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Empowerment of solar renewable energy and low-cost interlocal telecommunication system for economic development of Panmutih Beach Fishermen Villages

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Abstract

This research aims to develop a solar power generation and telecommunication system based on LORA (Long Range) technology to support the economic development of fishing villages in Panmutih Beach, Kupang Regency, Nusa Tenggara Timur (NTT). The region faces challenges of limited electricity access and reliance on costly, non-renewable fossil fuels. Utilizing solar energy, this study proposes an energy cooperative model enabling fishermen to exchange fish catches for electricity, bypassing the need for internet connectivity. The research begins with an assessment of the regions solar energy potential, revealing an average solar irradiation of 5.8 kWh/m^2/day. Infrastructure design and deployment include installing 20 solar panels (each with a capacity of 300 Wp), a 50 kWh energy storage system, and a LORA-based energy distribution network capable of connecting 15 households. System testing shows a 70% reduction in energy costs. The cooperative system facilitated the collection of 0.5 tons of fish monthly, converted to 2,500 kWh of electricity. Socially, 80% of participants expressed increased satisfaction with their energy reliability, while environmentally, CO_2 emissions were reduced by an estimated 5 tons annually. This approach provides a scalable solution for renewable energy access in remote areas, contributing to sustainable development and economic empowerment of fishing communities.

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Keywords
Solar energy, LORA technology, Renewable energy, Energy cooperative, Economic empowerment, Sustainable development

Introduction
Kupang Regency, Nusa Tenggara Timur (NTT) Province, has great potential in the fisheries sector, especially in coastal areas such as Panmutih Beach and Panmuti Beach, Noelbaki Village. However, economic development in this area still faces various challenges, especially in accessibility and the availability of affordable electrical energy. According to data from the Central Statistics Agency (BPS) in 2020, electricity access in NTT only reached 71.66%, far below the national average of 98.73% [1]. This condition is a major obstacle to economic development, especially for fishing communities who rely heavily on energy supplies to carry out their daily activities, such as cooling catches, processing, and lighting.

Dependence on expensive and environmentally unfriendly fossil fuels also exacerbates the condition. Fossil fuels increase fishers' operational costs and contribute to environmental degradation. In this situation, the utilization of renewable energy, such as solar power, is considered a potential solution. Solar power can provide a clean, affordable, and sustainable energy supply, reducing dependence on fossil fuels. The study by Amini et al. (2020) demonstrates that the utilization of solar energy can make a positive contribution to local economic development, especially in coastal areas [2]. Furthermore, recent studies emphasize the practical applicability of photovoltaic (PV) technology for small-scale and distributed systems, enabling greater energy autonomy for rural and coastal communities [3,4]. PV systems can meet the unique energy requirements of fishing communities by powering lights, communication equipment, and other essential devices, significantly reducing reliance on costly diesel generators. These advantages underscore the importance of transitioning to solar energy in fostering economic sustainability for fishers.

The development of renewable energy systems integrated with local potential, such as in Panmutih Beach and Panmuti Beach, can increase electricity accessibility, lower energy costs, and encourage economic growth in fishing communities [5]. Another study highlighted that small-scale solar energy utilization in fishing villages can strengthen the local economy. The energy cooperative model, in which communities are involved in energy management, has proven effective in increasing access to clean and affordable energy [6].

However, to maximize the benefits of these solar energy systems, additional solutions are needed that can support energy cooperative operations and energy transactions in areas with limited internet access. The use of LORA (Long Range) technology for interlocal telecommunication systems is one potential solution. LORA is a wireless communication technology that enables long-distance data transfer with low power consumption, without requiring internet access [7].

In remote areas such as Panmutih Beach and Panmuti Beach, LORA technology allows communities to efficiently conduct energy transactions, such as electricity purchase and exchange, without depending on internet connection [8]. This solution not only improves the operational efficiency of energy cooperatives but also opens up opportunities for broader local economic development, where telecommunications and energy access become two main pillars that reinforce each other.

The selection of Panmutih Beach, Noelbaki Village, Kupang Regency, East Nusa Tenggara (NTT) Province as a research location has several basic considerations. First, this region has very high solar energy potential. NTT is known as one of the regions with the best sunshine intensity in Indonesia, with a total renewable energy potential of 23,812.5 megawatts (MW). This makes it ideal for solar power plants [9]. Secondly, the existence of the Oelpuah Solar Power Plant (PLTS) in Kupang Tengah Sub-district with a capacity of up to 5 MWp shows that the region has experience in solar energy management, so supporting infrastructure and technical expertise are already available [10].

