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Development of an Efficient Renewable Energy Implementation for Remote Areas in Sumba Iconic Island

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Abstract

One of the strategies that can be implemented to achieve sustainable energy self-sufficiency is to increase the use of renewable energy sources. Renewable energy sources such as solar, wind, hydropower, and geothermal have the potential to provide clean, reliable, and affordable energy. Countries that are rich in renewable energy resources can leverage these resources to reduce their reliance on fossil fuels and achieve energy self-sufficiency. Based on the background and problem formulation that has been conveyed, this study aims to develop a decision-making framework to identify and recommend optimal renewable energy solutions for Southwest Sumba, considering local conditions, resource potential, and sustainability criteria. This research employs a systematic approach to develop a decision-making framework for identifying and recommending optimal renewable energy solutions in Southwest Sumba. The study will focus on creating a structured process that considers local conditions, resource potential, and sustainability criteria. The development of a comprehensive and adaptive decision-making framework is crucial for determining optimal renewable energy solutions in remote areas such as Southwest Sumba. A multi-stage approach that integrates Multi-Criteria Decision Making (MCDM) methods such as TOPSIS, considering the criteria of Consolidated, Controllable, Continuous, Clean, and Cheap (5C), and combining expert evaluation, local knowledge, and community-based approaches, can be a key solution to addressing the challenges of renewable energy implementation. The findings of this study indicate that the developed decision-making framework has significant implications in overcoming the challenges of renewable energy implementation in remote areas like Southwest Sumba. This framework not only provides guidance for policymakers and energy planners in developing and implementing renewable energy projects but also emphasizes the importance of a thorough business feasibility study after selecting the best alternative model.

Keywords
Sustainable , energy, Renewable ,wind, hydro, Geothermal

1. Introduction

Energy has a very important role in human life because almost all human activities depend on the availability of energy (Gyawali et al. 2020). Energy is needed to operate various lighting equipment, households, transportation, and industrial machines (Salvarli and Salvarli 2020). Therefore, every country must place energy as a strategic priority in its national development. Based on data from the Central Bureau of Statistics (BPS) in 2023, the growth of a country's

Gross Domestic Product (GDP) has a positive correlation with energy availability per capita. This means that the higher the energy availability per capita, the higher a country's economic growth tends to be. The importance of energy has become increasingly recognized, especially in recent years, as the world faces challenges such as climate change, environmental degradation, and energy security (Igbokoyi and Iledare 2016) Policymakers are now focusing on developing sustainable energy systems that can meet the growing demand for energy while minimizing the impact on the environment. One of the strategies that can be implemented to achieve sustainable energy self-sufficiency is to increase the use of renewable energy sources. Renewable energy sources such as solar, wind, hydropower, and geothermal have the potential to provide clean, reliable, and affordable energy. Countries that are rich in renewable energy resources can leverage these resources to reduce their reliance on fossil fuels and achieve energy self-sufficiency (Gabbasa et al. 2013).

Increasing global energy demand and environmental concerns are the main drivers for renewable energy development (Panwar et al. 2013). Indonesia, as an archipelago located in the tropics, has enormous potential in renewable energy development due to its rich natural resources (Rozali et al. 1993). However, there are still some areas in Indonesia, especially in the Central and Eastern parts, that still experience a lack of electricity supply. One example is Southwest Sumba Island, which has an electrification ratio of 43.89%. This situation has led to a slower pace of economic development in these regions.

Research shows that Indonesia has significant potential in renewable energy, particularly in solar, wind, hydropower, and geothermal (Ihsan et al. 2021). Developing renewable energy in rural and remote areas can help improve access to electricity and support local economic development (Winanti and Purwadi 2018; Ihsan et al. 2021) However, the adoption of renewable energy in Indonesia has been relatively slow due to various challenges, such as high initial investment costs, lack of financing mechanisms, and limited infrastructure and grid integration. Seeing the potential of renewable energy owned by Sumba Island, the Ministry of Energy and Mineral Resources (ESDM) has chosen Sumba Island as an icon of new renewable energy island in Indonesia. The “Sumba Island as Iconic Island of Renewable Energy” program aims to provide reliable energy access for people on small and medium-sized islands in Indonesia, with the target of realizing 100% energy availability from renewable energy sources. The selection of Sumba Island as an icon is based on several considerations, including low access to modern energy, high dependence on diesel power plants, and abundant renewable energy potential such as water, bioenergy, wind, and sunlight (Moristanto and Setiandanu 2020).

