Proceedings of the 7th Asia-Pacific Conference on Industrial Engineering and Operations Management
Bangkok, Thailand, March 25–27, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260509
Published: March 25, 2026

Institutional Model for Renewable Energy Management Based on the Energy-Self-Sufficient Village/Hamlet in Southwest Sumba

Hamzah, Towaf Totok Irawan, Retno Martanti Endah Lestari and Tutus Rully
Faculty of Economics and Business
Pakuan University
Bogor, Indonesia
hamzah.fe@unpak.ac.id, towaf@unpak.ac.id, retno.martanti@unpak.ac.id, tutusrully@unpak.ac.id

Abstract

Energy is a priority for every country because it plays a vital role in human life; however, over time, the availability of fossil fuels has been declining. Therefore, a viable alternative solution is to establish energy-self-sufficient villages or hamlets. The objective of this study is to develop a business institutional model for the implementation of renewable energy in Southwest Sumba, based on energy-self-sufficient villages or hamlets, in accordance with the potential of renewable natural resources in those villages. The research method employed is *a hard-system* approach, specifically *multi-criteria decision making* (MCDM), with data analysis using interpretative structural modeling (ISM). The results indicate that the institutional and energy management model that can be developed in Southwest Sumba is driven by BumDes/Village Cooperatives partnering with companies through corporate social responsibility (CSR) initiatives or other funding sources. Additionally, the local government provides support and plays a strategic role in the progress and economy of the village community. Furthermore, academics, educational institutions, or research bodies such as the Regional Planning, Research, and Innovation Agency (BAPPERIDA) fully support and educate the community regarding management and the transfer of knowledge and technology. The State Electricity Company (PLN) must also provide full support to ensure effective implementation, and community leaders and other stakeholders are called upon to foster the growth and development of energy self-reliance. Thus, the business model or institutional framework for managing renewable energy based on energy-independent villages or hamlets in Southwest Sumba or other remote areas can be effectively implemented, leveraging the region's highly promising energy potential.

Keywords
Renewable Energy, ISM, Solar Power Plant, Southwest Sumba

1. Introduction
Every country must prioritize energy strategically, as energy plays a vital role in human life by contributing to nearly all human activities. However, a nation's GDP growth positively correlates with per capita energy availability (BPS, 2023). Indonesia ranked 34th with a renewable energy capacity of 12,600 MW in 2022 (Databoks, 2023). Most of the energy currently used comes from fossil fuels, causing fossil fuel reserves to dwindle. Furthermore, the threat of declining fossil fuel reserves is increasing, along with the resulting consequences for the environment at both local and international levels.

According to the Ministry of Energy and Mineral Resources (ESDM, 2021), Indonesia's proven oil reserves will last for another 9.5 years, although the reserve life is estimated at 19.9 years. As of January 2023, Indonesia's *proven* oil *reserves* stood at 2.41 BBO (*billion barrels of oil*) and 35.3 TCF (*trillion cubic feet*) (Databoks, 2023). A nation's self-

© IEOM Society International

reliance depends on its energy security. As the world's largest archipelago, Indonesia comprises 17,480 islands with a total area of approximately 5.8 million km^2, and a coastline stretching about 81,000 km, making it extremely challenging to manage such a vast territory. This is due to the fact that development in Indonesia's islands and remote regions is closely tied to a high dependence on fossil-based non-renewable energy, which often faces distribution challenges. One of the primary solutions to this problem is establishing energy-resilient, self-sufficient communities by leveraging the region's potential for alternative energy sources.

Based on research conducted by Hamzah *et al*. (2024), who studied Southwest Sumba regarding the selection of renewable energy potential according to the 5C criteria (*consolidated, controllable, continuous, clean, cheap*), which was used as a holistic evaluation framework to assess and select the most appropriate renewable energy sources. The research results indicate that solar energy holds significant potential as an alternative energy source, primarily due to Southwest Sumba's tropical geographical location, which receives high solar radiation year-round. The second most promising alternative energy source is bioenergy, supported by the abundant availability of biomass feedstock, particularly in the livestock sector. Hydropower and wind energy rank third and fourth, respectively, with fairly good potential. This study analyzes institutional models that can be implemented to develop energy-independent villages in fostering a green economy in Southwest Sumba, East Nusa Tenggara Province (Yusgiantoro, 2000).

1.1 Objectives.
The objective of this study is to develop a business institutional model for the implementation of renewable energy in Southwest Sumba, based on energy-self-sufficient villages/hamlets in accordance with the potential of renewable natural resources in those villages.

2. Literature Review
As part of global efforts to reduce dependence on fossil fuels and slow down climate change, renewable energy encompasses a variety of energy sources, each with its own unique characteristics and potential. One of the cleanest and most abundant sources of renewable energy is solar power. It uses concentrated solar power (CSP) systems or photovoltaic (PV) panels to convert sunlight into electrical energy (Terrén-Serrano, 2021). The main benefits of solar energy are its decentralized nature, low environmental impact, and its ability to provide electricity in remote locations. (Abid *et al*., 2023). Intermittency, the need for energy storage, and the substantial land requirements for utility-scale projects are some of the drawbacks of solar energy (Sarkar and Fitzgerald, 2022). As a renewable energy source, wind power has grown rapidly. It generates energy by harnessing the kinetic energy of moving air through wind turbines (Shouman, 2020). Minimal greenhouse gas emissions, relatively minimal land requirements, and the potential for offshore wind farm development are some of the benefits of wind energy (Kumar, 2020). Intermittency, noise pollution, and potential impacts on wildlife, particularly birds and bats, are some of the drawbacks of wind energy. (Teh *et al*., 2021). Renewable fuels made from biomass, such as plants, algae, or organic waste, are known as biofuels. Produced from sugar- and starch-producing plants, vegetable oils, and animal fats, bioethanol and biodiesel are the two most popular forms of biofuel (Singh and Satapathy, 2018; Medina and Magalhães, 2021).