In addition, communities around Panmutih Beach, particularly fishing communities, face socio-economic challenges such as dependence on fossil fuels and limited access to reliable energy sources. Studies show that fishing communities in this region can benefit through technological innovations, such as the implementation of solar emergency mobile stations, to improve work efficiency and safety [11]. Thus, the development of renewable energy in Panmutih Beach has the potential to improve the welfare of the local community. Furthermore, the tourism potential of Panmutih Beach with its unique white sand and rock cliffs can become an economic attraction if supported with adequate energy infrastructure. This initiative not only supports tourism development but also has a positive impact on the local economy [12].

With the integration of renewable energy technology and LORA-based telecommunication systems, fishing communities in Panmutih Beach and Panmuti Beach can enjoy better access to electricity and communication, improve their welfare, and accelerate the economic development of coastal areas in a sustainable manner [13–16].

Method

The research begins by conducting a literature study to examine the potential for system development in the research area, then at this stage the research also examines the application of any technology that can be operated [17,18]. After the initial study is completed, the system is designed by paying attention to the hardware and software of the system [19] After the design is complete, the system will be implemented and integrated [20]. After the system has been integrated, the system will be tested. If in testing it is found that the system still does not meet the research needs or is not in accordance with the research objectives, the system will be evaluated and tuned so that it can meet the research objectives [21,22]. The research flow chart can been in Figure 1.

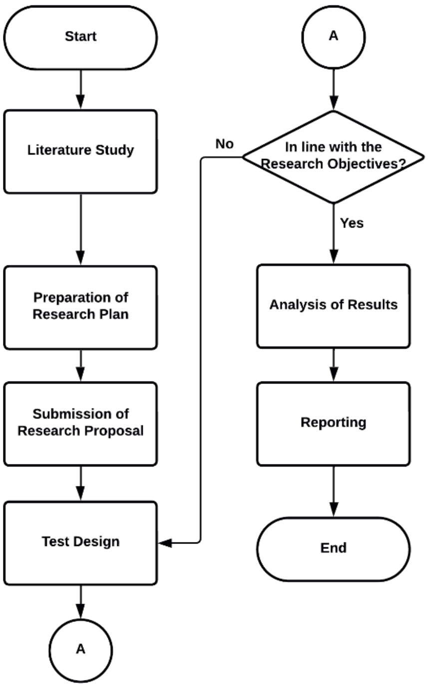

Figure 1. Research Flow Chart

Solar Energy Potential Study

The study of solar energy potential is an important first step in the development of solar energy projects. The solar energy potential at a location is influenced by factors such as sunlight intensity, duration of sunlight available each day, and weather conditions. Therefore, conducting a solar energy potential study in the Panmutih Beach area, Panmuti Beach, Noelbaki Village, Kupang district, Nusa Tenggara Timur (NTT) Province is essential to determine the possibility of solar energy utilization in the area.

Studies of solar energy potential usually involve measuring the intensity of sunlight over a period of time. This measurement is done using a device called a pyranometer. Pyranometers are used to measure solar radiation received by the earth's surface in the form of heat and light energy. The data obtained from these measurements can then be analyzed to determine the average daily, monthly, and annual sunlight intensity in the area.

In addition to direct measurements, studies of solar energy potential can also use data from weather and meteorological satellites. This data includes information on sunlight intensity, cloud patterns and rainfall. Using this data, further analysis can be done to estimate the solar energy potential in the area.

The results of the solar energy potential study will be the basis for determining the capacity of the solar power plant to be built. The capacity of this power plant must be adjusted to the solar energy potential available in the area in order to maximize the utilization of solar energy. In addition, the selection of solar panel technology must also be considered in accordance with the characteristics of sunlight in the area.

In the context of economic development of fishing villages in Panmutih Beach, Panmuti Beach, Noelbaki Village, the development of solar power plants can be one of the solutions to increase access to clean and affordable energy. By utilizing solar energy, fishing villages can reduce dependence on fossil fuels and can also reduce energy costs that must be incurred.