The Forest Ecosystem Valuation Study conducted in 2015 shows that the application of green economy concepts can provide greater benefits to a country compared to conventional business models. Green economy is a new economic paradigm that aims to realize sustainable development by reducing sources of environmental damage (Purwandani and Michaud 2021). Research conducted by Syamni et al. (2021) also shows that renewable energy has great potential as a stimulus in the development of a green economy in Indonesia. Renewable energy development can provide broad economic benefits, such as the creation of new jobs, reducing greenhouse gas emissions, and encouraging technological innovation. Loiseau et al.(2016) define green economy as an economic development concept that combines aspects of economic development with environmental sustainability . In their research (Putri et al. 2023). also analysed the effect of green economy variables on Indonesia's income from 2011 to 2020.

In contrast to previous studies that focus more on renewable energy potential in general, this research specifically aims to develop a comprehensive decision-making framework for Southwest Sumba. This framework will provide a structured flow for identifying, accessing, and utilizing the most suitable renewable natural resources for energy conversion in the region. The proposed approach will systematically assess factors such as resource availability, technological feasibility, economic viability, and environmental sustainability, while considering the local context and carrying capacity. By offering a step-by-step process, this research will create a tailored roadmap for Southwest Sumba, presenting renewable energy alternatives that are optimally aligned with the region's characteristics and needs. This framework is designed to be adaptable, potentially serving as a model for other areas in Indonesia with similar potential. The results of this research are expected to not only contribute to determining the most appropriate renewable energy solutions for Southwest Sumba but also to encourage economic growth, improve local welfare, and support Indonesia's broader goals of energy independence and sustainability. Furthermore, this structured approach could inform national policy formulation and become a best practice for renewable energy development across the country.1.1 Objectives

Based on the background and problem formulation that has been conveyed, this study aims to develop a decision-making framework to identify and recommend optimal renewable energy solutions for Southwest Sumba, considering local conditions, resource potential, and sustainability criteria.

2. Literature Review

2.1 Renewable Energy

Renewable energy is an energy source that can be naturally replenished in a relatively short period of time. Renewable energy sources are becoming increasingly important due to concerns about climate change and the depletion of fossil fuels (Udemba and Philip 2022). Renewable energy is seen as a sustainable solution to meet the growing global energy demand (Ikumapayi et al. 2023). Some of the most common types of renewable energy include solar energy, wind energy, biofuels, bioenergy/biomass, and hydropower. Each of these renewable energy types has its own characteristics, advantages, and challenges.

The development and utilization of renewable energy have increased rapidly in recent years. Many countries have set ambitious targets to increase the share of renewable energy in their energy mix. Government policies, financial incentives, and technological advancements have played a crucial role in driving the growth of the renewable energy sector (Alagoz and Alghawi 2023).Although renewable energy offers many benefits, there are still some challenges that need to be addressed (Alagoz and Alghawi 2023). These challenges include high upfront costs, intermittency of energy supply, integration with existing energy infrastructure, and the need for better energy storage technologies (Aboul-Atta and Rashed 2021). Overall, renewable energy is becoming an increasingly important component in the transition towards a more sustainable and low-carbon energy system. With sustained investment, research, and policy support, renewable energy has the potential to meet a significant portion of global energy needs in the future.

2.2 Solar Energy

Solar energy is one of the most abundant and clean sources of renewable energy (Abid et al. 2023). It involves harnessing the energy from the sun and converting it into electricity using photovoltaic (PV) panels or concentrated solar power (CSP) systems (Pérez-Cutiño et al. 2022). Solar energy has seen significant growth in recent years due to falling costs, improving efficiency, and supportive government policies. The main advantages of solar energy include its low environmental impact, decentralized nature, and the ability to generate electricity in remote areas (Terrén-Serrano and Martínez-Ramón 2021). However, challenges such as intermittency, storage requirements, and the need for large land areas for utility-scale projects still need to be addressed (Abid et al. 2023).