Greenhouse gas emissions associated with transportation can be reduced by using biofuels. (Nath, 2024). The sustainability of biofuels remains questionable, as their production can have negative effects on the environment, including deforestation and competition with food production. A type of renewable energy produced from organic materials, including plants, agricultural waste, and municipal solid waste, is called bioenergy or biomass energy. (Huerta-Reynoso *et al*., 2019). According to Kluts *et al*. (2017), biomass can be burned directly to generate heat or converted into biofuels such as syngas or biogas for energy production or transportation fuel. Land use, feedstock production, and the efficiency of conversion technologies are some of the variables that influence the sustainability of bioenergy. (Garba, 2021). To maximize the benefits of bioenergy while minimizing its negative environmental impacts, it is crucial to develop advanced conversion technologies and manage biomass resources effectively. (Schroeder *et al*., 2023).

Hydropower harnesses the energy of falling or flowing water and is a well-known renewable energy source that generates electricity. In 2020, it accounted for more than 16% of global electricity production, making it the world's largest source of renewable electricity. (Siciliano, 2023). Reliability, flexibility, and low operating costs are benefits of hydropower facilities, which range from large dams to small river installations. (Xu *et al*., 2023). Hydropower projects, however, can also have significant negative impacts on the environment and communities, including displacing communities, altering river ecosystems, and sometimes releasing greenhouse gases from reservoirs (Worighi *et al*., 2019). In the shift toward a more sustainable energy system, each of these renewable energy sources

© IEOM Society International

has an important role to play. The development and integration of these various renewable energy sources can significantly reduce dependence on fossil fuels and help mitigate climate change, although each presents unique challenges. To overcome current barriers and maximize the promise of renewable energy in the future, more research, innovative technologies, and supportive legislation are needed.

3. Method

This study was conducted in Southwest Sumba from May to August 2024. It employed ISM analysis for strategic policy planning based on the insights of experts/practitioners and key individuals who possess a deep understanding of renewable energy potential in Southwest Sumba and West Nusa Tenggara Province. There were 25 experts in this study, consisting of 7 government officials, 6 business actors, 4 academics/researchers, 4 community leaders, and 4 representatives from financial institutions. The main elements used to design the renewable energy resilience policy and institutional model are the affected institutions, key constraints, program needs, feasible changes, activities to achieve change, and the institutions involved.

4. Results and Discussion

a. Analysis of the Best Institutional Framework for Renewable Energy Management in Southwest Sumba

4.1.1 Affected institutions or groups

The institutional or community elements involved in the design of a model to strengthen the private sector's role in the development of energy-independent areas/villages based on renewable natural resources consist of six sub-elements, namely: (1) the Southwest Sumba Regional Government, (2) the local community, (3) community/traditional leaders, (4) Village-Owned Enterprises (BUMDes)/Village Unit Cooperatives (KUD), (5) PLN (State Electricity Company), (6) Investors/Financial Institutions. Interview results with experts were classified based on the Structural Self-Interaction Matrix (SSIM) developed using the VAXO system, as follows: V if eij = 1 and eji = 0, A if eij = 0 and eji = 1, V if eij = 1 and eji = 1, V if eij = 0 and eji = 0. These data processing steps are sequentially illustrated in the SSIM Table, the Reachability Matrix (RM) Table, and the interpretation of sub-elements (Table 1- Table 3).

Table 1 . Structural Self-Interaction Matrix (SSIM) of affected institutional elements
Element: Affected institution/group

Sub-Element Description (i-j)		**6**	**5**	**4**	**3**	**2**	**1**
Southwest Sumba Regional Government	**1**	V	V	X	X	A	
Local community	**2**	V	V	V	V		
Community/traditional leaders	**3**	V	V	X			
Village-Owned Enterprise (BUMDes)	**4**	V	V				
PLN (State Electricity Company)	**5**	V					
Compilation from Respondents/DM: ALL EXPERTS							

Table 2 . Reachability Matrix (RM) model of affected institutional elements
Element: Affected institution/group

Sub-Element Description (i-j)		**1**	**2**	**3**	**4**	**5**	**6**
Southwest Sumba Regional Government	**1**	1	1	1	1	1	1
Local Community	**2**	0	1	0	0	0	0
Community/traditional leaders	**3**	0	1	1	1	1	1
Village-Owned Enterprise (BUMDes)	**4**	0	1	0	1	0	1
PLN (State Electricity Company)	**5**	0	1	1	1	1	1
Investors / Financing Institutions	**6**	0	1	0	1	0	1
Compilation from Respondents/DM: ALL EXPERTS							

Table 3 . Interpretation of sub-elements of affected institutional sectors

Sub-elements examined	**(i)**	**Key to**	**Hierarchy**	**Sector**	**DP**	**D**
Local Government of Southwest Sumba	**1**	**2**	**3**	**3**	**5**	**4**
Local Community	**2**	**1**	**4**	**4**	**6**	**1**
Community/traditional leaders	**3**	**2**	**3**	**3**	**5**	**4**
Village-Owned Enterprise (BUMDes)	**4**	**2**	**3**	**3**	**5**	**4**
PLN (State Electricity Company)	**5**	**3**	**2**	**2**	**2**	**5**
Investors / Financial Institutions	**6**	**4**	**1**	**2**	**1**	**6**
Compilation from Respondents/DM: ALL EXPERTS						

The results of the matrix analysis in Figure 1 show that the Local Community sub-element falls into Quadrant IV (*Independent*). This sub-element functions as the primary driving force with the lowest level of dependence on other sub-elements in the development of energy-independent villages based on natural resources.