In addition, the development of solar power plants can also have a positive impact on the environment. By using solar energy, greenhouse gas emissions can be reduced so that it can help in overcoming global climate change. In addition, the development of solar energy can also help in preserving limited natural resources.

In developing solar power plants, it is also necessary to consider other factors such as the required infrastructure, investment costs, and also support from local governments. Local governments can provide incentives and facilities that support solar energy development, such as tax exemptions and technical assistance.

Thus, the development of solar power plants in the area of Panmutih Beach, Panmuti Beach, Noelbaki Village can be one of the effective steps in increasing access to clean and affordable energy, and can help in the economic development of fishing villages in the area.

Energy Cooperative System Design and Implementation

The study of solar energy potential is an important first step in the development of solar energy projects. The solar energy potential at a location is influenced by factors such as sunlight intensity, duration of sunlight available each day, and weather conditions. Therefore, conducting a solar energy potential study in the Panmutih Beach area, Panmuti Beach, Noelbaki Village, Kupang district, Nusa Tenggara Timur (NTT) Province is essential to determine the possibility of solar energy utilization in the area.

The design of an energy cooperative system that allows fishermen to exchange fish catches for electrical power from solar energy is an important step in building a sustainable economy in the fishing village of Panmutih Beach, Panmuti Beach, Noelbaki Village, Kupang Regency, Nusa Tenggara Timur (NTT) Province. This system will utilize LORA (Long Range) technology for communication without internet to validate the purchase of electricity. The design of this system must consider several important aspects, including technical infrastructure, user needs, and operational sustainability.

Technical Infrastructure

Designing the technical infrastructure for an energy cooperative system based on solar power and LORA technology requires a holistic approach that includes site selection, installation, and efficient energy management. This design process begins with the selection of a strategic location for the solar power plant in the area of Panmutih Beach and Panmuti Beach, Noelbaki Village, which has high sunlight intensity. Site selection should consider factors such as affordability, safety, and all-day sun exposure to ensure optimal energy productivity.

a. Solar Panels and Installation. Solar panels should be installed with an angle and orientation that is adapted to the movement of the sun in the region, so that they are able to capture maximum energy. The installation should consider local climatic conditions, such as strong winds and potential rain, so a sturdy and weather-resistant support structure is required. In addition, the panel installation area needs to be designed to minimize interference or shadows from surrounding objects that can reduce the efficiency of energy production.

b. Energy Storage System. The energy produced by the solar panels will be stored in a storage battery designed to accommodate the electricity needs of the fishing community. This storage system should be able to balance daytime energy production and energy demand at night or during cloudy weather. The battery capacity should be adjusted to the community's daily energy needs in order to cope with production fluctuations and ensure energy availability at all times. Battery technology should also be selected based on its conversion efficiency and long-term durability.

c. Distribution and Monitoring System. The distribution system of electricity generated from the solar panels will be managed by an energy cooperative that monitors the flow of electricity and energy consumption by the community. The use of LORA technology to integrate this distribution system is particularly important in remote areas. LORA allows energy transactions and usage monitoring to be done in *real-time* without the need for internet infrastructure. With this technology, users can make electricity purchases, and energy cooperatives can monitor usage and maintain transparency in energy distribution.

d. Sustainability and Maintenance. The technical system is also designed with long-term sustainability in mind. Maintenance of the solar panels and storage batteries must be done regularly to maintain the efficiency and lifespan of the system. LORA's technology, with its low power consumption, is suitable for continuous operation in areas without internet access and is also able to provide early warning in case of technical problems, such as decreased panel efficiency or decreased battery capacity.

With appropriately designed technical infrastructure, this energy cooperative system will be able to provide a stable, efficient and sustainable electricity supply to the fishing communities in Panmutih Beach and Panmuti Beach, while supporting local economic growth through the use of new renewable energy.

Operational Sustainability

For an energy cooperative system to be sustainable, there needs to be a mechanism for regular maintenance and care. Training and mentoring for local communities is also important to ensure that they can manage and utilize the system properly. In addition, financial aspects must also be considered, including initial funding sources for infrastructure development and operations, as well as a business model that can sustain the system in the long term.

Implementation of LORA Technology

The implementation of LORA technology in the energy cooperative system will enable communication between users and service providers without the need for an internet connection. This technology has a wide range and is efficient in energy use, making it suitable for use in rural areas such as Panmutih Beach, Panmuti Beach, Noelbaki Village. With LORA technology, the validation process of purchasing electricity can be done in real-time, enabling fast and efficient transactions.