2.3 Wind Energy

Wind energy is another rapidly growing source of renewable energy. It involves using wind turbines to capture the kinetic energy of moving air and convert it into electricity (Sarkar and Fitzgerald 2022). Wind energy has become increasingly cost-competitive with conventional energy sources, and many countries have invested heavily in wind power projects (Sobhy et al. 2022). The main advantages of wind energy include its low greenhouse gas emissions, relatively low land use requirements, and the potential for offshore wind farms (Shouman 2020). However, wind energy also faces challenges such as intermittency, noise pollution, and the impact on wildlife, particularly birds and bats (Kumar 2020).

2.4 Biofuels

Biofuels are renewable fuels produced from biomass, such as plants, algae, or organic waste. The two most common types of biofuels are bioethanol and biodiesel. Bioethanol is produced from sugar and starch crops, while biodiesel is made from vegetable oils and animal fats (Teh et al. 2021)(Singh and Satapathy 2018). Biofuels can be used as a substitute for fossil fuels in transportation and have the potential to reduce greenhouse gas emissions (Medina and Magalhães 2021). However, the sustainability of biofuels has been debated, as the production of some biofuels may compete with food production, lead to deforestation, and have other environmental impacts. Research is ongoing to develop more sustainable and efficient biofuel production methods, such as using non-food crops and algae.

2.5 Bioenergy/Biomass

Bioenergy, or biomass energy, is a form of renewable energy derived from organic matter, such as plants, agricultural waste, and municipal solid waste (Nath, 2024). Biomass can be burned directly for heat or converted into biofuels, such as biogas or syngas, which can be used for electricity generation or as transportation fuels (Huerta-Reynoso et al., 2019). Bioenergy has the potential to provide a renewable alternative to fossil fuels, and it can also help reduce greenhouse gas emissions if produced sustainably. However, the sustainability of bioenergy depends on factors such as land use, feedstock production, and the efficiency of conversion technologies (A.M. and Sharma, 2023). Proper management of biomass resources and the development of advanced conversion technologies are crucial for maximizing the benefits of bioenergy while minimizing its environmental impacts (Garba, 2021).

2.6 Hydropower

Hydropower is a mature and well-established form of renewable energy that harnesses the energy of falling or flowing water to generate electricity (Schroeder et al., 2023). It is the largest source of renewable electricity worldwide, accounting for around 16% of global electricity generation in 2020 (Schroeder et al., 2023). Hydropower plants can range from large-scale dams to small run-of-river installations. The main advantages of hydropower include its reliability, flexibility, and low operating costs (Siciliano, 2023). However, hydropower projects can also have significant environmental and social impacts, such as altering river ecosystems, displacing communities, and emitting greenhouse gases from reservoirs in some cases (A global-scale framework for hydropower development incorporating strict environmental constraints - Nature Water, 2023). Addressing these challenges and ensuring the sustainability of hydropower projects is crucial for the future development of this renewable energy source.

3. Methods

This research employs a systematic approach to develop a decision-making framework for identifying and recommending optimal renewable energy solutions in Southwest Sumba. The study, conducted from May to August 2024, will focus on creating a structured process that considers local conditions, resource potential, and sustainability criteria. The framework development will involve: (1) identifying key decision factors through literature review and expert consultations, (2) establishing evaluation criteria that reflect local needs goals, (3) designing a multi-step decision process that incorporates these factors and criteria, (4) creating tools for assessing and ranking renewable energy alternatives within the framework, and (5) validating the framework through stakeholder feedback and hypothetical case applications. Data will be collected through focus group discussions with local experts, surveys of relevant stakeholders, and review of existing renewable energy policies and best practices. The resulting framework will be designed to be adaptable and applicable for guiding renewable energy decisions in Southwest Sumba, with the potential for broader application in similar contexts.

4. Results and Discussion

4.1 Results

4.1.1 Research Process

A literature review on renewable energy decision-making reveals significant developments in evaluation methods and implementation in remote areas. Analysis of recent scientific articles indicates that Multi-Criteria Decision Making (MCDM) approaches have become the primary method for evaluating renewable energy projects. This method is capable of integrating various complex aspects such as social, technical, economic, and environmental factors that are often conflicting. For example, the DEMATEL-ANP model and Complex Proportional Assessment are used to assess the performance of renewable energy technologies based on predetermined criteria (Yazdani et al. 2018). Additionally, the Triple Bottom Line approach, which combines economically, environmentally, and socially sustainable life cycle analysis, is also applied in small-scale renewable energy planning (Barboza 2015).