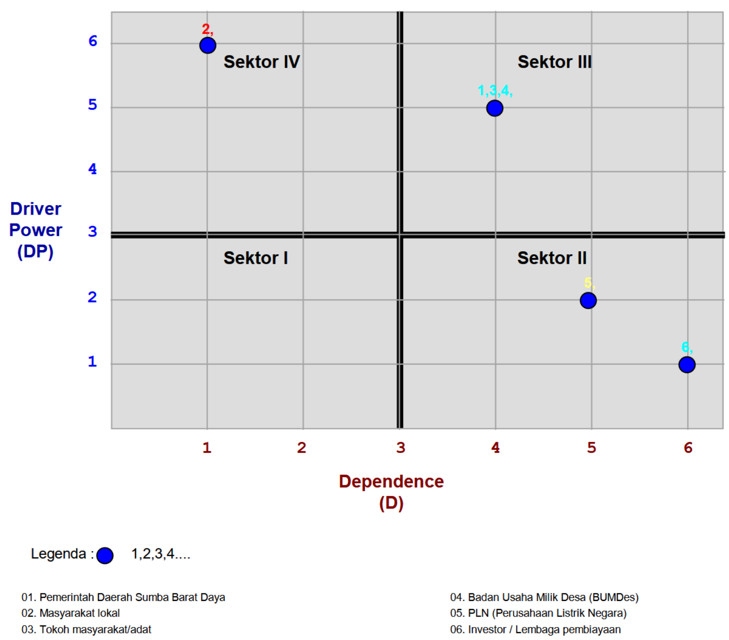


Figure 1. Scatter plot of ISM results for affected institutional sector elements

The hierarchical structure of the affected institutions or groups is presented in Figure 2. Local communities serve as the primary drivers in this system, while investors and financing institutions have a high degree of dependence on other elements in the development of energy-independent areas or villages based on renewable natural resources.

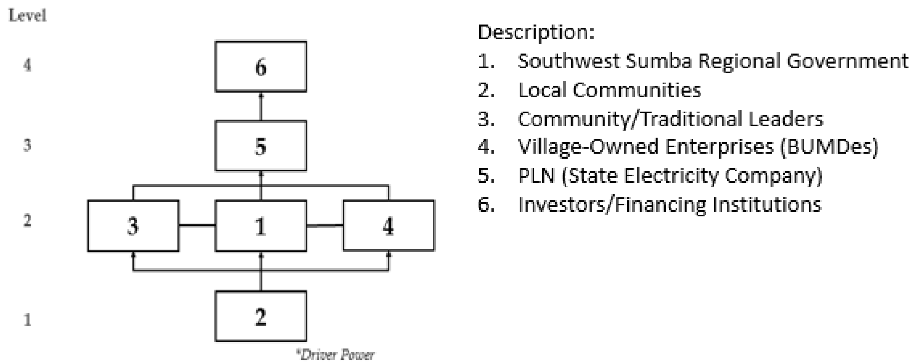


Figure 2. ISM Hierarchy of Affected Institutions or Groups

4.1.2. Key Challenges

The main constraints in the development of energy-independent communities based on renewable natural resources consist of 10 sub-elements, namely (1) Lack of public awareness and knowledge about renewable energy (mindset), (2) Lack of support from local industries regarding renewable energy components, (3) Commitment to securing low-interest financing, (4) Technical constraints on renewable energy power generation and knowledge transfer, (5) Great distances between villages, (6) Suboptimal management of Village-Owned Enterprises (BUMDes) and Village Cooperatives, (7) Production costs for renewable energy power plants that remain relatively high, (8) Vandalism against village renewable energy infrastructure, (9) Low competency of local human resources in renewable energy management (human resources are not yet ready), (10) The influence of community and traditional leaders on program acceptance.

The results of the matrix analysis show that sub-element (1), "Lack of public awareness and knowledge about renewable energy (mindset)," falls into Quadrant IV (Independent). This sub-element serves as the primary driving force with the lowest level of dependence on other sub-elements in the development of energy-independent villages based on renewable natural resources.

The hierarchical structure of the main constraint elements is presented in Figure 3. The influence of community/traditional leaders on program acceptance holds a position as the primary driver in this system. Meanwhile, there are four sub-elements in Quadrant III (Linkage) of the ISM, which function as *secondary driving forces*, namely: (6) Suboptimal management of Village-Owned Enterprises (BUMDes) and Village Cooperatives, (7) Relatively high production costs for renewable energy power plants, (9) Low competency of local human resources in renewable energy management (human resources are not yet ready), and (10) The influence of community/traditional leaders on program acceptance. These elements possess strong driving power as well as high interdependence, thereby playing a crucial role in the dynamics of developing renewable natural resource-based energy resilience zones.

