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The Mediating Roles of Infrastructure and Innovation in the Impact of Renewable Energy Development on Local Economy and Workforce Welfare in Eastern Indonesia

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Abstract: The development of abundant renewable energy resources in Eastern Indonesia presents a promising opportunity to enhance local economic conditions and workforce welfare. This study examines the relationship between infrastructure availability, innovation, and renewable energy development, with a focus on their impact on local economic performance and workforce welfare. Although previous studies have recognized that infrastructure improves regional economic performance, the direct impact of policies advocating renewable energy on employment remains unexamined. This study utilizes Structural Equation Modeling–Partial Least Squares (SEM-PLS) to analyze the survey responses of 170 community stakeholders involved in renewable energy initiatives from various perspectives. The findings demonstrated that the advancement of renewable energy did not substantially affect local economic conditions when evaluated as independent variables ($P = 0.423$). Upon the inclusion of infrastructure availability, the equation attains statistical significance ($P = 0.000$). The development of infrastructure has emerged as a crucial connection between renewable energy and increased employment, facilitated by enhanced market performance. The results suggest that environmentally sustainable energy policies should align with infrastructure development, offer incentives for innovation, and facilitate training to optimize their effectiveness. The study contributes to the literature by empirically demonstrating the dual mediating roles of infrastructure and innovation—dimensions that have received limited attention in previous empirical research.

Keywords: Employment creation; Green energy policy, Infrastructure; Local economy; Partial Least Squares; Renewable energy; Sustainable development

1 Introduction

Indonesia has a high renewable energy potential, estimated at 419 GW, sourced from hydro, geothermal, bioenergy, solar, wind, and macro-hydro power [1]. Consistent with these findings, Paundra and Nurdin [2] noted that the government has established renewable energy targets, aiming to increase its share in the national energy mix to 23% by 2025 and 31% by 2050.

Moreover, the progress of renewable energy technologies still encounters technical, social, and policy-related obstacles, such as insufficient local expertise and limited funding for small-scale initiatives [3]. The increasing global demand for clean energy highlights the urgency of adopting renewable sources as viable alternatives to fossil fuels. Increasingly, renewable energy development is recognized worldwide as a key strategy to address the energy crisis and mitigate climate change, prompting substantial investment in new technologies that aim to improve efficiency and sustainability. In the Indonesian context, Maulana [4] demonstrated that energy consumption and capacity expansion significantly contribute to economic growth and, in turn, support employment generation. Similarly, Haseeb et al. [5] found that investments in renewable energy have stimulated Gross Domestic Product (GDP) growth by creating additional employment opportunities.

However, the application of renewable energy in the Maluku and Papua regions remains limited. According to National Energy Council of the Republic of Indonesia [6], only about 10% of Indonesia's renewable energy potential has been utilized to date. This slow progress is attributed to several challenges, including inadequate infrastructure, restricted technological access, and insufficient policy support, all of which require urgent attention.

The eastern part of Indonesia, specifically the provinces of Maluku and Papua, has considerable potential for renewable energy development, although it remains underutilized. Based on data from the Ministry of Energy and Mineral Resources, the Republic of Indonesia [7], Maluku Province has a renewable energy potential of approximately 6,396 gigawatts (GW), including hydropower (430 MW), mini and micro hydro (190 MW), solar (2.02 GW), wind (3,188 GW), and geothermal power (568 MW). North Maluku has a potential of 4,134 GW. Papua, on the other hand, has a lot of renewable energy sources, such as solar, wind, hydro, and geothermal, that can produce more than 10 GW of power but are still not being used to their full potential [8]. Approximately 1.26 MW, or 0.019% of the total 6.5 GW potential, has been utilized in the Maluku region. Most of this energy comes from solar sources. The active involvement of government, society, and the private sector is crucial in creating an ecosystem that fosters the development of renewable energy, relevant infrastructure, and innovation.

Low energy usage reduced economic growth, limited employment opportunities for local communities, and widened socio-economic gaps. The eastern region faced several geographical challenges, such as complex topography and limited infrastructure, which hindered the energy transition. In Papua, those factors led to an electrification ratio of approximately 94%, slightly less than the national average of 99% [9]. Meanwhile, the electrification ratio in the Maluku region was below the national average [10]. The gap affected community productivity, access to basic services, and regional competitiveness, thereby widening the economic gap between eastern and western Indonesia. The energy transition through the use of renewable energy potential was perceived as a strategic solution to reduce the electrification gap, thereby promoting more inclusive economic development. The benefits also included job creation and an improvement in the quality of life through better access to energy.

The eastern region has a significant renewable energy potential, which has prompted the development of environmentally friendly infrastructure, improved socio-economic conditions, and increased employment opportunities [4]. In this context, the development of environmentally sustainable infrastructure has enhanced household welfare, strengthened energy security, and contributed to the reduction of greenhouse gas emissions [11, 12]. However, the development process encountered problems related to land conflicts, energy needs, agricultural activities, indigenous community rights, and incentives for investors [13, 14]. These factors triggered an imbalance in income distribution between the local and foreign workforces, particularly in large-scale projects, resulting in a less direct impact on the community. Additionally, government policies regulating renewable energy investment and infrastructural development played a crucial role in achieving the expected objectives.

Referring to several renewable energy development projects, Shofiyana et al. [15] reported that socioeconomic benefits were often unevenly distributed, specifically among local community groups who were unemployed. This raised questions about how the development could effectively drive a sustainable local economy. Therefore, the current study examined the relationship between renewable energy development, infrastructure, innovation, local economic conditions, and job creation to determine the most effective mechanisms for improving economic growth in Eastern Indonesia. The relationship was also expected to yield evidence-based policy recommendations that promote sustainable energy development, encourage local community participation, and provide sustainable employment opportunities. Furthermore, the findings were expected to motivate a more equitable distribution of economic benefits, leading to improved welfare for the people.

A critical and decolonial perspective must be employed to analyze the development of renewable energy in Eastern Indonesia, alongside considerations of technical and economic disparities. Historically, development policies in this region have demonstrated centralized, top-down approaches, often reinforcing dependence on external entities. A decolonial perspective emphasizes the importance of local agency, indigenous knowledge systems, and community ownership in advancing sustainable energy transitions [16]. Therefore, renewable energy initiatives encompass more than mere technological advancements; they also serve as mechanisms to alter power relations and promote inclusive development that considers the local context.