Examination of case studies on renewable energy implementation in remote areas reinforces the importance of using MCDM methods in determining optimal solutions. A study in the Caribbean region utilized MCDM to evaluate technical, social, and economic criteria, concluding that solar power is the best solution for the area (Algarín et al. 2017). Meanwhile, research on the island of Thassos, Greece, employed a similar approach and concluded that a combination of wind energy, biomass, and PV systems could efficiently meet energy needs (Mourmouris & Potolias, 2013).

Identification of key factors in sustainable energy planning demonstrates that technological, economic, environmental, and social aspects must be comprehensively considered. Although technical and environmental criteria often take priority, social factors and risk assessment are increasingly being considered in the decision-making process (Algarín et al. 2017). Furthermore, the importance of economic sustainability and stakeholder involvement throughout the entire life cycle of renewable energy projects is also emphasized in the literature (Barboza 2015). These findings provide a strong foundation for the development of a comprehensive and contextual decision-making framework for renewable energy implementation in remote areas such as Southwest Sumba.

4.1.4 Renewable Energy Criteria Development

The development of renewable energy requires a comprehensive and systematic approach to ensure its sustainability and effectiveness. In this context, the 5C criteria (Consolidated, Controllable, Continue, Clean, Cheap) emerge as a holistic evaluation framework for assessing and selecting the most appropriate renewable energy sources. Each criterion within the 5C framework plays a crucial role in ensuring seamless integration, operational efficiency, and long-term sustainability of renewable energy sources.

The 'Consolidated' criterion emphasizes the importance of effective integration between renewable energy sources and existing electricity infrastructure. This is essential for maintaining grid stability, particularly given the intermittent nature of some renewable energy sources, such as wind and solar. The use of smart grid technology, as discussed by Shafiullah et al. (2010) and Yu et al. (2011), enables more efficient and stable integration through automatic control and real-time monitoring.

The 'Controllable' criterion refers to the flexibility of energy sources to be regulated according to demand. Al-Shetwi et al. (2020) highlight the importance of energy storage technologies and automated control systems in stabilizing renewable energy supplies. The 'Continue' criterion underscores the importance of long-term reliability, with Sarkar and Odyuo (2019) noting the significant role of energy storage technology in ensuring the continuity of supply.The 'Clean' aspect of renewable energy, as discussed by Shafiullah et al.(2013), is critical in global efforts to reduce greenhouse gas emissions and combat climate change. Finally, the 'Cheap' criterion ensures that renewable energy can be widely and rapidly adopted. Worighi et al. (2019) demonstrate how technologies such as smart grids can lower operational costs and enhance energy efficiency.By considering these five criteria simultaneously, developers and policymakers can make more informed and effective decisions in selecting and implementing renewable energy sources. The 5C approach ensures that renewable energy solutions are not only environmentally friendly but also reliable, efficient, and economically sustainable in the long term.

4.1.5 Business Feasibility and Barrier Analysis

Business feasibility analysis and the identification of barriers are critical components in the planning and implementation of renewable energy projects. A comprehensive, multidimensional approach to business feasibility assessment for these projects is required, encompassing aspects such as costs, benefits, risks, and potential returns on investment. The research by Arnold and Yildiz (2015) highlights the importance of utilizing Monte Carlo simulation methods to analyze the economic risks and uncertainties inherent in renewable energy technologies, particularly decentralized ones. This method enables decision-makers to account for various scenarios and variables that could influence project success. Additionally, the development of appropriate business models and the implementation of effective risk management strategies are essential to address the high transaction costs and significant financial risks that often characterize renewable energy projects.

In the process of developing and implementing renewable energy, several significant barriers have been identified, spanning economic, technological, social, political, and institutional aspects. Comparative studies by Engelken et al. (2016) reveal that one of the main obstacles, particularly in developing countries, is the high initial cost of investing in renewable energy technologies. This often deters investors, especially when faced with market and regulatory uncertainties. Richards et al. (2012) address the issue of infrastructure, specifically the limited capacity of electrical grids, as a significant technical barrier. These limitations hinder the integration of renewable energy sources such as wind and solar into existing grids, thereby restricting the scale and effectiveness of renewable energy projects.