© IEOM Society International

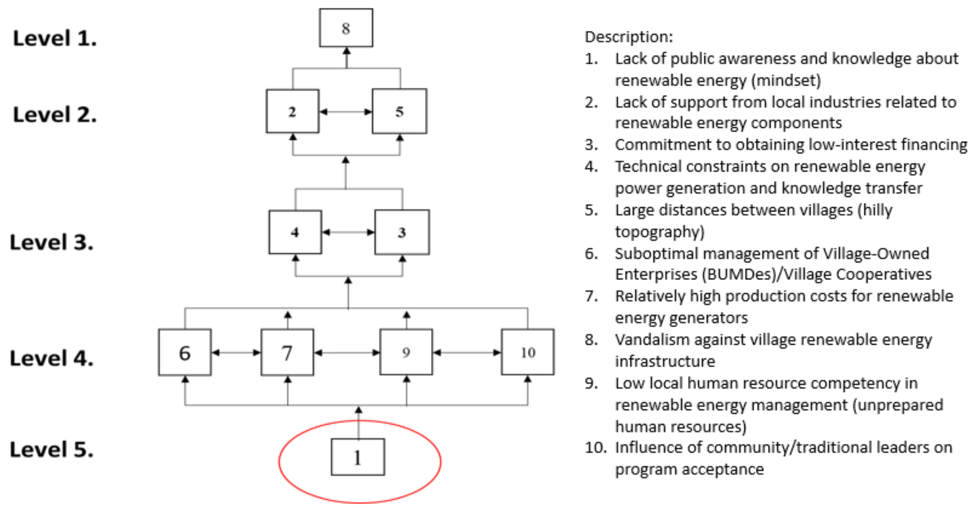


Figure 3. ISM Hierarchy of Major Constraints

4.1.3. Program Requirements (Needs)

The program requirements for the development of energy-independent communities based on renewable natural resources consist of nine sub-elements, namely: (1) Development of more efficient and affordable renewable energy technologies; (2) Capacity building for local industries in the production of renewable energy components; (3) Funding schemes that support renewable energy projects; (4) Capacity building for local human resources in renewable energy management; (5) Empowerment and revitalization programs for Village-Owned Enterprises (BUMDes) and Rural Credit Cooperatives (KUD), (6) Education and training for local communities on renewable energy, (7) Engagement and empowerment of community and traditional leaders, (8) Policies supporting the development of renewable energy and the green economy, (9) Programs for the development of supporting infrastructure between villages. The hierarchical structure of the program's key elements is presented in Figure 4. The development of more efficient and affordable renewable energy technologies serves as the primary driver within this system. Meanwhile, there are two sub-elements in Quadrant III (Linkage) of the ISM, which function as secondary drivers: (6) Education and training for local communities on renewable energy, and (7) Engagement and empowerment of community and traditional leaders. These elements possess strong driving power as well as high interdependence, thereby playing a crucial role in the dynamics of developing energy-independent regions/villages based on renewable natural resources.

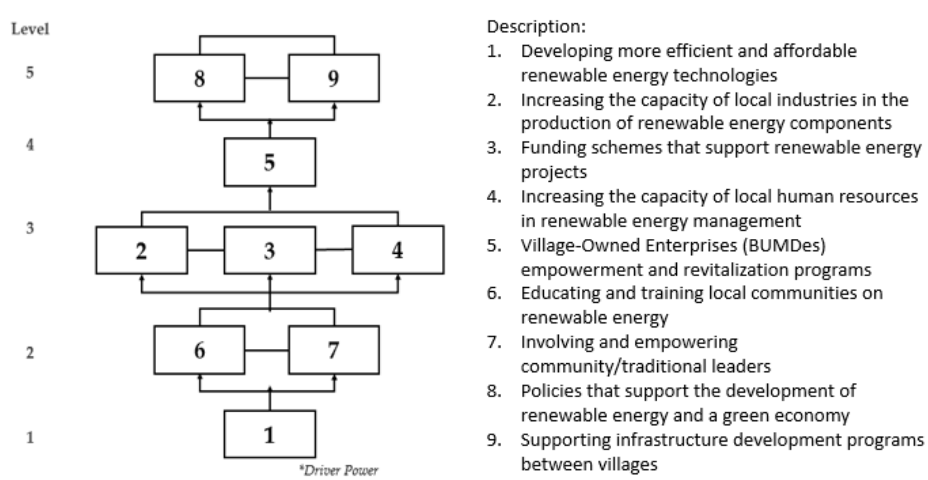


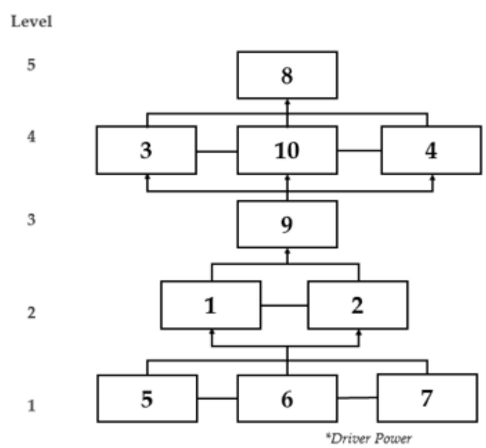
Figure 4. ISM Hierarchy of Program Needs

4.1.4. Possible Changes

The elements of change that are possible in the development of energy-independent communities based on renewable natural resources consist of 10 sub-elements, namely: (1) Increasing the electrification rate in target areas, (2) Reducing the cost of renewable energy production, (3) Increasing local industry participation in the renewable energy supply chain, (4) Green economic growth in target areas, (5) A shift in mindset and increased public acceptance of renewable energy, (6) Improved management effectiveness of BUMDes/KUD, (7) Enhanced collaboration with community and traditional leaders, (8) Reduction in acts of vandalism against renewable energy infrastructure, (9) Enhancement of local human resource competencies in the field of renewable energy, (10) Improvement of regional energy resilience and self-reliance.

The results of the matrix analysis show that the sub-elements "Change in mindset and increased public acceptance of renewable energy," "Improved management effectiveness of BUMDes/KUDs," and "Enhanced collaboration with community and traditional leaders" fall into Quadrant IV (Independent). These sub-elements serve as the primary driving force with the lowest level of dependence on other sub-elements in the development of energy-independent villages based on renewable natural resources.

The hierarchical structure of the potential change elements involved is presented in Figure 5. A shift in mindset and increased public acceptance of renewable energy, improved management effectiveness of BUMDes/KUDs, and enhanced collaboration with community and traditional leaders serve as the primary drivers in this system. Meanwhile, there are two sub-elements in Quadrant III (Linkage) of the ISM that function as secondary drivers: (1) increased electrification rates in target areas, and (2) reduced production costs for renewable energy. These elements possess strong driving power and high interdependence, making them crucial in the dynamics of developing energy-independent villages/hamlets based on renewable natural resources.



Description:
1. Increasing the electrification ratio in target areas
2. Reducing renewable energy production costs
3. Increasing local industry participation in the renewable energy supply chain
4. Green economic growth in target areas
5. Mindset change and increased public acceptance of renewable energy
6. Increasing the effectiveness of village-owned enterprise (BUMDes) management
7. Increasing collaboration with community/traditional leaders
8. Reducing vandalism against renewable energy infrastructure
9. Increasing local human resource competency in the renewable energy sector
10. Increasing regional energy resilience and independence

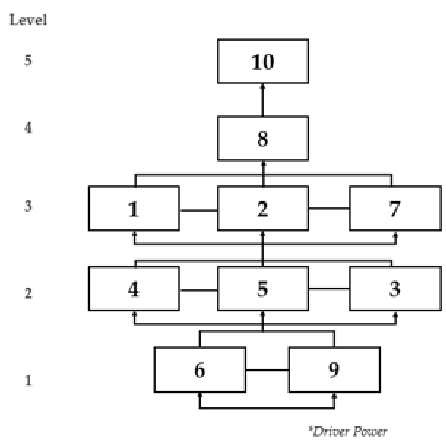
Figure 5. ISM Hierarchy of Possible Changes

