Y1.1	0.754	Valid
	Y1.2	0.776	Valid
	Y1.3	0.727	Valid
	Y1.5	0.788	Valid
	Y1.6	0.769	Valid
	Y1.7	0.827	Valid
	Y1.8	0.806	Valid
	Y1.9	0.735	Valid
	Y1.10	0.835	Valid
	Y1.11	0.795	Valid
	Y1.12	0.798	Valid
	Y1.13	0.843	Valid
	Y1.14	0.853	Valid

The results of the convergent validity test indicate that all indicators in the study met the established criteria, with factor loadings above 0.70 or within the acceptable range of 0.60–0.70. The factor loadings for the APBD variable ranged from 0.706 to 0.811, for E-Budgeting from 0.704 to 0.777, and for Poverty Reduction from 0.727 to 0.853, indicating that all indicators effectively represent the latent constructs.

Furthermore, convergent validity is also supported by Average Variance Extracted (AVE) values exceeding 0.50, indicating that each construct explains more than 50% of its indicator’s variance. Thus, all research constructs are deemed to possess adequate convergent validity and are suitable for proceeding to the next stage of analysis.

Table 3. Average Variance Extracted (AVE) Values for Each Construct

Construct	Average Variance Extracted (AVE)
Regional Revenue and Expenditure Budget (APBD)	0.563
E-Budgeting	0.544
Poverty Reduction	0.623

Source: Primary data analyzed using SmartPLS, 2025.

The AVE results indicate that all research constructs meet the criteria for convergent validity, as they have AVE values above 0.50. The APBD construct obtained an AVE value of 0.563, E-Budgeting of 0.544, and Poverty Reduction of 0.623, indicating that each construct is able to explain more than 50% of the variance in its respective indicators. Therefore, all constructs are deemed valid and suitable for use in the research analysis.

2. Discriminant Validity (Discriminant Validity)

Discriminant validity testing was conducted to ensure that each indicator is better able to measure the intended construct compared to other constructs. This testing can be performed through cross-loading analysis or the Fornell-Larcker criteria. An indicator is deemed valid if it has a higher loading value on its own construct compared to other constructs, or if it has a loading value above 0.50. Meanwhile, under the Fornell-Larcker criteria, discriminant validity is met if the square root of the AVE for each construct is greater than its correlation with other constructs. The results of the discriminant validity test based on cross-loadings are presented in the following table.

Table 4. Cross-Loading Values

Indicator	APBD	E-Budgeting	Poverty Reduction
X1.1	0,711	0,410	0,219

X1.2	0,733	0,429	0,123
X1.3	0,732	0,439	0,236
X1.4	0,723	0,416	0,263
X1.5	0,724	0,569	0,276
X1.6	0,798	0,478	0,332
X1.7	0,790	0,591	0,384
X1.8	0,803	0,554	0,342
X1.9	0,811	0,536	0,287
X1.10	0,721	0,466	0,408
X1.11	0,706	0,539	0,343
X1.12	0,739	0,495	0,399
Z1.1	0,569	0,722	0,409
Z1.2	0,549	0,721	0,415
Z1.3	0,588	0,737	0,465
Z1.4	0,569	0,704	0,506
Z1.5	0,627	0,755	0,400
Z1.6	0,490	0,769	0,475
Z1.7	0,542	0,773	0,479
Z1.8	0,438	0,715	0,483
Z1.9	0,375	0,735	0,441
Z1.10	0,391	0,722	0,474
Z1.11	0,408	0,711	0,441
Z1.12	0,406	0,754	0,566
Z1.13	0,427	0,756	0,541
Z1.14	0,418	0,728	0,527
Z1.15	0,423	0,719	0,511
Z1.16	0,570	0,777	0,525
Y1.1	0,538	0,688	0,754
Y1.2	0,483	0,668	0,776
Y1.3	0,348	0,626	0,727
Y1.5	0,356	0,572	0,788
Y1.6	0,279	0,491	0,769
Y1.7	0,303	0,508	0,827
Y1.8	0,298	0,532	0,806
Y1.9	0,247	0,500	0,735
Y1.10	0,382	0,600	0,835
Y1.11	0,427	0,513	0,795
Y1.12	0,432	0,478	0,798
Y1.13	0,277	0,494	0,843
Y1.14	0,321	0,526	0,853
Y1.15	0,181	0,396	0,793
Y1.16	0,236	0,346	0,755
Y1.17	0,204	0,425	0,786
Y1.18	0,191	0,342	0,801
Y1.19	0,227	0,369	0,819
Y1.20	0,206	0,358	0,764
Y1.21	0,241	0,382	0,748