Regulatory and policy aspects also play a crucial role in the renewable energy landscape. Findings by Herbes et al. (2017) emphasize the negative impact of unstable regulations and policy uncertainty on long-term investments in this sector. Sudden or inconsistent policy changes can result in market uncertainty, discouraging investors from making the long-term commitments required for renewable energy projects. Furthermore, Lobo (2013) highlights information barriers and knowledge limitations as significant factors impeding the widespread adoption of renewable energy technologies. A lack of understanding of these technologies among policymakers, investors, and the general public can lead to resistance to change and slow adoption of clean energy solutions.

To address these challenges, several key strategies have been proposed by researchers and practitioners in the renewable energy field. Herbes et al. (2017) stress the importance of innovation in business models as one of the primary solutions. The development of models such as public-private partnerships or community-based businesses is seen as a way to overcome investment barriers, expand access to funding, and increase public participation and acceptance of renewable energy projects. These models can help distribute risks and benefits more equitably among various stakeholders, thereby enhancing the feasibility and sustainability of projects. Burke et al. (2019) emphasize the need for clear and consistent policy and regulatory support. The implementation of supportive policies, such as well-targeted subsidies, stable feed-in tariffs, and attractive tax incentives, is crucial for providing security and certainty to investors. These policies not only help reduce financial risks for investors but also accelerate the adoption of renewable energy technologies by making these projects more competitive compared to conventional energy sources.

Engelken et al. (2016) suggest that significant investment in infrastructure strengthening is a crucial step toward overcoming technical barriers. Increasing the capacity of electrical grids and developing more efficient energy storage technologies are considered top priorities. Investment in this infrastructure will not only facilitate better integration of renewable energy sources into existing grids but also enhance the reliability and efficiency of the overall energy system.

Finally, Painuly's (2001) study underscores the importance of education and awareness-raising as a long-term strategy for overcoming knowledge and information barriers. Developing comprehensive education and training programs for various stakeholders in the energy sector, including policymakers, technicians, and the general public, is seen as a crucial step. These programs can help increase understanding of the benefits and challenges of renewable energy and build local capacity to effectively implement and manage renewable energy projects.

By thoroughly understanding the existing barriers and implementing appropriate strategies to overcome them, the development of renewable energy can be carried out more effectively and sustainably. A holistic approach that considers economic, technological, social, and policy aspects is essential to ensuring the long-term success of renewable energy project implementation. This not only helps achieve energy sustainability goals but also contributes significantly to climate change mitigation and sustainable economic development.

4.1.6 Framework Validation Process

the validation phase within the proposed framework is designed to ensure that the developed model aligns with real-world scenarios and effectively addresses the requirements of renewable energy projects. This phase consists of several steps as follows:

Simulation and Testing: Following an analysis of feasibility and business constraints, the model is tested across various hypothetical and real cases to evaluate its performance under diverse conditions. Validation encompasses not only technical feasibility but also economic and social sustainability.

Expert Review: Experts in relevant fields review the model to ensure that the assumptions, criteria, and processes utilized are valid for decision-making in renewable energy projects.

Pilot Implementation: A small-scale pilot project is implemented using recommendations generated by the model to test its functionality in real-world environments.

Validation is not a one-time process but rather iterative. After each validation cycle, the model is refined based on the feedback received, ensuring that it evolves to address the following aspects:

Accuracy: Ensuring that the recommendations align with technical and financial constraints.
Adaptability: The model must be sufficiently flexible to accommodate various geographical, economic, and policy environments.
Practicality: Insights obtained from field implementation or expert feedback are integrated to enhance the model's application in real-world situations.

Iterative refinement helps the model remain relevant and accurate in response to technological advancements, market conditions, and evolving policies over time.

4.1.7 Final Framework Presentation

The developed flow diagram begins with data and information collection to evaluate the potential for renewable energy in a specific location. The decision tree branches according to the electrification ratio of the area. In cases of low electrification ratio, an analysis of the current energy conditions is conducted, incorporating input from local experts.