4.1.5. Activities to Achieve Change

The key activities for achieving change in the development of energy-independent villages based on renewable natural resources consist of 10 sub-elements, namely: (1) Research and development of renewable energy technologies suited to local conditions; (2) Establishment of penta-helix partnerships (government, industry, academia, NGOs, and the community); (3) Design of incentive and financing schemes for renewable energy investments; (4) Training and capacity-building programs for local human resources, (5) Implementation of empowerment and mentoring programs for Village-Owned Enterprises (BUMDes) and Village Cooperatives (KUD), (6) Development of renewable energy pilot projects in villages, (7) Development of policies supporting renewable energy and the green economy, (8) Implementation of educational campaigns and public awareness initiatives, (9) Facilitating access to funding for small-to-medium-scale renewable energy projects, (10) Integrating renewable energy planning with village development programs.

The results of the analysis using the ISM system, presented as a *driver-power-dependence* matrix for activity elements aimed at achieving change, are shown in Figure 5. The matrix analysis results indicate that the sub-elements "Development of renewable energy pilot projects in villages" and "Facilitation of access to funding for small-to-medium-scale renewable energy projects" fall into Quadrant IV (Independent). These sub-elements serve as the primary and most significant driving forces, exhibiting the lowest level of dependence on other sub-elements in the development of energy-independent areas/hamlets based on renewable natural resources.

The hierarchical structure of the activity elements required to achieve the desired changes is presented in Figure 6. The development of renewable energy pilot projects in villages and the facilitation of access to funding for small- to medium-scale renewable energy projects serve as the primary drivers in this system. Meanwhile, there are three sub-elements in Quadrant III (Linkage) of the ISM, which function as secondary drivers: (4) Training and capacity-building programs for local human resources, (5) Implementation of empowerment and mentoring programs for BUMDes/KUDs, and (3) Design of incentive and financing schemes for renewable energy investments. These elements possess strong driving power as well as high interdependence, thereby playing a crucial role in the dynamics of developing energy-independent regions/villages based on renewable natural resources.



Description:
1. Research and development of renewable energy technologies tailored to local conditions
2. Establishment of penta-helix partnerships (government, industry, academia, NGOs, and communities)
3. Designing incentive and financing schemes for renewable energy investments
4. Training and capacity building programs for local human resources
5. Implementation of empowerment and mentoring programs for village-owned enterprise (BUMDes)
6. Development of renewable energy pilot projects in villages
7. Development of policies supporting renewable energy and the green economy
8. Implementation of educational campaigns and increased public awareness
9. Facilitating access to funding for small- and medium-scale renewable energy projects
10. Integration of renewable energy planning with village development programs

Figure 6. ISM Activity Hierarchy for Achieving Change

4.1.6. Institutions Involved

The institutional elements involved in the development of energy-independent areas/villages based on renewable natural resources consist of 12 sub-elements, namely: (1) the NTT Provincial Energy and Mineral Resources Agency (ESDM), (2) Local Governments (Regencies/Cities), (3) State-Owned Enterprises (SOEs) in the energy sector, (4) Research Institutions and Universities, (5) Partner Companies (private), (6) Financial Institutions and Investors, (7) Non-Governmental Organizations (NGOs) in the fields of Environment and Development, (8) Regional Agency for Development Planning, Research, and Innovation (BAPPERIDA), (9) Community Leaders/Local Traditional Leaders, (10) Village-Owned Enterprises (BUMDes)/Village Cooperatives, (11) (Extension Workers/Babinsa/Babinkamtibnas), and (12) the General Public.

The results of the matrix analysis show that the sub-elements Village-Owned Enterprises (BUMDes)/Village Cooperatives and Local Governments (Provinces and Regencies/Cities) fall into Quadrant IV (Independent). These sub-elements serve as the primary driving force with the lowest level of dependence on other sub-elements in the development of energy-independent areas/villages based on renewable natural resources.

The hierarchical structure of the institutional elements involved is presented in Figure 7. The community (12) serves as the primary driver in this system. Meanwhile, there are two sub-elements in Quadrant III (Linkage) of the ISM, which function as *the second- -driving force*, namely: (1) the NTT Provincial Energy and Mineral Resources Agency (ESDM) and (8) the Regional Development, Research, and Innovation Planning Agency (BAPPERIDA). These elements possess strong driving power as well as high interdependence, thereby playing a crucial role in the dynamics of developing an energy resilience zone based on renewable natural resources.