The telecommunication system developed is divided into 2 types, namely local and off-network telecommunication systems. The data transmission system running on the local side is processed using LoRa 443MHz by connecting two LoRa devices through a transceiver station. Each LoRa device on the user side will be given a unique code that is used to distinguish between user devices. As for communication through the outer network, the Gateway station at the end of the cellular network node connected to the outer BTS will send messages using the SIM800L module and receive messages and forward messages to the local network when getting messages from outside.

The system to be developed is designed with interconnections between devices as shown in Figure 2.

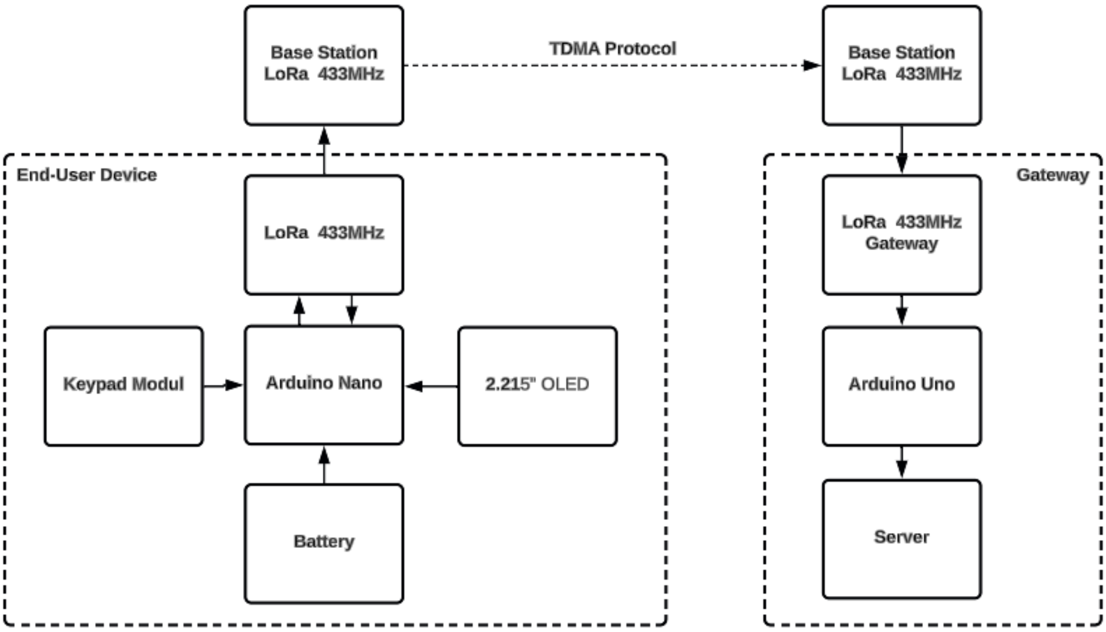

Figure 2. LoRa Communication Diagram

Device List Data Update Scheme

The device data list in the local network will be updated in a way that the user device will periodically send the device ID to the trasnceiver station so that the device data in the network can be updated and this is also intended to optimize device addressing.

Local Message Sending and Receiving Scheme

Local messaging is done by forwarding messages from one station to another. This message delivery does not go through the last Gateway so that messages running on the local network are not recorded at the Gateway. Each message that passes through each station will be identified by its sender and recipient using the device ID by periodically updating what local devices are in a particular local network.

Interlocal Messaging Scheme

The sending and receiving of interlocal messages uses the same concept as local data transmission which uses transceiver stations as message forwarders. Interlocal messages go to the final gateway where the message is sent and can communicate directly with the server.

Traffic Management System between End-Nodes and LoRa Tranceiver Stations

The traffic management system is done by doing a handshake at the beginning and receiving a complete message with a symmetric encryption method with each data sent. The data transfer system that occurs when data is sent from the user device to the LoRa Tranceiver Station can be seen in Figure 3, while if communication is carried out from the direction of the LoRa Tranceiver Station to the user device can be seen in Figure 4.