2 Literature Review

Renewable energy plays a crucial role in promoting economic growth and sustainability, particularly in regions with limited access to conventional energy sources. Several studies have shown that its utilization contributes to economic expansion. According to Gyimah et al. [17] technical efficiency plays a crucial role in mitigating the impact of renewable energy on the global economy. However, this study does not account for specific constraints faced by developing regions, such as Eastern Indonesia, where infrastructure and technological resources remain limited. Erdiwansyah et al. [18] highlights that inadequate infrastructure and complex geographical conditions continue to make life difficult for developing countries. The availability of renewable energy has played a crucial role in increasing access to electricity, thereby supporting economic growth. According to Lam et al. [19], Vietnam has successfully increased access to electricity in rural areas through community-based solar energy initiatives. This method not only increased electricity availability but also contributed to local job creation, resulting in the formulation of a relevant model for Eastern Indonesia that incorporates community participation in efforts to generate renewable energy.

The importance of electricity consumption for Indonesia's economic growth has been widely documented [4]. However, the study does not explain the mediating factors—such as innovation and improved infrastructure development—that have the potential to enhance the economic contribution of renewable energy. The utilization of solar, wind, and biomass energy sources has significantly reduced dependence on fossil fuels and helped mitigate the effects of climate change. In Vietnam, community involvement in renewable energy projects has increased electricity access, stimulated economic growth, and reduced environmental degradation. Similar approaches have also generated notable benefits in Indonesia.

Based on existing evidence, the expansion of renewable energy growth is closely linked to job creation, particularly within the green technology sector. Empirical studies have shown that investments in renewable energy enhance energy access and foster local economic growth. For instance, International Energy Agency (IEA) [20] reported that similar initiatives implemented in Indonesia resulted in the creation of approximately 10,000 jobs, thereby increasing community income levels. Haseeb et al. [5] also argue that renewable energy use in Asia helped provide jobs related to investing in clean energy technologies and the supporting sectors. In line with this result, Jones et al. [21] reported that similar investments have a significant impact on job creation in less developed countries. However, the study did not distinguish the effects of job creation across different geographic and socioeconomic contexts, such as variations in population distribution or dependence on imported technology—factors that are particularly relevant to Eastern Indonesia. According to Dewanthi et al. [8], technological advancements in renewable energy have diversified employment opportunities, extending beyond traditional sectors such as agriculture and fisheries. This diversification is especially important in Eastern Indonesia, where the majority of the population works in the primary sector. Furthermore, the expansion of renewable energy has facilitated the creation of more diverse and sustainable employment opportunities [4].

Infrastructure played a critical role in the efficiency and long-term sustainability of renewable energy deployment. According to Kurniawan et al. [22], the success of related projects depended on the infrastructure used for energy distribution. This phenomenon aligned with the situation in Eastern Indonesia, where limited access to electricity and transportation networks was perceived as a significant barrier to the widespread adoption of green energy. The availability of infrastructure, including a stable electricity grid and efficient transportation systems, played a critical role in the effective deployment of renewable energy projects. The factor also affected the development process and economic growth [3]. Infrastructural limitations hindered renewable energy projects from offering adequate benefits [18]. Moreover, without adequate infrastructure, renewable energy projects are prone to inefficiency, high operational expenses, and limited scalability, reducing their impact on regional development [1]. Adequate infrastructure, including energy distribution networks and accessibility, also played an essential role. Inadequate infrastructure ensured that the renewable energy potential was not optimally used [23].

Innovation is a crucial enabler in overcoming geographic and technological barriers to the growth of renewable energy. Liu et al. [24] helped solve production and distribution problems in remote areas. Community solar power systems and decentralized microgrids are among the most innovative solutions to ensure a reliable energy supply in areas that the traditional electricity grid does not reach. On small islands in Eastern Indonesia, which are often highly physically constrained, renewable energy solutions are seen as key to enhancing electricity access and supporting local development. Arifin et al. [25] identified that on-grid solar PV systems are significantly more cost-effective and reliable for rural and residential applications, making them particularly suitable for remote island contexts. Similarly, Alzgool et al. [26] demonstrated that the implementation of smart grids powered by solar and wind energy in sparsely populated areas can reduce transmission losses and enhance energy self-sufficiency. These models provide practical and scalable solutions to the geographic and infrastructural challenges faced in Eastern Indonesia.

Previous studies have reported that the implementation of new energy solutions, such as solar-based microgrid systems, in certain areas has increased energy availability and local economic activity [27]. Additionally, local economic conditions played a significant role in the success of related projects. Therefore, areas with stronger economies had better access to the relevant technology and resources required to support the development process [28].

Already, some research has been conducted that has highlighted the relationship between renewable energy and economic development; however, there are inconsistencies related to infrastructure and innovation in eastern Indonesia. Prior works by Gyimah et al. [17] and Haseeb et al. [5] focused on the macro-level and disregarded local economic contexts. Investments in renewable energy have also diminished the reliance of labor on traditional industries by stimulating diversification of employment, which resulted from technological development [11]. Such diversification enhances economic resilience in the face of market instability. Additionally, government interventions—particularly fiscal incentives and the Renewable Energy Support Program—have effectively attracted investment and expanded project implementation [7].

The United Nations Industrial Development Organization [29] reported that renewable energy meets the need for clean energy, significantly contributing to economic and social welfare. Therefore, stakeholders perceived appropriate infrastructural support and innovation, leading to increased technical efficiency, as crucial elements associated with success [5, 30]. According to Dearing and Cox [31], collaboration among multiple stakeholders is essential for the development of a sustainable innovation ecosystem. Furthermore, innovation in the renewable energy sector has created employment opportunities beyond the agricultural and fishing industries, thereby strengthening the economic resilience of local communities [11].

In this context, Vanegas Cantarero [32] emphasized that adequate infrastructure plays a crucial role in facilitating the distribution of renewable energy and promoting economic development. In remote regions, however, insufficient electricity and transportation networks continue to be significant obstacles to the large-scale adoption of green energy [33]. Based on Lopez et al. [34], investments in green energy have directly created employment opportunities for specialists and technicians, which have subsequently stimulated related sectors such as manufacturing, logistics, and vocational training. Thus, broader national economic strategies increasingly regard renewable energy development as a core component.