Source: Primary data analyzed using SmartPLS, 2025.

The cross-loading test results show that each indicator has the highest loading value on the construct it measures compared to other constructs, indicating that all indicators are able to accurately represent the latent variable and meet the criteria for discriminant validity. To reinforce these results, a test was conducted using the Fornell-Larcker criterion, whereby discriminant validity is deemed met if the root AVE value of each construct is greater than its correlation value with other constructs. The results of the Fornell-Larcker test are presented in the following table.

Table 5. Fornell-Larcker Criterion Values

Variable	APBD	E-Budgeting	Poverty Reduction
APBD (Regional Revenue and	0.750		

Expenditure Budget)			
E-Budgeting	0.667	0.738	
Poverty Reduction	0.413	0.649	0.789

Source: Primary data analyzed using SmartPLS, 2025.

Test results using the Fornell-Larcker criteria indicate that all constructs meet discriminant validity, as each construct is better able to explain its indicators than other constructs in the model. These findings confirm the clear distinctiveness of each variable and reveal no issues of measurement overlap between constructs. Therefore, the research model is deemed to meet the criteria for discriminant validity and is suitable for proceeding to the structural analysis stage.

3. Composite Reliability and Cronbach’s Alpha

Reliability testing aims to assess the level of consistency and internal reliability of a construct in the research. The test was conducted by examining Cronbach’s Alpha as the lower threshold for reliability and Composite Reliability as a reinforcement of the measurement results. A construct is considered reliable if it has a Cronbach’s Alpha value above 0.70, although in exploratory research, a value around 0.60 is still acceptable.

Table 6. Research Construct Reliability Values

Variabel Laten	Cronbach's Alpha	rho_A	Composite Reliability
APBD (Regional Revenue and Expenditure Budget)	0,929	0,933	0,939
E-Budgeting	0,944	0,945	0,950
Poverty Reduction	0,968	0,973	0,971

Source: Primary data analyzed using SmartPLS, 2025.

All constructs in this study namely the Regional Budget (APBD), E-Budgeting, and Poverty Reduction were found to be reliable, as the values for Cronbach’s Alpha, rho_A, and Composite Reliability were above 0.70. Thus, the research instruments used are valid and reliable for proceeding to the structural equation modeling phase.

4. Model Fit Test (Model Fit)

The purpose of this test is to determine whether a model fits the data used or not. The criteria for determining whether a model can be considered a good fit are based on the SRMR value; if the value is less than 0.10, the model is considered a good fit. The results of the model fit test are as follows:

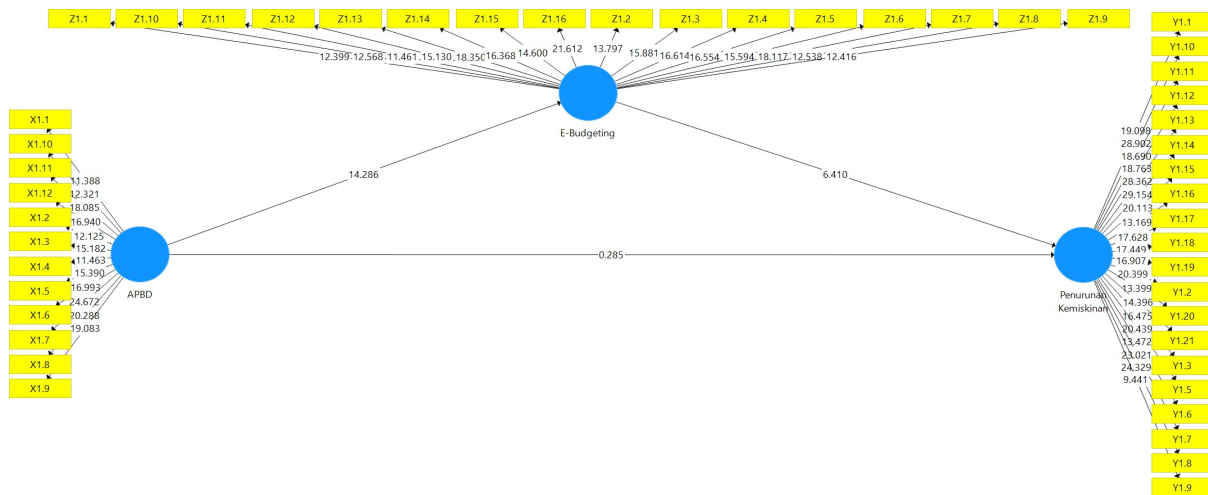
Table 7. Results of the Model Fit Test

Coefficient	Saturated Model	Estimated Model
SRMR	0,100	0,100

Source: Primary data analyzed using SmartPLS, 2025.

Based on the results of the model fit test, an SRMR value of 0.100 for both the Saturated Model and the Estimated Model indicates that the model remains within acceptable fit limits. Although this value has not yet reached the ideal category (<0.08), PLS-SEM criteria state that an SRMR value ≤0.10 still reflects an adequate level of model fit. Furthermore, the results of the convergent validity and construct reliability tests show that all indicators have met the required criteria and are capable of consistently representing the latent variables.

Results of the Structural Model Testing (Inner Model)



Source: Primary data analyzed using SmartPLS, 2025
Figure 2. Structural Model Estimation Results (Path Coefficients)

At this stage, the assessment is conducted using the R-Square value, which describes the proportion of variation in the dependent variable that can be explained by the independent variables. The R-Square value also provides an indication of the strength of the relationship between variables, with a value of 0.67 indicating a strong effect, 0.33 indicating a moderate effect, and 0.19 reflecting a weak effect. The results of the R-Square calculations in this study are shown as follows:

Table 8. R-Square and Adjusted R-Square Values for Research Variables

Variables	R-Square	R-Square Adjusted
E-Budgeting	0,445	0,439
Poverty Reduction	0,423	0,411

Source: Primary data analyzed using SmartPLS, 2025.

The R-Square test results show that the E-Budgeting variable has an R-Square value of 0.445 (Adjusted R-Square 0.439), meaning that 44.5% of the variation in E-Budgeting can be explained by the Regional Budget (APBD), while the remaining 55.5% is influenced by other factors outside the model. Meanwhile, the Poverty Reduction variable obtained an R-Square value of 0.423 (Adjusted R-Square 0.411), indicating that 42.3% of the variation in poverty reduction can be explained by the APBD and E-Budgeting. Based on Chin’s (1998) classification, both R-Square values fall into the moderate category, suggesting that the model has a reasonably good explanatory power regarding the endogenous variables under study.

Hypothesis Testing

Hypothesis testing was conducted using the bootstrapping method in SmartPLS 3.0 to test the significance of relationships between variables in the model. Hypothesis decisions were based on t-statistic and p-value, where a relationship is considered significant if the t-statistic is greater than 1.98 or the p-value is less than 0.05 at a 5% significance level. Additionally, the direction of the effect is determined based on the original sample values, with positive coefficients indicating a positive relationship and negative coefficients indicating a negative relationship. The results of the hypothesis testing for direct effects are presented in the following table.