Subsequently, renewable energy options are assessed using the 5C criteria (Consolidated, Controllable, Continue, Clean, Cheap). After identifying the optimal energy alternative, a business feasibility analysis is performed to determine whether the energy solution is viable for implementation. If deemed feasible, the analysis proceeds to identify potential obstacles that may arise, followed by a validation process. The final recommendation is generated at the concluding stage of this process. Each stage in the decision-making process plays a crucial role:

- Data and Information Collection: Gather all necessary data related to the energy conditions and resources in the area under review.
- Site Inspection: At this stage, the ratio of electrification is examined to determine whether the area requires immediate attention.
- Expert Assessment: Local experts and specialists in the relevant fields provide input on the current energy solutions and the potential for renewable energy in the region.
- 5C Evaluation: Renewable energy sources are evaluated based on the 5C criteria to ensure that the proposed solution meets requirements such as stability, cost-effectiveness, and environmental benefits.
- Business Feasibility Analysis: This phase evaluates the financial and technical viability of the identified renewable energy options.
- Barriers and Constraints: If deemed feasible, potential barriers such as regulatory, social, or technical issues are further analyzed.
- Model Validation: The overall framework is validated using pilot projects or simulations to ensure that the generated recommendations can withstand real-world conditions.

The developed framework is designed with a logical, iterative flow, starting with the collection of foundational data and advancing into expert-based analysis, technical evaluation (5C), and business feasibility. The iteration between identifying barriers and re-analyzing renewable energy alternatives ensures that no steps are overlooked in addressing potential issues. This structured approach enables a comprehensive assessment of whether renewable energy solutions are suitable for a particular location, while also allowing for refinement based on feedback obtained during the validation process. The developed flow is optimized for decision-making in rural or underdeveloped areas with low electrification rates, making it applicable within the context of global development goals. The complete flow diagram can be seen in Figure 1

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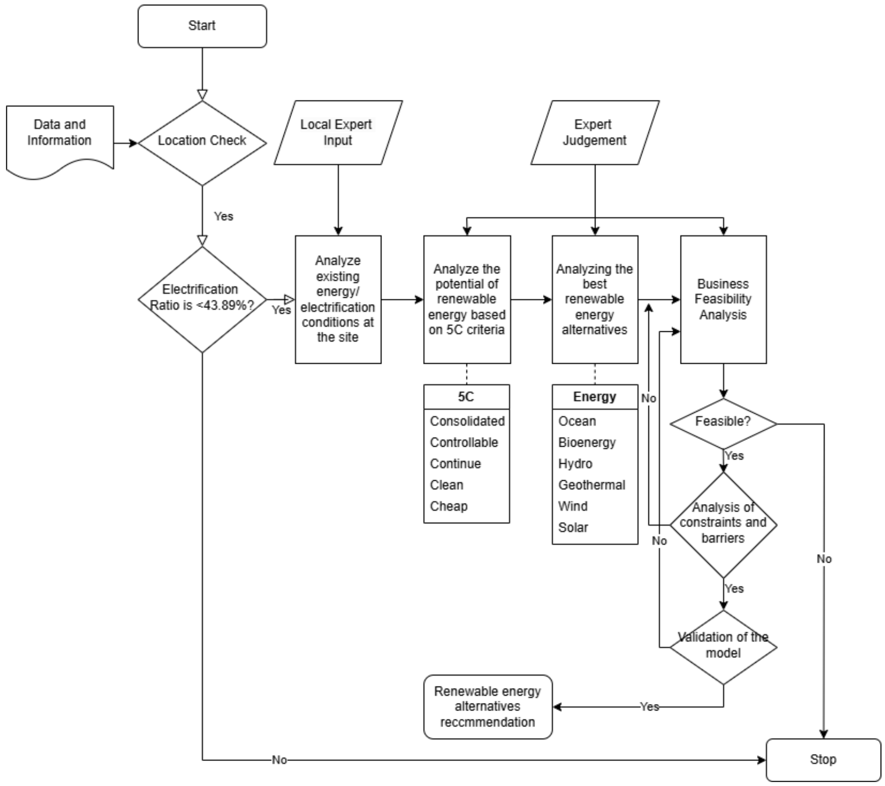

Figure 1. Decision-Making Framework To identify and recommend optimal renewable energy solutions for Southwest Sumba

5. Discussion

The development of a decision-making framework for renewable energy projects in remote areas, such as Southwest Sumba, is essential to ensure the sustainability, efficiency, and adaptability of these projects. The proposed multi-stage approach has the strength of integrating both quantitative and qualitative factors and offers flexibility for application in various contexts. Multi-Criteria Decision Making (MCDM) methods, such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), have emerged as relevant and effective approaches for evaluating and selecting renewable energy sources (Ebrahimi 2018; Lee & Chang 2018; Rathore et al. 2020; Xu et al. 2020).