The successful implementation of renewable energy depended on economic and infrastructural considerations, as well as social support and the participation of local communities. Putnam [35] stated that strong community participation in related projects increased the adoption of new technologies, prompting the equitable distribution of benefits. In Eastern Indonesia, community-based methods effectively enhanced the use of renewable energy, including the transition to a green economy. Hypothetically, renewable energy growth offered maximum economic benefits with respect to the following crucial elements: infrastructure, innovation, and social participation.

In the context of transitioning to sustainable energy, increased investments have played a crucial role in enhancing energy security while also promoting innovation and greater resource efficiency [36]. Shifting toward a green economy has improved industrial competitiveness and stimulated economic growth, which in turn has led to the emergence of new job opportunities across multiple sectors. The proposed hypothesis centers on the interconnection between development, technological innovation, and the role of infrastructure in influencing both economic growth and employment outcomes. Although prior research indicates that the impact of renewable energy on local economies and labor markets can vary, significant benefits tend to arise when renewable energy initiatives are supported by adequate infrastructure and advanced technological solutions.

For example, Colarossi et al. [37] found that adding energy prediction and storage to the cold ironing architecture achieves an efficiency of 24.9%. This highlights the importance of technology interdependence on the reliability and performance of energy systems. Similarly, Rimantho et al. [38] reported that the development and optimization of biomass pellets had increased fuel quality, which could satisfy international market requirements, leading to growth in local job creation and the bioenergy industry. The test of the hypothesis follows to establish a stronger link between the development of renewable energy, innovation, infrastructure availability, economic expansion, and workforce well-being, particularly in addressing the developmental problems and opportunities that exist in Eastern Indonesia. This research led to the formulation of a targeted hypothesis to further explore these dynamics.

H1: Renewable energy development had a positive effect on innovation.

The development process has the potential to drive innovation through the advancement of green energy technologies, increased efficiency, and the formulation of new solutions in energy production and distribution [39]. Greater investment in green energy correlates with increased motivation for innovation in related technologies. In addition, innovation includes new technologies like solar panels and wind turbines, but also the development of the energy storage capabilities that such devices require [40].

H2: Renewable energy development had a positive effect on infrastructure availability.

This process requires the establishment of infrastructure, including electrical grids, access roads to power plant locations, and facilities for energy storage and distribution [41]. Projects contribute to infrastructure expansion by requiring effective connectivity for efficient energy distribution and transmission [42]. Consequently, investments in green energy directly foster improvements in infrastructure availability.

H3: Renewable energy development had a positive effect on local economic conditions.

Considering the formulated hypothesis, renewable energy had a positive impact on the local economy. However, preliminary studies reported that the direct impact was insignificant [43]. Renewable energy development contributed to economic growth when combined with investment in infrastructure and local business participation [44]. Its effect on the local economy varies depending on other supporting factors.

H4: Innovation had a positive impact on local economic conditions.

Innovation has improved the local economic situation by raising productivity, competition advantages in breeding, and increasing employment [45]. Furthermore, it has brought increases in local business development and operational efficiency, with the benefits of enhanced revenue as part of the larger economic growth [46].

H5: Infrastructure availability had a positive impact on local economic conditions.

Adequate infrastructure enhances local economic growth, accessibility, logistics efficiency, and business connectivity [47]. According to Calderón-Rivera [42], regions with sufficient infrastructure experience higher levels of economic growth due to facilitated business activities, which in turn attract new investors.

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H6: Local economic conditions had a positive effect on the workforce.

A stable and growing local economy leads to the provision of job opportunities in the industrial, service, and small-and medium-sized business sectors [48]. According to Thomsen et al. [49], sustainable economic growth contributed to an increase in the workforce, resulting in lower unemployment rates.

H7: Renewable energy development had a positive effect on local economic conditions through Innovation, serving as a mediating variable.

Renewable energy improved local economies through innovation pathways. This was because innovations in green energy technologies provided new business opportunities and energy efficiency [39]. Several studies have shown that technological innovations focused on large companies and had no direct impact on the local economy [11].

H8: Renewable energy development had a positive effect on local economic conditions through infrastructure availability as a mediating variable.

The availability of adequate infrastructure closely correlated with the impact of renewable energy on the local economy [50]. This led to the distribution of green energy, increased economic activity, improved business competitiveness, and the provision of investment opportunities [42].

H9: Innovation had a positive effect on the Workforce through local economic conditions as a mediating variable.

Innovation catalyzes local economic growth, resulting in increased employment opportunities [45]. However, The Directorate-General for Research and Innovation, European Commission [51], reported that its impact depended on the readiness of the local workforce to adopt new technologies. Assuming the workforce lacked the appropriate skills, this variable increased efficiency but did not provide new jobs.

H10: Infrastructural availability had a positive effect on the workforce through local economic conditions as a mediating variable.

Adequate infrastructure strengthens local economic performance and contributes to increased employment opportunities [52]. Specific infrastructure elements, including reliable electricity networks and efficient transportation systems, play a critical role in enhancing industrial productivity, which in turn stimulates workforce expansion [43].

H11: Renewable energy development had a positive effect on the workforce through local economic conditions, serving as a mediating variable.

The impact on employment often occurred indirectly through local economic growth [53]. According to Wei and Nie [43], the green energy sector provided temporary jobs, such as those in the construction phase of related projects.

H12: Renewable energy development had a positive effect on the workforce through innovation and local economic conditions, which served as mediating variables.

Innovation pathways impacted employment through local economic growth. However, a previous study reported that it improved efficiency compared to the provision of new jobs [46]. In line with this finding, the impact of innovation on employment required further exploration. The development of renewable energy has had a positive impact on the workforce by improving infrastructure availability and fostering economic development in the local area, serving as a mediating variable.

This paper employs two primary theoretical approaches to investigate the mediating roles of infrastructure and innovation in the relationship between renewable energy development and socioeconomic outcomes.

The initial theory is the Endogenous Growth Theory [54, 55] which explains how new technologies are used and spread in societies. This leads to more productivity, efficiency, and new job opportunities. These theories converge within the field of renewable energy development: infrastructure enables energy generation and distribution, while innovation enhances system efficiency and flexibility.

The second theoretical framework relevant to technological adoption is the Innovation Diffusion Theory [56], which explains how new technologies are adopted and diffused within societies. This process leads to higher productivity, improved efficiency, and expanded employment opportunities. In the field of renewable energy development, these theories are linked: infrastructure supports energy generation and distribution, while innovation makes systems more efficient and flexible. They work together to create systems that depend on each other, making renewable energy projects even more crucial for enhancing worker health and safety, as well as boosting the local economy.