Table 9. Hypothesis Testing Results (Path Coefficient)

		Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Local Budget (APBD)	-> E-Budgeting	0,667	0,674	0,047	14,286	0,000
Local Budget (APBD)	-> Poverty Reduction	-0,036	-0,038	0,125	0,285	0,776

E-Budgeting Poverty Reduction	->	0,673	0,684	0,105	6,41	0,000
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Source: Primary data analyzed using SmartPLS, 2025.

1. The APBD does not have a significant effect on poverty reduction, as indicated by a path coefficient of -0.036, a t-statistic of 0.285, and a p-value of 0.776. Thus, Hypothesis 1 is rejected.
2. The APBD has a positive and significant effect on E-Budgeting with a coefficient of 0.667, a t-statistic of 14.286, and a p-value of 0.000. These results indicate that improved APBD management will enhance the implementation of E-Budgeting. Therefore, Hypothesis 2 is accepted.
3. E-Budgeting has a positive and significant effect on poverty reduction with a coefficient of 0.673, a t-statistic of 6.410, and a p-value of 0.000. This finding indicates that the effective implementation of E-Budgeting can support poverty reduction through increased transparency, accountability, and efficiency in budget management. Thus, Hypothesis 3 is accepted.

Next, to address the third hypothesis stating that the Regional Budget (APBD) influences public spending oriented toward poverty reduction through the implementation of E-Budgeting, a test of the indirect effect was conducted. The results of the indirect effect calculation are presented in the following table:

Table 10. Results of the Indirect Effect Test

	<i>Original Sample (O)</i>	<i>Sample Mean (M)</i>	<i>Standard Deviation (STDEV)</i>	<i>T Statistics (O/STDEV)</i>	<i>P Values</i>
Local Budget -> E-Budgeting -> Poverty Reduction	0,449	0,461	0,076	5,898	0,000

Source: Primary data analyzed using SmartPLS, 2025.

The analysis results indicate that the indirect effect of the Regional Budget (APBD) on public spending aimed at poverty reduction through E-Budgeting is positive and significant. This is evidenced by a path coefficient of 0.449, a t-statistic of 5.898 (>1.96), and a p-value of 0.000 (<0.05). This confirms that E-Budgeting acts as a mediating variable that strengthens the relationship between the APBD and poverty reduction. Therefore, it can be concluded that Hypothesis 3 is accepted.

Since the direct effect of the quality of APBD management on the effectiveness of public spending that is oriented toward poverty reduction is not significant, while the indirect effect through e-budgeting is significant, then e-budgeting acts as a full mediator (full mediation).

Discussion

Quality of local government budget management and the Effectiveness of Pro-Poor Public Spending

The non-significant direct effect of the quality of local government budget management on the effectiveness of pro-poor public spending indicates that improvements in planning, budgeting, execution, and oversight processes do not automatically guarantee high-quality policy implementation. This finding is consistent with a substantial body of public financial management and governance literature, which emphasizes that budgets constitute a necessary precondition, but not a sufficient determinant, of successful public policy outcomes. Enhancements in budgeting procedures often fail to translate directly into effective policy performance when they are not supported by adequate institutional mechanisms.

Evidence from the Italian central government, for example, shows that misalignment between strategic planning and budgeting processes has resulted in inconsistent policy implementation across ministries, despite notable improvements in the budgeting system itself (Bonomi Savignon et al., 2019). This highlights the importance of integrating planning and budgeting at the institutional level to ensure coherent and consistent policy execution. Similarly,

studies on public financial management reforms across different countries suggest that improvements in budgetary efficiency and transparency do not necessarily lead to stronger policy outcomes when implementing institutions lack sufficient capacity or are not supported by strong political commitment (Rashied et al., 2024).

In developing-country contexts, weak monitoring mechanisms and limited accountability further constrain effective policy implementation. Empirical evidence from Kenya and several Sub-Saharan African countries demonstrates that deficiencies in monitoring, accountability, and the rule of law result in inefficient public service delivery, even where budgeting procedures are continuously refined (Lledó & Poplawski-Ribeiro, 2013; Musiega, Nyawira, et al., 2023; Musiega, Tsofa, et al., 2023). These findings underscore that budgets primarily provide a formal framework for policy implementation, while actual performance depends on organizational capacity, political dynamics, and overall governance quality.