TOPSIS operates by identifying the alternative that is closest to the positive ideal solution and furthest from the negative ideal solution. This method is particularly well-suited for renewable energy decision-making as it can manage conflicting criteria and provide clear solutions for decision-makers. Ebrahimi's (2018) research highlights that the fuzzy TOPSIS method is more realistic in prioritizing renewable energy technologies compared to other methods such as fuzzy PROMETHEE, as it better captures the complexity of renewable energy technologies and accounts for uncertainty in data.

The application of a comprehensive decision-making framework has the potential to significantly impact the adoption of renewable energy in Southwest Sumba. By considering technical, social, economic, and environmental aspects, this approach aligns with local development goals and existing constraints. The use of TOPSIS can help overcome challenges in implementing renewable energy in remote areas, such as limited infrastructure and high initial costs, by providing a more objective and comprehensive evaluation (Lee & Chang 2018; Xu et al. 2020).

The developed decision-making framework needs to balance data-driven decisions with expert insights. Expert judgment and local knowledge play a crucial role in renewable energy planning, especially in remote contexts such as Southwest Sumba. The integration of community-based approaches, such as community energy storage (CES), can facilitate the adoption of renewable energy by considering local contexts and reducing dependency on central grids that are often limited (Bhola et al. 2023).

The decision-making framework developed can provide guidance to policymakers and energy planners in developing and implementing renewable energy projects in remote areas. This approach also has the potential to be applied in other regions with similar challenges. By integrating technical, social, economic, and environmental aspects into the decision-making process, a more adaptive and contextualized framework can be developed to ensure the success of renewable energy projects (Ebrahimi 2018 Lee & Chang, 2018; Rathore et al. 2020; Xu et al. 2020).

In conclusion, the use of comprehensive MCDM methods such as TOPSIS, integrated with community-based approaches, expert judgment, and local knowledge, along with strong policy support, can be a key solution to addressing the challenges of renewable energy development in remote areas like Southwest Sumba. TOPSIS has proven effective in prioritizing renewable energy technologies, particularly in scenarios where multiple conflicting criteria exist, making it a prime choice for decision-making in the development and implementation of renewable energy projects across various scenarios (Ebrahimi, 2018; Rathore et al. 2020).

From the best alternative models identified using the TOPSIS method, the next step is to conduct a comprehensive business feasibility study. This study is important to ensure that the selected renewable energy project is not only technically feasible but also has the potential for economic success and long-term sustainability. Several aspects that need to be analysed in the business feasibility study include:

1. Market analysis: Evaluate energy demand in Southwest Sumba, growth potential, and customer segmentation.
2. Financial analysis: Project cash flows, calculate financial indicators such as NPV (Net Present Value), IRR (Internal Rate of Return), and payback period.
3. Risk analysis: Identify and assess various potential risks, such as technological, regulatory, and market risks.
4. Socio-economic analysis: Evaluate the project's impact on the local community, including job creation and improvements in quality of life.
5. Sustainability analysis: Ensure that the project aligns with sustainable development goals and has minimal environmental impact.

Following the comprehensive business feasibility study, the next step is to determine the most appropriate business development model for implementing the renewable energy project in Southwest Sumba. This business development model should consider the unique characteristics of remote areas, local capacities, and the long-term goals of the project. The selection of the appropriate business development model will greatly depend on the results of the business feasibility study, project characteristics, and the specific conditions in Southwest Sumba. The chosen model should be able to address major challenges such as limited access to capital, lack of local technical expertise, and the need to ensure long-term sustainability. By combining the results of the TOPSIS analysis, a comprehensive business feasibility study, and the selection of the right business development model, the renewable energy project in Southwest Sumba will have a strong foundation for achieving long-term success and sustainability. This approach will not only meet the energy needs of remote areas but also contribute to local economic development and environmental protection.