When development aligns with adequate infrastructure, the impact on the workforce becomes more significant [50]. This enabled wider energy distribution, supported business activities, and provided jobs in various sectors related to green energy [42].

3 Research Methodology

This study employed an explanatory research design to describe and test the causal relationships among renewable energy development, infrastructure, innovation, local economic conditions, and workforce outcomes. The article aims to clarify how renewable energy development yields socio-economic benefits mediated by infrastructure and innovation. To apply this design, the research utilized the Structural Equation Modeling–Partial Least Squares (SEM–PLS) technique, which is well-suited for handling complex models with multiple mediating factors and relatively small sample sizes. Unlike exploratory or descriptive designs, explanatory research enables the testing of empirical hypotheses and the validation of relevant theories, thereby providing a stronger understanding of causal mechanisms and supporting evidence-based policy recommendations. Structured questionnaires were used to collect primary data, complemented by secondary sources, including government reports, renewable energy project files, and local statistical records.

Table 1. Variables and measurement items

Latent Variables	Measurement Items	Code	Reference
Innovation (INV)	Development of new renewable and innovative energy technologies (technological innovation for local adaptation)	INV_1	[56, 57]
	Implementation of technological innovation to improve system efficiency (process innovation and performance improvement)	INV_2	[57, 58]
	Industry adoption and diffusion of innovative renewable energy practices (innovation transfer and sectoral learning)	INV_3	[16, 56]
	Development of new business models or financing mechanisms for renewable projects (business model innovation and sustainability strategy)	INV_4	[57, 59]
Workforce (WF)	Increase in certified renewable energy workforce (skilled labor participation)	WF_1	[60, 61]
	Capacity development programs for workforce skills in renewable energy (training and skill enhancement)	WF_2	[62]
	Creation of new employment opportunities in the renewable energy sector (green job expansion)	WF_3	[23, 63]
	Implementation of vocational and technical competency training (human capital improvement)	WF_4	[62, 64]
Renewable Energy Development (RED)	Installed capacity of renewable energy systems (generation capacity expansion)	RED_1	[20, 62]
	Adoption of renewable energy technologies by industries and communities (technology uptake and deployment)	RED_2	[65, 66]
	Contribution of renewable energy to total regional energy consumption (share of renewables in energy mix)	RED_3	[20, 62]
	Renewable energy addresses environmental, economic, and social sustainability aspects (triple-bottom-line contribution)	RED_4	[23]
Local Economic Conditions (LEC)	Local economic stability supports renewable energy investment (financial resilience and market readiness)	LEC_1	[23]
	Levels of local private and public investment in renewable energy projects (investment growth and capital inflow)	LEC_2	[67]
	Availability of local government funding and fiscal incentives (policy support and budget allocation)	LEC_3	[64]
	Regional GDP growth linked to renewable energy projects (economic expansion and productivity gains)	LEC_4	[25]
Infrastructure Availability (INF)	Availability of basic infrastructure supporting renewable-energy projects (transportation, logistics, and utilities)	INF_1	[23]
	Electricity grid-connectivity and integration for renewable energy (grid extension and network stability)	INF_2	[20]
	Distribution infrastructure for renewable energy technologies (supply network and accessibility)	INF_3	[62]
	Infrastructure integration within renewable energy systems and grids (system interoperability and operational reliability)	INF_4	[23]

The investigation focused on five key variables: renewable energy development, infrastructure availability, innovation, local economic conditions, and workforce development. Renewable energy development (RED) is defined as the level of implementation of related projects in the study area, measured using indicators such as installed capacity, number of active projects, and the scale of renewable energy investment.

All indicators were measured using a five-point Likert scale to capture respondents' perceptions. Participants evaluated the level of renewable energy development in their respective regions by rating aspects such as installed capacity, project activity, and investment intensity from low (1) to high (5). This perception-based approach enabled the standardization of data for use in SEM–PLS analysis. It also acknowledges the value of localized contextual data that may not be fully captured in official statistics.

Infrastructural availability (INF) includes the level of road accessibility, the electricity network, and communication facilities. The innovation variable (INV) is measured based on participation in universities or research institutions, the adoption of new technologies, and the number of local patents related to renewable energy. Local economic conditions (LEC) refer to the average household income level, the growth of local businesses, and market access. The workforce variable (WF) is measured based on the number of permanent and contract workers in the renewable energy sector, as shown in Table 1.

The relationship between these variables is shown in Figure 1 below.

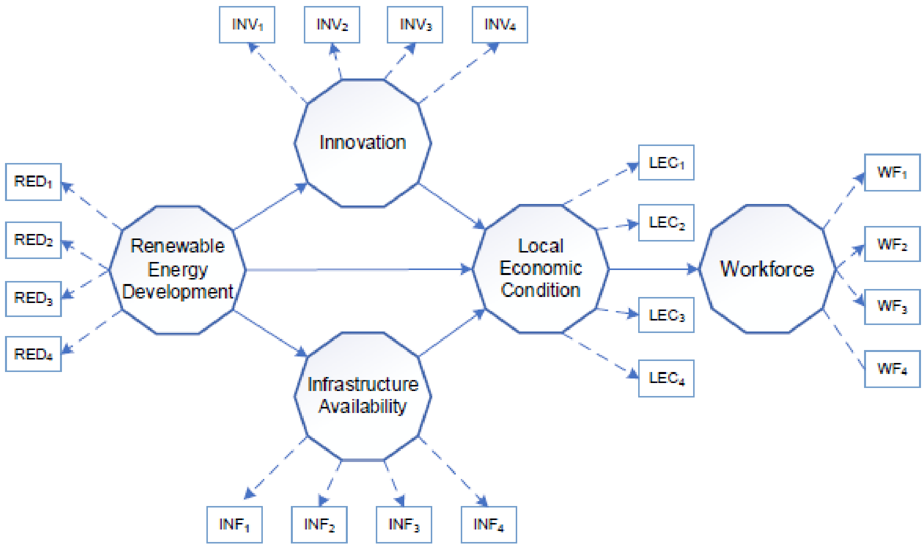

Figure 1. Research model

The study involved participants from multiple stakeholder groups, including local government representatives, the State Electricity Company, academic experts, and community members residing in areas where renewable energy development is ongoing. The sample was selected using a purposive sampling technique to ensure the inclusion of respondents with relevant knowledge and experience. According to the power analysis by Cohen [68], a sample size of at least 91 was required for a five-variable model, assuming a moderate effect size ($f^2 = 0.15$), a statistical power of 0.80, and a significance level of $\alpha = 0.05$. To allow for non-response and incomplete questionnaires, the target sample size was set at 170 respondents. This decision is consistent with the recommendation of Hair et al. [69], who promote the use of larger samples in Structural Equation Modeling–Partial Least Squares (SEM–PLS) to improve the accuracy and stability of estimates.