At the local government level, budget management is frequently challenged by institutional fragmentation, limited coordination among government agencies, and weak internal oversight mechanisms. These conditions are consistent with findings from studies on participatory budgeting in South Korea and Kazakhstan, which suggest that, while innovative budgeting mechanisms may improve administrative efficiency, policy success remains highly dependent on leadership quality and broader governance reforms (Jung, 2022; Kadyrova, 2013). As a result, public spending formally designated for poor and vulnerable groups is not always translated into well-targeted and effective programs at the implementation stage.

From a sustainability perspective, these findings imply that improving budget procedures alone is insufficient to ensure the long-term effectiveness and continuity of poverty alleviation policies. The quality of local government budget management should therefore be understood as a structural foundation that enables policy implementation but must be complemented by institutional mechanisms, such as organizational capacity, interagency coordination, leadership commitment, and effective accountability systems, to generate public spending that is genuinely pro-poor and sustainable over time.

The Role of E-Budgeting in Enhancing the Effectiveness of Pro-Poor Public Spending

The finding that the implementation of e-budgeting has a positive and statistically significant effect on the effectiveness of pro-poor public spending underscores the critical role of digital budget governance as an institutional mechanism in policy implementation. Digital transformation in public financial management enables more transparent, integrated, and data-driven budgeting processes, thereby strengthening accountability, improving coordination, and enhancing the effectiveness of social programs targeting poor and vulnerable groups.

E-budgeting facilitates planning, budgeting, and execution processes that are more transparent and systematically documented, thereby enhancing budget traceability and reducing information asymmetry. Studies on digitally enabled participatory budgeting indicate that information technology supports citizen involvement throughout the budget cycle—from proposal formulation to monitoring budget realization—thereby improving the effectiveness of public spending in achieving social and economic objectives (Ekaterinovskaya et al., 2023). Digital budgeting initiatives are also widely recognized as instruments for strengthening fiscal transparency and democratic accountability in public resource allocation (Justice et al., 2006).

Beyond transparency, e-budgeting improves coordination among organizational units by integrating budget information systems. Data-driven decision-support tools enhance evidence-based policymaking and facilitate sustained interaction among government agencies, program implementers, and citizens throughout the budget cycle (Zhyber et al., 2024). Experiences with digital financial management systems in Indonesia's Village Fund program further demonstrate that digitization can strengthen governance quality, financial efficiency, and public trust. However, challenges related to digital infrastructure and financial literacy persist (Ardiputra et al., 2025).

More broadly, insights from New Public Management and Digital-Era Governance suggest that digital governance enhances transparency, accountability, and citizen orientation while improving the effectiveness of public service delivery, particularly in fiscally constrained environments (Liu & Zhang, 2024). From a sustainability perspective, e-budgeting contributes not

by increasing expenditure levels but by reinforcing the institutional conditions required for resilient, inclusive, and long-term effective public spending systems.

E-Budgeting as a Mediating Mechanism between Local Government Budget Management and Pro-Poor Spending Effectiveness

The mediation analysis demonstrates that e-budgeting plays a pivotal role in bridging the relationship between the quality of local government budget management and the effectiveness of pro-poor public spending. This finding indicates that improvements in local budget management yield tangible gains in policy implementation quality only when supported by effective digital governance mechanisms. Empirical evidence shows that digital capacity and budget managers' competencies in applying e-budgeting systems enhance decision-making quality, transparency, and public trust, thereby strengthening the link between budget quality and policy performance (Erвина et al., 2025; Girsang et al., 2025).

Research on the digitization of public administration further suggests that information technology and innovations such as blockchain improve administrative efficiency, reduce corruption, and strengthen accountability by enhancing institutional processes rather than directly influencing welfare outcomes (Zhuk, 2022). In this sense, digital public financial systems serve as enabling mechanisms that connect budget design with implementation practices by improving transparency, traceability, and coordination.