6. Conclusion

The development of a comprehensive and adaptive decision-making framework is crucial for determining optimal renewable energy solutions in remote areas such as Southwest Sumba. A multi-stage approach that integrates Multi-Criteria Decision Making (MCDM) methods such as TOPSIS, considering the criteria of Consolidated, Controllable, Continuous, Clean, and Cheap (5C), and combining expert evaluation, local knowledge, and community-based approaches, can be a key solution to addressing the challenges of renewable energy implementation.

The findings of this study indicate that the developed decision-making framework has significant implications in overcoming the challenges of renewable energy implementation in remote areas like Southwest Sumba. This framework not only provides guidance for policymakers and energy planners in developing and implementing renewable energy projects but also emphasizes the importance of a thorough business feasibility study after selecting the best alternative model.

A business feasibility study that includes market, financial, risk, socio-economic, and sustainability analysis is a crucial step to ensuring the economic success and long-term sustainability of the project. Furthermore, the determination of the appropriate business development model, such as public-private partnerships, community-based models, or hybrid approaches, must be tailored to the unique characteristics of remote areas and the results of the feasibility study.

This approach has the potential to be applied in other regions with similar challenges, but further research is needed to explore the application of this framework in a broader and more diverse context. A framework that combines TOPSIS with a business feasibility study and the selection of an appropriate business development model provides a strong foundation for achieving the long-term success and sustainability of renewable energy projects.

In conclusion, the use of comprehensive MCDM methods such as TOPSIS, integrated with community-based approaches, expert evaluation, and local knowledge, supported by thorough business feasibility studies and the selection of appropriate business development models, can be a key solution for addressing the challenges of renewable energy development in remote areas such as Southwest Sumba. This holistic approach not only meets the energy needs of remote areas but also contributes to local economic development and environmental protection, making it a model that can be adapted for various renewable energy implementation scenarios in the future.

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Biographies

Hamzah has worked in IT, MIS, and data analytics since 1995. He has also worked as a Non-Permanent Lecturer at a number of private universities in Bogor and Jakarta, as well as at IPB University. Dr. Hamzah has worked at the IPB Business School as R&D Staff and Computer Laboratory Supervisor. He has also tutored and mentored students in data analysis and processing. He is a trained strategic business analyst as well as an internationally recognized quantitative techniques expert and data analytics specialist with a global reputation in applied and quantitative research methods for over 22 years. He has worked in many institutions in Indonesia and overseas as a research specialist (Research Consultant, specialist, and Resource Person). Aside from that, it has broadened a variety of research methods, including statistical and non- statistical approaches, systems approaches, and multi-criteria decision making (MCDM). Masters/S3 students and the general public can benefit from methodology consulting services, data analysis tools, and data processing and decision-making software. He is also the founder and President Director of PT KUNCI KONSULTASI, a consulting firm that provides services such as research, data analysis, surveys, information technology, and human development. From 2016 to 2019, he lectured at the Doctoral/Masters Program in Sharia Banking Management at FEB UIN Jakarta. In addition, he teaches Applied Quantitative and Qualitative Methodology, Applied Statistics, Research Methods, and Strategic Marketing. He worked as a Permanent Expert for Human Resources and Benefits at BPKH RI from 2017 to 2018. He has been a permanent lecturer at Pakuan Bogor University's Postgraduate School and Faculty of Economics and Business since September 2019. From October 2020 to July 2023, he was the Director of the Centre for Scientific Data Bases and Processing at Pakuan University in Bogor's Faculty of Economics and Business. He has also served as Advisor to the Chairman of the Foundation at STEI Indonesia Jakarta from November 2022. Dr. Hamzah is a well- known national and worldwide speaker. He has also published books, essays, and scientific papers in national and international journals. In addition, he has provided research consultations, data analysis, seminars, and training to over 300 Masters and 302 doctorate candidates in Indonesia and overseas.

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Heirunissa was born in the city of Bogor, May 17, 1980. The author completed the Bachelor program (S1) at the Bogor Agricultural University in the Statistics study program in 2002 and completed the Postgraduate program (S2) at the same university, namely the Agribusiness Management Master study program in 2004. Currently the author is a permanent lecturer at STIE GICI as a lecturer in the main courses of Business Statistics, Supply Chain Management, Business Models, International Business, and Quality Management. Books that have been written and published include Introduction to Business Administration: Comprehensive Theory and Basic Statistics Textbook. In addition, the author is listed as a data research consultant expert team at PT Kunci Konsultasi.