Data were collected through a questionnaire survey, which utilized a five-point Likert scale to measure respondents' perceptions of each construct. Secondary data were sourced from government documents, statistical reports, and academic literature. To examine the validity and reliability of the questionnaire, it was pretested before being distributed as a data collection tool for the empirical study.

Structural relationships between the model and its components were examined using SEM–PLS based on structured questionnaire data, with t-test values computed. Meanwhile, supplementary data—i.e., official reports, energy statistics, and regional planning documents—were used to validate the selected variables and to provide contextual validity for the results, thereby enriching the descriptive component of the analysis. We combined these two datasets to build the model and interpret the findings. Moreover, this strategy ensured confidence that the empirical results were not only statistically valid but also robust and reflective of conditions at the study site.

Data analysis was conducted using SEM–PLS, which was selected because it is one of the methods capable of handling models with a large number of variables and multiple mediating variables. Despite the hypothesis-testing nature of this study, Partial Least Squares Structural Equation Modeling (PLS–SEM) was used instead of Covariance-

Based SEM (CB-SEM) to reflect the emphasis on prediction and variance explanation rather than theory confirmation. PLS–SEM is more suitable for models with several mediating variables, varying sample sizes, and non-normal data distributions, as applied herein [70, 71]. Furthermore, PLS-SEM enables the estimation of direct and indirect effects jointly, considering its explanatory nature, such as in assessing how renewable energy development influences economic welfare and the workforce through infrastructure and innovation. This methodological choice enables the model to capture both theoretical and practical aspects of the mediation mechanisms examined in this study.

The Structural Equation Modeling–Partial Least Squares (SEM–PLS) method was selected to explain and predict causal relationships among latent variables based on non-experimental survey data. SEM–PLS is suitable for complex models with mediating effects, limited sample sizes, and non-normal data [69]. Unlike covariance-based SEM, it emphasizes prediction and variance explanation, making it suitable for explanatory studies in social and regional development. Although experimental data were not used, bootstrapping (5,000 subsamples) and reliability–validity tests (Cronbach's alpha, Composite Reliability, and Average Variance Extracted) confirmed the model's robustness and theoretical soundness.

The SEM–PLS approach is particularly suitable for small sample sizes and data that are not normally distributed. The analytical process consisted of evaluating the measurement model (outer model) and the structural model (inner model), as described by Cheung et al. [72]. When assessing convergent validity, the Composite Reliability (CR) and Cronbach's alpha (α) values for each construct should exceed 0.70. Furthermore, the Average Variance Extracted (AVE) should be greater than 0.50, and the outer loadings of all items must exceed 0.70 to confirm satisfactory convergent validity [69]. The Fornell–Larcker criterion was used to test for discriminant validity, and the CR and α values exceeded 0.70 for construct reliability.

In the inner model (structural model), the appropriateness of the significance of the path loadings was assessed in relation to how well the model explained the endogenous constructs and their predictive ability. Assessment measures included the coefficient of determination (R^2), predictive relevance (Q^2), path coefficients, and effect size (f^2) [73]. In particular, R^2 was used to measure the amount of variance accounted for by the endogenous constructs, f^2 estimated the local effect size of the exogenous constructs, and Q^2 determined the predictive relevance of the model.

In line with the results, mediation analysis was conducted to identify the roles of infrastructure and innovation as mediators between renewable energy development, local economic growth, and job creation. Mediation was tested using the procedure developed by M. Namazi and N.-R. Namazi [74], which was adapted for SEM–PLS analysis. Path significance testing was conducted using t-statistics with a significance level of 5% ($p \leq 0.05$). The study aimed to determine whether significant relationships existed among the variables. Direct and indirect path analyses were also used to ascertain the relationships among the variables.

4 Results

Based on data collected during Focus Group Discussion (FGD) activities and surveys, it was found that the majority of respondents who provided views on renewable energy development were over 50 years old, with the most significant proportion reaching approximately 46.7%. These results suggest that older respondents paid considerable attention to energy issues, likely due to their experience with conventional nergy challenges. Furthermore, 27.8% and 17.8% of respondents belonged to the 40–49 and 30–39 age groups, respectively, while only 7.8% were under the age of 30. This pattern suggests that, although younger respondents possess considerable innovative potential, their contributions to the discussion were less frequent than those of older participants. This distribution is summarized in Table 2, which presents the demographic characteristics of the survey respondents.

In terms of educational attainment, the majority of respondents were graduates of higher education institutions. Approximately 37.8% held a bachelor's degree, followed by 33.3% with a master's degree and 17.8% with a doctorate. Therefore, more than half of the respondents had a strong academic background, suggesting that this group understood the importance of renewable energy development. Respondents with lower educational attainment, such as high school and diploma (D3) graduates, although fewer in number, contributed important pragmatic and practical perspectives on the application of renewable energy. Overall, renewable energy development was understood and supported across diverse age groups and educational levels. However, the predominance of older and highly educated respondents may have influenced the perceptions captured in this study, but it does not directly determine the implementation of renewable energy.

Convergent validity was established in the SmartPLS model assessment using a reflective measurement approach, with all factor loadings exceeding 0.70. The constructs also demonstrated acceptable reliability ($\alpha > 0.70$ and $\mathrm{CR} > 0.70$). Furthermore, the AVE estimates were higher than 0.50 for each construct, supporting adequate internal consistency and convergent validity across all constructs [75].

Discriminant validity was confirmed, as most construct pairs had HTMT values below 0.85, except for the relationship between RED and INV. Additionally, the HTMT value for RED–INF exceeded the conservative threshold (HTMT < 0.90). This is acceptable provided that the structural model does not indicate multicollinearity. All AVE values exceeded the squared correlations between constructs; therefore, discriminant validity was confirmed based on the Fornell–Larcker criterion. As discriminant validity was confirmed using both HTMT and the Fornell–Larcker criterion, the evaluation proceeded to the structural model. The negative correlations between latent constructs were interpreted theoretically, indicating no evidence of multicollinearity in the proposed model.