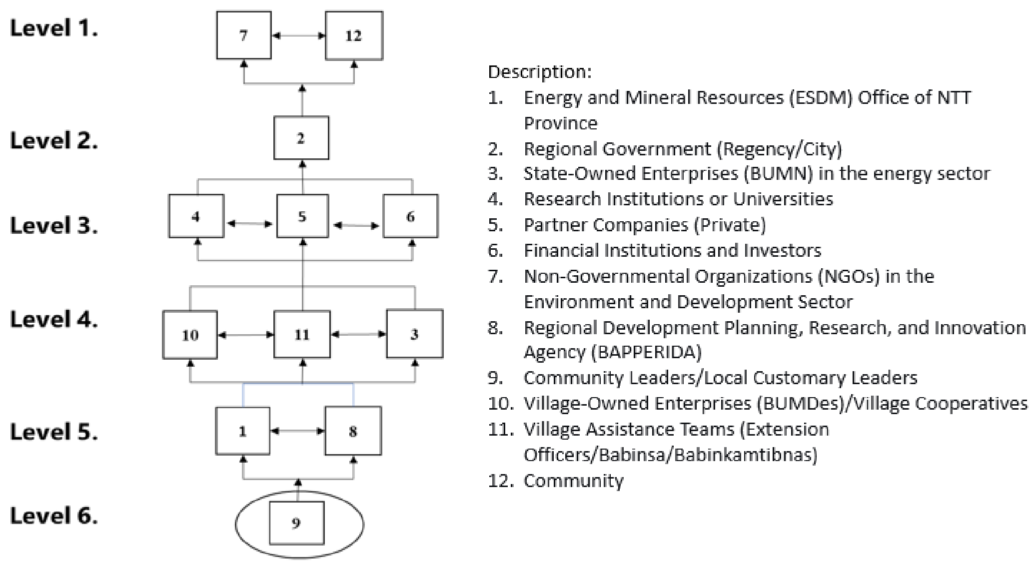


Figure 7. ISM Hierarchy of Involved Institutions

4.2. Institutional Business Model for Renewable Energy Management (PLTS) in an Energy-Self-Sufficient Area/Village

Based on research findings using the *Interpretative Structural Modeling* (ISM) method, an institutional and potential energy management model was developed for a remote area or village in Southwest Sumba, driven by a Village-Owned Enterprise (BUMDes)/ Village Unit Cooperatives (KUD) collaborating with partner companies (both private and state-owned enterprises) through CSR programs or other funding partnerships in the form of grants or mutually beneficial business arrangements. Of course, the local government and village government must provide support and play a strategic role to ensure the implementation of energy self-sufficiency can be carried out to support the progress and economy of the village community.

© IEOM Society International

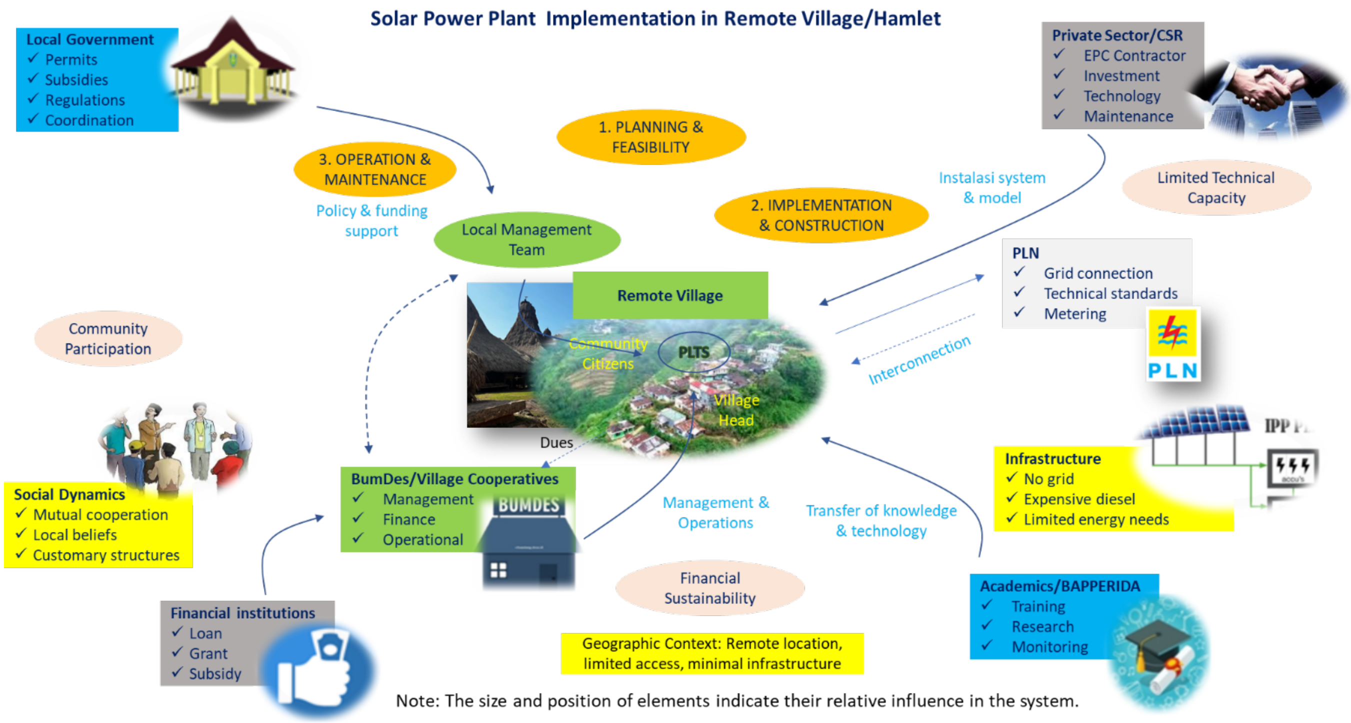


Figure 8. Institutional Model: Cooperation Framework for Managing Energy-Self-Sufficient Zones

In addition, academics, secondary and higher education institutions, and other research and development agencies must provide full support and educate the public regarding both management and the transfer of science and technology. Likewise, the local PLN office must provide full support to ensure successful implementation, and community leaders and other stakeholders are also required to ensure that energy self-reliance and economic growth continue to develop and advance (Figure 8). Based on the results of the ISM analysis, expert validation, various references, and conditions in remote villages in Southwest Sumba, the institutional business model for community-based solar power (PLTS) management can be illustrated in detail in Figure 9.

This Institutional Business Model for Community-Based Solar Power (PLTS) diagram serves as a comprehensive blueprint integrating: appropriate stakeholders with clearly defined roles. A structured and sequential implementation process requires a transparent and accountable governance framework. Funding mechanisms must be sustainable and blended. In this model, community engagement plays a crucial role as the foundation of success. This model is specifically designed for the context of Southwest Sumba and other remote areas in Indonesia, taking into account:

- Infrastructure limitations
- Limited local capacity
- High solar energy potential
- Need for energy independence
- The importance of community empowerment

The success of implementation depends on:

1. Effective collaboration among stakeholders
2. Long-term commitment from all parties
3. Adaptation to the local context
4. Continuous learning and improvement
5. Active community participation at all stages

This diagram is a living framework that can and should be evaluated and refined based on implementation experiences in the field.