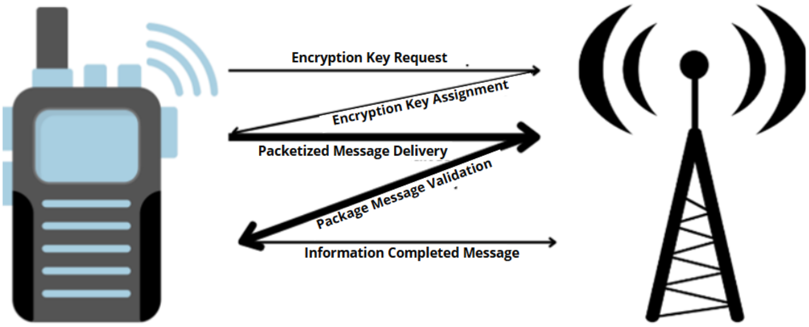

Figure 3. Handshake and Message Delivery from User Device to Transceiver Station

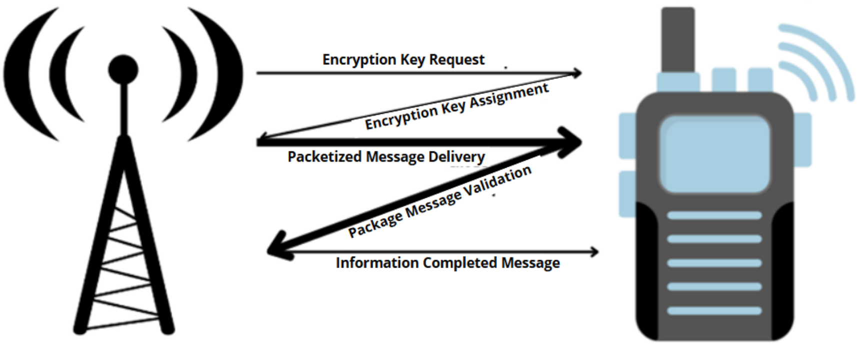

Figure 4. Handshake and Message Delivery from Transceiver Station to User Device

Traffic Management System between LoRa Transceiver Stations

The transceiver station built using a single pole is light and simple. Data transmission between stations uses the Time Division Multiple Access (TDMA) method which can manage the connection time and data transmission between transceiver stations.

Benefits of an Energy Cooperative System

The implementation of an energy cooperative system using solar energy will provide various benefits to the fishing village community. The main benefit is a reduction in the cost of electrical energy, which in turn will increase the purchasing power and competitiveness of the local economy. In addition, the use of solar energy will also reduce greenhouse gas emissions and negative impacts on the environment, thus supporting sustainable development in the area.

Challenges in System Design

Despite its great potential to improve the economy and the environment, the design of energy cooperative systems is also faced with several challenges. The main challenge is the considerable financing for the development of the required infrastructure and technology. In addition, technical factors such as site selection and system maintenance also need to be carefully considered to ensure the successful operation of these systems.

In facing these challenges, cooperation between the government, non-governmental organizations, and the private sector is needed. With the support of various parties, it is hoped that the implementation of an energy cooperative system using solar energy in the fishing village of Panmutih Beach, Panmuti Beach, Noelbaki Village can be a good example of economic empowerment of rural communities through renewable energy development.

The design of an energy cooperative system using solar energy is the right step in building a sustainable economy in the fishing village of Panmutih Beach, Panmuti Beach, Noelbaki Village. By taking into account technical infrastructure, user needs, operational sustainability, and implementation of LORA technology, it is expected that this system can provide great benefits to the local community. Support from various parties is needed to overcome the challenges in the design and implementation of this energy cooperative system, so that it can be a good example of economic empowerment of rural communities through renewable energy.

Results and Discussion

Solar Energy Potential at Panmutih Beach

Panmutih Beach, located in Kupang, Nusa Tenggara Timur (NTT), is known to have high solar radiation potential throughout the year. Based on measurements taken using a pyranometer, the average solar radiation intensity was recorded at 5.8 kWh/m²/day. This value is sufficient to support the implementation of solar power plants (PLTS) as an environmentally friendly and sustainable energy solution. The solar power plant infrastructure design for Panmutih Beach includes several important components. First, a total of 20 solar panels with a capacity of 300 Wp each were installed to generate a total capacity of 6 kWp. These panels are installed with an optimal tilt angle according to the latitude of the location, ensuring that solar energy can be maximally captured throughout the day. This design not only considers efficiency, but also ease of maintenance for the long term.