Table 2. Respondent demographic distribution

Category	Subgroup	Frequency (n)	Percentage (%)
Gender	Male	104	61.2
	Female	66	38.8
Age (years)	< 30	13	7.8
	30–39	30	17.8
	40–49	47	27.8
	≥ 50	80	46.7
Education level	High-School/Diploma	19	11.1
	Bachelor's Degree	64	37.8
	Master's Degree	57	33.3
	Doctoral Degree	30	17.8
Occupation/Organization	Government Official	48	28.2
	Academic/Researcher	53	31.2
	Energy-Practitioner (PLN/Private)	44	25.9
	NGO/Community Representative	25	14.7
Total		170	100

Source: Primary survey data (2024)

The R-squared values indicated that most of the constructs were adequately explained by the model, particularly LEC and INF. Each construct had an R-squared value greater than 0.63; therefore, all were suitable for decision-making purposes. Detailed R-squared values for each construct are presented in Table 3.

Table 3. Determination coefficients of the affected variables

Variables	R-square	R-square Adjusted
Infrastructure Availability	0.630	0.628
Innovation	0.568	0.565
Local Economic Conditions	0.632	0.625
Workforce	0.454	0.450

Source: SmartPLS analysis results (2024)

Based on the f^2 effect sizes, the relationships among the variables in the model are shown in the following table. The effect sizes of each predictor on the outcome variables, calculated using Cohen's f^2, are presented in Table 4, illustrating the relative contribution of each construct to the structural model.

Table 4. The effect of variables

Variables	f-square
Infrastructure Availability → Local Economic Conditions	0.231
Innovation → Local Economic Conditions	0.079
Local Economic Conditions → Workforce	0.830
Renewable Energy Development → Infrastructure Availability	1.702
Renewable-Energy Development → Innovation	1.313
Renewable Energy Development → Local Economic Conditions	0.011

Source: SmartPLS analysis results (2024)

Using the Cohen [68] criteria, effect sizes are categorized as small (f^2 = 0.02), moderate (f^2 = 0.15), and large (f^2 = 0.35) based on their relative influence of independent variables on dependent constructs. The analysis revealed that Renewable Energy Development had a substantial impact on Infrastructure Availability (f^2 = 1.702) and Innovation (f^2 = 1.313), indicating positive effects on both constructs. In contrast, its effect on local economic conditions was negligible (f^2 = 0.011), indicating that no meaningful direct relationship exists between Renewable Energy Development and local economic performance.

The cross-loading analysis indicated that each indicator had a higher loading on its corresponding construct than on any other construct, confirming adequate discriminant validity. Consequently, the results suggest that there are no issues related to construct overlap. To further verify the robustness of the measurement model, discriminant validity was reassessed during the stage of structural model evaluation. These direct relationships, along with their statistical significance, are summarized in Table 5.

Table 5. The direct relationship between variables

Variables	T Statistics (O/STDEV)	*P*-values
Infrastructure Availability → Local Economic Conditions	4.422	0.000
Innovation → Local EconomicConditions	1.965	0.049
Local Economic Conditions → Workforce	13.895	0.000
Renewable Energy Development → Infrastructure Availability	28.256	0.000
Renewable Energy Development → Innovation	12.622	0.000
Renewable Energy Development → Local Economic Conditions	0.802	0.423

Source: SmartPLS analysis results (2024)

The findings suggest that renewable energy development has significant implications for infrastructure availability and innovation, but a limited direct impact on local economic conditions. Both infrastructure availability and innovation individually have a positive impact on local economic conditions, with the effect of infrastructure being more substantial. Moreover, the regional economic context has a strong impact on the workforce, which justifies its importance in shaping employment outcomes. Overall, renewable energy development significantly contributes to infrastructure availability and innovation, while local economic drivers exert a more direct influence on workforce outcomes.

Indirect effects were tested to determine the extent of full and partial mediation. The findings indicate that infrastructural availability and renewable energy development exerted considerable positive effects on local economic conditions, which in turn enhanced workforce readiness. The increase in renewable energy development had a substantial impact on infrastructure, resulting in improved economic conditions and expanded workforce opportunities. However, it did not have a direct effect on workforce outcomes due to economic conditions. Innovation had a weak effect and, in some instances, insignificant effects on workforce outcomes and local economic conditions. Infrastructure projects and renewable energy initiatives were the primary drivers of economic and workforce development, with innovation playing a relatively minor role in the proposed model. The significance of these mediated paths is summarized in Table 6.

Table 6. Indirect relationships between variables

Variables	T Statistics (O/STDEV)	*P*-values
Infrastructure Availability → Local Economic Conditions → Workforce	4.124	0.000
Innovation → Local Economic Conditions → Workforce	1.924	0.054
Renewable Energy Development → Innovation → Local Economic Conditions	1.922	0.055
Renewable Energy Development → Infrastructure Availability → Local Economic Conditions	4.203	0.000
Renewable Energy Development → Local Economic Conditions → Workforce	0.790	0.429
Renewable Energy Development → Innovation → Local Economic Conditions → Workforce	1.877	0.061
Renewable Energy Development → Infrastructure Availability → Local Economic Conditions → Workforce	3.899	0.000

Source: SmartPLS analysis results (2024)

The results suggest that innovation and local economic conditions do not function as primary mediators in the relationships among the constructs. Innovation does not consistently enhance local economic conditions and therefore cannot be considered a potent mediator in the proposed model. Local economic conditions were found to be an ineffective pathway for linking renewable energy development to employment outcomes. This implies that renewable energy development has a limited direct impact on employment when its effects are mediated solely by local economic conditions. As a result, development plans should prioritize components with direct and meaningful benefits—such as infrastructure—rather than relying on innovation as a mediator in this context.

The results indicated that several hypotheses were statistically insignificant, suggesting that the relationships among the examined variables were weak or were possibly mediated by other contextual factors. The direct effect of renewable energy development on local economic conditions was minimal ($p > 0.05$), primarily because large corporations typically dominate investments in green energy [43]. Prior studies have similarly noted that the economic benefits of renewable energy become more evident when policy frameworks actively encourage the participation of Micro, Small, and Medium Enterprises (MSMEs) in the renewable energy supply chain [53]. Innovation had a weak impact on local economic conditions, as it tended to prioritize industrial and technological efficiency over local economic development [45]. Large companies responsible for major renewable energy innovations were not well integrated into the local economy due to a lack of practical knowledge transfer.