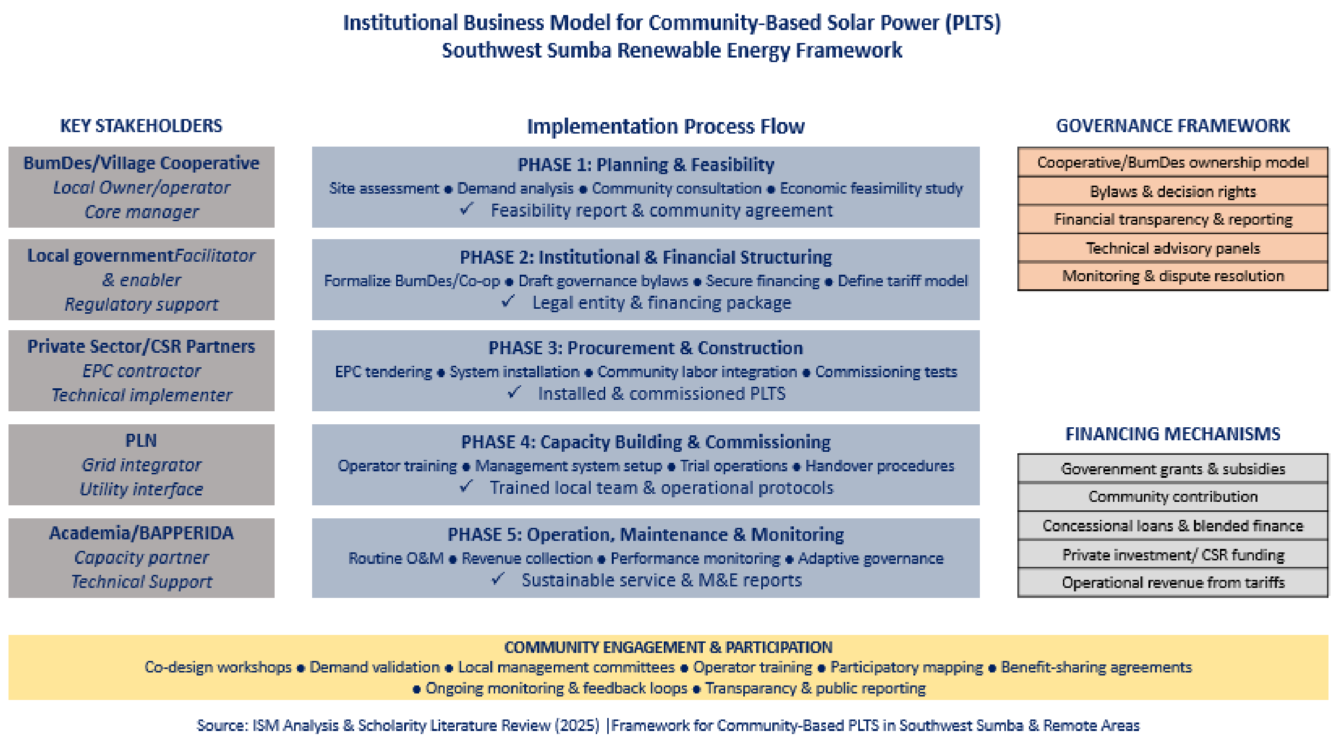


Figure 9. Institutional Business Model for Community-Based Solar Power (PLTS) Southwest Sumba Renewable Energy Framework
(Source: ISM Analysis & Scholarity Literature Review (2025) | Framework for Community-Based Solar Power Plants in Southwest Sumba and Remote Areas)

The Southwest Sumba framework addresses these challenges through a number of specific design features: positioning BumDes/cooperatives as local managers with an ownership role and clear governance; coordinating multi-stakeholder partnerships that provide complementary support; implementing a phased process with clear outcomes and accountability; establishing blended financing that combines grants, CSR funds, community contributions, and tariff revenue; and integrating sustained community engagement throughout the project's lifecycle.

This institutional business model is designed to be replicated in other remote areas of Indonesia and in similar contexts globally. The modular structure, reliance on existing institutions, documented processes, and alignment with the " " policy support adaptation to diverse contexts while maintaining core principles. However, successful replication requires context-specific adaptations, taking into account local solar resources, community organizational capacity, availability of technical partners, economic conditions, and cultural factors.

Moving forward, advancing the implementation of community-based solar energy requires coordinated action across various sectors. Policymakers must establish supportive regulatory frameworks, provide targeted financial support, build intermediary infrastructure, integrate solar energy with rural development programs, and support knowledge exchange. Practitioners must invest in institutional design, prioritize community engagement, systematically build local capacity, design for financial sustainability, and plan for adaptive management. Researchers should conduct long-term sustainability studies, comparative governance analyses, economic impact assessments, research on financing innovations, studies on technology-institutional interactions, and scalability pathway analyses.

5. Conclusions and Recommendations

5.1. Conclusion

The ISM analysis indicates that local communities and Village-Owned Enterprises (BUMDes)/Village Cooperatives are the primary drivers of renewable energy development in Southwest Sumba, supported by the local government. A shift in community mindset, capacity building for BUMDes/Village Cooperatives, and collaboration with community and traditional leaders are key to driving change. Pilot projects and facilitating access to funding are critical activities. Institutionally, Village-Owned Enterprises (BUMDes) and Village Cooperatives, along with the local government, serve as the primary drivers, supported by partner companies and other stakeholders.

The institutional business model for Southwest Sumba provides a comprehensive framework for transforming renewable energy potential into sustainable benefits for the community. By integrating technical, institutional, financial, and social dimensions, this framework offers a pathway to achieving energy independence, economic development, and improved quality of life in remote areas. Success requires sustained commitment from all stakeholders—communities, government, the private sector, utility companies, and academic institutions—working in a coordinated partnership toward the shared goals of energy access, sustainability, and community empowerment. This business model can serve as a guide for community-based energy self-sufficiency initiatives in remote villages by optimizing local renewable energy potential.