Conceptually, e-budgeting reduces the gap between budget planning and program execution by strengthening consistency and information flows throughout the implementation process. Integrated, data-driven budgeting systems that provide transparent and accessible information to all budget actors support continuous monitoring, feedback, and institutional learning (Zhyber et al., 2024). Moreover, improved financial reporting accuracy supported by digital systems contributes to stronger governance and organizational sustainability, which are essential prerequisites for effective and durable policy implementation (Neiroukh & Çağlar, 2025).

Accordingly, e-budgeting should be understood not as a direct determinant of welfare outcomes but as an institutional mechanism that mediates the relationship between the quality of local government budget management and the effectiveness of pro-poor public spending. By enhancing transparency, efficiency, accountability, and institutional capacity within local government agencies, e-budgeting facilitates the sustainable translation of budget management quality into public spending that is more targeted, coordinated, and responsive to the needs of poor and vulnerable groups.

In the specific context of West Tanjung Jabung Regency, these findings reflect the institutional reality of a local government navigating fiscal pressure and poverty challenges simultaneously. The transition from budget surpluses to deficits between 2022 and 2023, combined with persistently high poverty rates relative to the provincial average, underscores the critical role of governance quality in maximizing the social impact of constrained public resources. Local conditions—including limited digital infrastructure, varied capacity among agency personnel, and the coordination demands of multiagency pro-poor programs—suggest that strengthening e-budgeting is not merely a technical matter but also requires sustained organizational change management and leadership commitment. These contextual factors help explain why budget management quality alone is insufficient without the mediating role of e-budgeting as an institutional enabler.

CONCLUSION

The findings of this study indicate that the quality of local government budget management does not have a significant direct impact on the effectiveness of pro-poor public spending. This suggests that improvements in planning, budgeting, implementation, and oversight processes are necessary prerequisites but are insufficient to ensure the implementation of spending that favors the poor without adequate governance mechanisms. Conversely, the implementation of e-budgeting has been shown to have a positive and significant impact on the effectiveness of pro-poor spending, as it enhances transparency, accountability, budget traceability, and interagency coordination, thereby enabling spending targeted at poor

communities to be carried out more consistently with planning frameworks and policy objectives. Furthermore, e-budgeting has been shown to function as a full mediator in the relationship between the quality of budget management and the effectiveness of pro-poor spending, meaning that improvements in budget management can lead to meaningful improvements in the quality of policy implementation only when supported by an effective digital governance system.

From a theoretical perspective, this study confirms that the effectiveness of pro-poor spending is determined not solely by fiscal capacity but also by the quality of institutional implementation mechanisms. It also contributes to the public financial management literature by demonstrating how digital governance bridges the gap between budget management quality and policy implementation effectiveness in the context of decentralization. From a policy perspective, these findings underscore that increasing budget allocations alone is insufficient; local governments must ensure that budget management and execution are supported by a transparent, accountable, integrated, and digitally based governance system. Therefore, strengthening e-budgeting should be made a strategic priority, accompanied by investments in human resource capacity building, the integration of planning and evaluation systems, and the strengthening of internal oversight mechanisms. This study has limitations because the effectiveness of pro-poor spending is measured based on the perceptions of local government agencies; therefore, future research is advised to integrate institutional approaches with both macro- and micro-level data to assess the contribution of budget governance and digitalization to community welfare more comprehensively.

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Conceptualization, S.F. and S.T.; methodology, A.H.; software, S.F.; validation, A.H. and Z.Z.; formal analysis, S.F.; investigation, Z.Z.; resources, S.T.; data curation, S.F.; writing—original draft preparation, S.F., and A.H.; writing—review and editing, S.T. and Z.Z.; visualization, A.H.; supervision, Z.Z.; project administration, S.F.; funding acquisition, S.F. All authors have read and agreed to the published version of the manuscript.

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