The mediation pathway linking renewable energy development, innovation, and local economic conditions indicated that the workforce had no substantial mediating effect. This suggests that MSMEs had not fully adopted renewable energy innovations [76]. The effects of innovation on the workforce were more evident in the long run than in the short run [39]. Furthermore, innovation contributed to improvements in local economic conditions. The workforce was also considered inadequate, as innovation often required advanced skills that were lacking in the local labor pool [77]. The pathway from renewable energy development to regional economic conditions and workforce outcomes appeared negligible, indicating that the impact of green energy on employment is limited without adequate infrastructure support [41]. The results showed that renewable energy production could not improve local economies on its own; it requires supportive policies that encourage local businesses to participate, invest in infrastructure, and develop workforce skills. As a result, similar programs must prioritize strengthening innovative ecosystems, facilitating technology transfer to local companies, and increasing workforce capacity to ensure sustainable and long-term impacts [42].

The established hypotheses suggest that infrastructure has a significant impact on local economic and workforce conditions, whereas innovation has only a limited impact in these models. Renewable energy development exerted indirect effects on the workforce through infrastructure; however, it did not directly influence local economic conditions or innovation. Therefore, renewable energy policies should prioritize infrastructural improvements rather than relying solely on innovation to enhance economic and workforce outcomes. In line with these results, the present study accepted three mediation hypotheses.

4.1 Mediation of Local Economic Conditions in the Relationship between Infrastructure and Workforce

The results suggest that infrastructural availability has a significant impact on local economic conditions, which in turn has a positive effect on employment. Adequate infrastructure—including basic facilities, grid integration, the adoption of renewable energy technologies, and the enhancement of related frameworks—improves firm productivity, attracts investment, and generates additional employment opportunities. Energy system optimization can reduce operational expenses by up to 37%, while hybrid PV–wind systems can meet approximately 17.66% of energy demand at a competitive cost [25]. Furthermore, the implementation of renewable energy infrastructure creates high-quality jobs that require expertise in forecasting, modeling, and optimization algorithms, as well as investment in energy storage systems to stabilize the grid [78].

Studies by Panjaitan [78] and Du et al. [79] have shown that infrastructural investment is positively associated with regional economic growth and job creation, particularly in developing countries. According to Calderón-Rivera [42], improvements in physical infrastructure—especially in transportation and telecommunications—directly enhance employment opportunities and household income. Furthermore, International Labour Organization (ILO) [60] and Hou et al. [80] reported that the influence of infrastructure on workforce development varies depending on government policy frameworks and the extent to which regions can leverage emerging economic opportunities. Therefore, to improve local economic conditions and workforce outcomes, the government and relevant stakeholders must prioritize the development of broad and accessible infrastructure, particularly in areas affected by poverty.

4.2 Infrastructure Mediation in the Relationship between Renewable Energy Development and Local Economic Conditions

The findings suggest that renewable energy development has a significant impact on infrastructure expansion, which in turn enhances local economic performance. Renewable energy projects—such as solar and wind installations—require the development of supporting infrastructure, including power grids, access roads, and logistics facilities, thereby stimulating regional economic activity. According to Szabó et al. [81], investments in renewable energy promote infrastructure improvements, as such projects rely on dependable electricity networks and efficient mobility for installation and maintenance. Similarly, International Renewable Energy Agency (IRENA) [82] reported that renewable energy investments in developing countries have expanded electricity access in rural areas, fostering local economic growth. Furthermore, Zhou and Feng [83] noted that these economic benefits are maximized through legislative support, including incentives that encourage domestic enterprises to participate in renewable energy initiatives. Consistent with these findings, policy frameworks that promote green energy investment have accelerated the transition toward a sustainable energy system while concurrently strengthening infrastructure and supporting local development. Additionally, collaboration among government entities, investors, and local communities ensures the broad distribution of benefits derived from renewable energy initiatives.

4.3 Impact of Renewable Energy Development on Employment through Infrastructure and Local Economic Conditions

The formulated theory posits that renewable energy development has an indirect impact on employment by enhancing local infrastructure and economic conditions. However, it does not generate jobs immediately; instead, its impacts occur over the long term through infrastructure enhancement and the stimulation of local economic activity. According to Fridleifsson et al. [84], renewable energy projects primarily create employment opportunities during the construction and early operational stages. At the same time, their long-term effects are most evident in infrastructure development and the expansion of related industries. As noted by Zhang et al. [85], the transition to renewable energy heavily depends on the development of significant infrastructural and technological assets to address issues such as intermittent energy supply and integrating renewable sources into existing energy systems.

Based on the description of the hypothesis testing, it was inferred that infrastructure played an important role in improving local economic and workforce conditions, as reported by previous studies. Renewable energy development has helped improve local infrastructure and economic conditions, indirectly benefiting the workforce through enhanced infrastructure and economic growth. Policies that motivated investment in infrastructure and renewable energy increased economic growth, creating jobs. However, such policies should be complemented by regulatory support, incentives for local companies, and workforce development initiatives to maximize benefits. The results of this study were consistent with the global trend of growth in infrastructure and renewable energy. It also showed that without adequate legislative support, the impact on the workforce would be limited.

Regulatory frameworks and fiscal incentives, as instruments of national policy, have significantly contributed to the development of green employment by reducing investment-related risks and fostering private sector participation [86]. In a case study on U.S. renewable energy projects, Wei and Nie [43] observed that employment creation in the sector was highly dependent on access to appropriate infrastructure, such as modern electricity distribution systems and efficient transportation networks. Likewise, Markard and Rosenbloom [53] found that regions implementing policies related to workforce development and technological adaptation experienced improved employment prospects. These effects were primarily secondary, stemming from infrastructure enhancements and broader economic growth that generated job opportunities. Consequently, strategic measures are required to maximize these benefits, including strengthening workforce capacity and providing incentives for local enterprises to participate in renewable energy initiatives.