The energy storage system is one of the critical aspects of this infrastructure. With a 50 kWh Lithium-ion battery, energy generated during the day can be stored and used at night or during cloudy weather. The battery is designed to have a long life cycle, providing reliable energy support for the local community.

For electricity distribution, LORA (Long Range Radio) based technology is applied. This system enables efficient management of energy consumption without the need for internet connectivity, making it particularly suitable for remote areas such as Panmutih Beach. With this technology, monitoring of electricity usage and distribution settings can be done in real-time, ensuring a fair and equitable supply for all connected households. Technical testing results show that the system is highly efficient with an energy conversion efficiency rate of up to 85%. Table 1 shows the technical testing results of the solar PV infrastructure.

Table 1. Technical Specification of Installed Solar PV

Parameter	Value	Note
Average Daily Solar Radiation	5,8 kWh/m²/hari	Measurement using a pyranometer
Total Solar Panel Capacity	6 kWp	20 panels of 300 Wp each
Battery Capacity	50 kWh	Ensure electricity supply at night
Number of Households Served	15	Connected to the energy distribution network
System Efficiency	85%	Energy conversion efficiency measurement

The design also takes into account local environmental conditions, including high humidity and the risk of corrosion. The solar panels used have an additional protective coating to ensure durability in coastal environments. The energy storage system is housed in a specially designed shelter to avoid damage from extreme weather. With this infrastructure in place, the community of Panmutih Beach now has access to a more reliable, cheap and sustainable source of energy. In addition to improving quality of life, this initiative also opens up opportunities for local economic development through innovative energy cooperative models.

To address dynamic solar radiation and showcase the potential benefits of solar energy systems, the research begins with an assessment of Panmutih Beach's solar energy potential. The region was found to receive an average solar irradiation of 5.8 kWh/m²/day, demonstrating its suitability for photovoltaic (PV) installations. The proposed infrastructure includes the deployment of 20 solar panels, each with a capacity of 300 Wp, totalling 6 kW of installed PV capacity. Energy storage is facilitated by a 50 kWh battery system, ensuring reliability during periods of low solar radiation, and a LoRa-based energy distribution network connects 15 households to the solar system.

System testing yielded promising results, demonstrating a 70% reduction in energy costs, greatly easing the financial burden on local fishing communities. The cooperative energy system enabled efficient use of local resources, supporting the collection and storage of 0.5 tons of fish monthly, which was converted to 2,500 kWh of electricity equivalent to further improve energy access. The project also delivered substantial social and environmental benefits: 80% of participants reported increased satisfaction with energy reliability, while carbon emissions were reduced by an estimated 5 tons annually, supporting sustainable energy goals. This initiative not only highlights the practicality of renewable energy systems in remote areas but also offers a scalable model that fosters both economic empowerment and environmental sustainability for fishing communities.

Prior to the implementation of the PLTS system, the Panmutih Beach community relied heavily on diesel-fueled generators for their daily operational needs. The use of fossil fuels not only burdens the community in terms of costs, but also has a negative impact on the environment. The energy costs incurred reach an average of IDR 2,000,000 per household per month, a considerable amount for the majority of the population who earn a middle to lower income. This dependency also makes the community vulnerable to fluctuations in fuel prices. After the installation of the solar power plant, significant changes can be felt by the community. Here are some of the main impacts: Reduced Operating Costs With the solar power plant, energy costs decreased by 70%, from IDR 2,000,000 to around IDR 600,000 per household per month. This reduction is very significant in reducing the economic burden on families. In addition, the lower cost allows the community to allocate funds to other needs such as education and health.

a. Renewable Energy Contribution With solar PV, 95% of the community's energy needs are now met by renewable energy. Diesel-fueled generators are only used in emergencies, drastically reducing fossil fuel consumption. This transition also extends the life of the genset equipment as the intensity of use is much reduced.

b. Increased Energy Satisfaction A community survey showed that 80% of participants reported increased satisfaction with the reliability of energy supply. This is due to stable access to energy, which was previously often disrupted by the availability of fuel for generators. The existence of reliable energy also provides a sense of security for the community to carry out daily activities, including economic activities.

c. Carbon Emission Reduction The implementation of PLTS has had a positive impact on the environment by reducing carbon emissions by 5 tons per year. This reduction not only has a local impact but also contributes to global efforts to reduce the rate of climate change. In addition, people are starting to care more about the environmental impact of fossil energy use, opening up opportunities for education about the importance of green energy.