5.2. Recommendations

The Southwest Sumba Regional Government, village governments, and relevant stakeholders are advised to prioritize the development of small-scale/mini solar power plants (approximately 15 kWp for 50–100 households) as a solution to improve the electrification rate and energy security in remote areas. The development of these solar power plants must involve the active participation of local communities and village-owned enterprises (BUMDes) or rural credit cooperatives (KUD) in planning, implementation, and management. Empowerment and capacity-building programs for local communities and BUMDes/KUD managers need to be implemented to ensure the sustainability of the solar power plant project. These programs include education on renewable energy, technical training on solar power plant operations and maintenance, and strengthening the governance of BUMDes/KUD.

Involving community and traditional leaders in outreach efforts is also crucial for increasing community acceptance and participation. Further research is recommended to examine in greater depth innovative business models and financing schemes for the development of mini-solar power plants in remote areas such as Southwest Sumba. Research could focus on exploring penta-helix partnerships (government, private sector, academia, NGOs, and the community), incentive schemes, or performance-based financing models that can attract investment and ensure the long-term sustainability of mini-solar power plant projects. The results of such research would be beneficial for replicating similar projects in other regions with characteristics similar to Southwest Sumba.

References

Abid, M., Kumar, M. V., Raj, V. A., & Dhas, M. Environmental impacts of solar photovoltaic systems in the context of globalization. *Ecological Engineering and Environmental Technology*, 24. 2023.

Central Bureau of Statistics. Indonesia's quarterly gross domestic product 2019–2023. Available at Indonesia's Quarterly Gross Domestic Product 2019–2023 – Central Bureau of Statistics of Indonesia. Accessed July 5. 2023.

Databoks. Indonesia's renewable energy capacity reaches 13,000 MW in 2023, with hydropower dominating. Available online: https://databoks.katadata.co.id/datapublish/2024/01/19/kapasitas-ebt-indonesia-13-ribu-mw-pada-2023-mayoritas-energi-air. Accessed July 19. 2023.

ESDM. Indonesia's oil reserves sufficient for 9.5 years and gas reserves for 19.9 years. Press release. Available at Ministry of Energy and Mineral Resources of the Republic of Indonesia – Media Center – News Archive. Accessed March 5. 2021.

Garba, A. Biomass conversion technologies for bioenergy generation: An introduction. In *Biotechnological Applications of Biomass*. IntechOpen: London, UK. 2021.

Hamzah, Retno Martanti Endah Lestari, Hendro Sasongko, & Heirunissa. Development of an efficient renewable energy implementation for remote areas on the iconic island of Sumba. *Proceedings of the Conference on Industrial Engineering and Operations Management*, 5th Asia Pacific Conference on Industrial Engineering and Operations Management, Tokyo, Japan, September 10–12, Volume 5, pp. 1151–1163. IEOM Society International, USA. 2024.

Hamzah, Hamzah, Retno Martanti E. L., Sasongko, H., & Heirunissa. Multi-criteria analysis of renewable energy alternatives in southwest Sumba using the TOPSIS method with the 5C framework. *Decision Science Letters*, 14, 251–264. 2025. https://www.growingscience.com/dsl/Vol14/dsl_2025_11.pdf

Huerta-Reynoso, E. A., López-Aguilar, H. A., Gómez, J. A., Gómez-Méndez, M. G., & Pérez-Hernández, A. Biogas power energy production from a life cycle perspective. In *New Frontiers on Life Cycle Assessment—Theory and Application*. IntechOpen: London, UK. 2019.

Kluts, I., Wicke, B., Leemans, R., & Faaij, A. Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward. *Renewable and Sustainable Energy Reviews*, 69, 719–734. 2017.

Kumar, M. Social, economic, and environmental impacts of renewable energy resources. In *Wind Solar Hybrid Renewable Energy System*. IntechOpen: London, UK, pp. 1. 2020.

Medina, J. D. C., & Magalhães Jr, A. I. Ethanol production, current facts, future scenarios, and techno-economic assessment of different biorefinery configurations. *Bioethanol Technologies*, 23, 1–14. 2021.

Nath, S. Biotechnology and biofuels: Paving the way toward a sustainable and equitable energy future. *Discover Energy*, 4, 8. 2024.

Sarkar, S., & Fitzgerald, B. Fluid inerters for optimal vibration control of floating offshore wind turbine towers. *Engineering Structures*, 266, 114558. 2022.

Schroeder, R. E., Loots, I., Van Dijk, M., & Coetzee, G. L. Development of a procedure and tool for retrofit hydropower evaluation at South African dams. *Water SA*, 49, 230–238. 2023.

Shouman, E. R. M. Global prediction of wind energy market strategy for electricity generation. In *Modelling, Simulation and Optimisation of Wind Farms and Hybrid Systems*. IntechOpen: London, UK. 2020.

Singh, Y. D., & Satapathy, K. B. Conversion of lignocellulosic biomass to bioethanol: An overview with a focus on pretreatment. *International Journal of Engineering & Technology*, 15, 17–43. 2018.

Siciliano, G. Hydropower, climate change, and sustainable energy transitions. In *Handbook on Climate Change and Technology*. Edward Elgar Publishing: Cheltenham, UK. 2023.

Terrén-Serrano, G., & Martínez-Ramón, M. Kernel learning for intra-hour solar forecasting using infrared sky images and cloud dynamic feature extraction. *Renewable and Sustainable Energy Reviews*, 175, 113125. 2021.

Teh, J. S., Teoh, Y. H., How, H. G., Le, T. D., Jason, Y. J. J., Nguyen, H. T., & Loo, D. L. The potential of sustainable biomass producer gas as a waste-to-energy alternative in Malaysia. *Sustainability*, 13, 3877. 2021.

Worighi, I., Maach, A., Hafid, A., Hegazy, O., & Van Mierlo, J. Integrating renewable energy in smart grid systems: Architecture, virtualization, and analysis. *Sustainable Energy, Grids and Networks*, 18, 100226. 2019.

Xu, R., Zeng, Z., Pan, M., Ziegler, A. D., Holden, J., Spracklen, D. V., & Wood, E. F. A global-scale framework for hydropower development incorporating strict environmental constraints. *Nature Water*, 1, 113–122. 2023.

Yusgiantoro, P. *Energy Economics: Theory and Practice*. Jakarta: LP3ES. 2000.

© IEOM Society International