This study demonstrates that renewable energy development has no direct impact on local economic conditions; instead, its significance becomes apparent when mediated by infrastructure. Furthermore, economic benefits tend to be greater when renewable energy projects are supported by adequate infrastructure development, including electricity grids, transportation networks, and ancillary services. When infrastructure is insufficient, local communities and businesses are unable to capitalize on the benefits offered by green energy initiatives fully. Empirical evidence from previous studies [40, 41] shows that the economic impacts of renewable energy generation are significantly strengthened when investments in this sector are integrated with parallel infrastructure development. Consequently, as it is no longer sufficient for green energy policies to focus solely on energy generation, equal attention should be directed toward establishing infrastructure that stimulates local economic development and fosters employment growth. Within this context, local entrepreneurs are likely to assume more prominent roles in Nigeria's renewable energy supply chain. The findings of this study further show that local economic conditions serve as a key intermediary connecting available infrastructure to workforce outcomes, while innovation demonstrates a comparatively weaker mediating influence. Consequently, the development of renewable energy projects should prioritize the enhancement of local infrastructure and economic capacity to generate a more substantial impact on employment and community well-being.

4.4 Synergy between Infrastructure, Economy, and Employment

Infrastructural development and regional economic conditions are regarded as important intermediaries linking workforce outcomes to renewable energy development. Adequate infrastructure enhances efficiency and accessibility, thereby generating broader employment opportunities. The study further indicates that a robust local economy increases labor demand and creates an environment conducive to industrial expansion [87].

Extending this discussion, infrastructure also constitutes a key factor in strengthening workforce capacity in regions with favorable economic conditions. Although Foreign Direct Investment (FDI) is typically associated with facilitating knowledge transfer, evidence from Special Economic Zones (SEZs) shows that inflows of foreign investment substantially improve local labor skills through the transfer of technology and managerial expertise, thereby reinforcing regional economic linkages [88]. This relationship highlights the synergistic relationship between infrastructure and local economic vitality as key drivers of employment growth.

In this context, innovation does not consistently function as a strong mediating variable. Its influence on the local economy remains limited when it is not supported by adequate infrastructure and favorable economic conditions. Although preliminary evidence suggests that innovation can increase productivity, local communities may not fully benefit from it in the absence of sufficient infrastructural and economic support [89]. Therefore, strengthening local economic conditions and infrastructure should be prioritized to achieve more substantial improvements in workforce outcomes.

Based on the description, broader political action is needed if responses to employment demand in the renewable energy sector are to be effectively supported. Strong local economic growth and targeted infrastructure investment serve as key examples that raise living standards and provide enduring employment opportunities. Such a strategic approach enhances the competitiveness of the renewable energy sector while simultaneously stimulating broader local economic development [90, 91].

Beyond its economic implications, the findings of this study suggest that renewable energy initiatives in Eastern Indonesia also contribute to a decolonial development trajectory by strengthening local capacities, reducing structural dependency, and encouraging innovation that emerges from within communities. This perspective aligns with critical development scholarship that advocates knowledge pluralism and participatory models of growth [59].

4.5 Study Limitations and Future Directions

Several limitations are associated with the survey sample used in this study, which primarily consists of older and more highly educated individuals. This characteristic may generate sampling bias and restrict the generalizability of the findings. Although this demographic profile corresponds to stakeholders directly involved in renewable energy development in Eastern Indonesia—such as government officials, project managers, and academics—it may not be representative of the broader population. Consequently, the generalizability of the findings is confined mainly to professional settings. To enhance generalizability in future research, incorporating a more diverse range of respondent groups—such as local community members, younger participants, and small business stakeholders—would be advantageous.

Another limitation of this study is the absence of control variables that could be critical in explaining why areas located closer to renewable energy sources exhibit different socio-economic outcomes, such as regional remoteness, population density, and varying levels of government investment. These factors are likely to act as confounders in the modeled relationships. Due to data constraints and the specific focus of this research—namely, exploring how infrastructure and innovation function as mediators—these variables were not included. Future studies should incorporate such contextual conditions as control variables to obtain more robust and generalizable results.

5 Conclusions

In conclusion, this study proved that renewable energy development in Eastern Indonesia had significant potential to improve local economic conditions. However, the analysis revealed that adequate infrastructure could support this positive impact. The availability of adequate infrastructure served as a catalyst, facilitating the implementation of renewable energy technologies and ensuring better accessibility for the community, leading to the following inferences.

First, without adequate infrastructure, such as electricity grids, transportation, and related supporting facilities, the potential of renewable energy would not be utilized optimally. As a result, investing in infrastructural development should be a top priority in national energy policy. The government should allocate sufficient resources for related projects, specifically in remote areas.

Second, this study outlined the importance of collaboration between various stakeholders. The government, private sector, and community should collaborate to create an ecosystem that supports the development of renewable energy. For example, training programs for the local workforce in the renewable energy sector have helped improve skills development, motivating participation in this new economy.

Third, to ensure the benefits of renewable energy were experienced widely, a general and sustainable method was adopted. This included developing policies that focused on economic aspects, such as social and environmental impacts.

Finally, further studies that include other factors affecting the relationship between renewable energy development and the local economy should be conducted. A more profound understanding enabled the effectiveness and sustainability of the strategies implemented, thereby providing a greater positive impact on communities in Eastern Indonesia.

Although the results are context-specific to Eastern Indonesia, the causal relationships identified in this study provide a conceptual basis that may be relevant to other developing regions facing similar infrastructure and innovation challenges.

6 Policy Implications and Recommendations

The empirical findings of this study offer several policy and practical implications for advancing renewable energy development in Eastern Indonesia. The results indicate that infrastructure availability plays a crucial mediating role. Accordingly, policymakers should prioritize cohesive infrastructure investments, including grid expansion, energy storage systems, and digital connectivity, to support the effective implementation of renewable energy initiatives.

Second, the strong influence of innovation underscores the need for innovation-driven policies, such as tax incentives for local entrepreneurs and research collaborations between universities and energy firms. Knowledge-sharing initiatives may also facilitate community-based technological adaptation; for instance, an online knowledge exchange platform could help solar adopters connect with peers regarding feasibility, system performance, and technology selection.

Third, the findings suggest that renewable energy programs have substantial impacts on employment and local economic growth when implemented effectively. Therefore, policy frameworks should incorporate vocational training programs, expand employment opportunities for residents, and provide participatory mechanisms that account for the needs of rural and island communities.

Lastly, over the long term, an implementation mechanism is required to coordinate national energy strategies with decentralized governance structures, enabling local governments to tailor renewable energy development to their specific regional conditions and resource capacities. Such alignment would ensure that renewable energy contributes not only to national sustainability targets but also to regional equity and community empowerment.

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Data Availability

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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