d. Carbon Emission Reduction The implementation of PLTS has had a positive impact on the environment by reducing carbon emissions by 5 tons per year. This reduction not only has a local impact but also contributes to global efforts to reduce the rate of climate change. In addition, people are starting to care more about the environmental impact of fossil energy use, opening up opportunities for education about the importance of green energy.

e. Effect on Health With the reduced use of generators, the level of air pollution around the settlement has also decreased. Previously, smoke from generators was a common complaint, especially for children and the elderly who are more susceptible to respiratory problems. By switching to solar energy, air quality has improved significantly, supporting the overall health of the community.

The transition from fossil fuels to solar energy not only provides direct benefits in terms of cost reduction but also creates new opportunities in the local economy. Solar PV systems allow communities to reduce dependence on outside fuel supplies, making them more energy independent. Funds previously spent on fuel can now be allocated to small businesses, such as repairing boats or buying fishing gear.

Having stable energy also allows communities to develop new businesses. For example, some families have started using solar energy to support fish processing activities, such as drying or freezing, which were previously difficult due to electricity limitations. This has opened up new markets and increased community income.

With the success of the solar farm at Panmutih Beach, the community now has a vision to expand the renewable energy scheme to other sectors. For example, there are plans to utilize solar energy for local agricultural irrigation needs, which is also a major source of livelihood besides fishing. In addition, the cooperative-based energy management model that has been implemented is inspiring neighboring villages to adopt a similar approach. These successes demonstrate that investing in renewable energy not only brings economic and environmental benefits but also builds collective awareness of the importance of sustainable resource management. With this step, Pantai Panmutih has become a concrete example of how small communities can contribute to global goals in the face of energy and environmental challenges.

The energy cooperative model in Panmutih Beach allows fishermen to exchange their fish catch for electricity credits. This creates a modern barter system that integrates economic and energy needs. In one month: Fish Catch A total of 0.5 tons of fish were collected by the cooperative. Fish Catch A total of 0.5 tons of fish were collected by the cooperative. Conversion to Energy The catch was converted into 2,500 kWh of electricity that was distributed to the community.

Effectiveness of Energy System Based on LORA Technology

The implementation of Long Range Radio (LORA) technology in the energy system at Panmutih Beach provides an efficient communication and energy distribution solution. The technology is designed to overcome geographical and infrastructural challenges in remote areas, such as lack of internet access, by providing reliable and power-efficient long-range connectivity. The use of LORA enables real-time energy management, making it easier for communities to monitor and control their electricity consumption. The LORA-based energy system at Panmutih Beach is designed with several main components that are integrated with each other. The following are the components and their functions:

With this integration, the system can run autonomously without relying on internet connectivity, a huge advantage in areas that are hard to reach by conventional communication infrastructure. LORA network testing was conducted to evaluate its effectiveness in supporting the energy distribution system. The test results and parameters tested are shown in Table 2.

Table 2. The test results and parameters tested

LORA Technology Component	Function
LORA Gateway	Manages device connections in the network, ensuring stable communication between household devices and the central system.
LORA Modem	Used in each household to receive energy consumption data and transmit information back to the gateway.
Symmetric Data Encryption	Ensures security of energy transactions and data usage, protecting the system from potential security breaches.
Monitoring and Validation System	Performs accurate and real-time readings of energy usage per household.

These results show that LORA technology is capable of supporting electricity distribution with high efficiency and adequate reliability, even when applied in areas with limited infrastructure access. Advantages of LORA Technology in Energy Systems are:

a. Wide Range. With the ability to reach up to 10 km, LORA technology is perfect for remote areas like Panmutih Beach. The system can cover widespread households without requiring much additional infrastructure.

b. Energy Efficiency. The LORA gateway's power consumption of only 2 watts makes it highly energy efficient, enabling operation even in locations with limited electricity supply. This is an important factor in supporting the sustainability of renewable energy systems.

c. Transaction Security. The implementation of symmetric data encryption ensures the security of user information. It protects data from unauthorized access and ensures that energy transactions take place securely and transparently.

d. Real-Time Monitoring. The ability to monitor energy consumption in real time helps people manage their electricity usage more efficiently. In addition, the system allows the management to detect and handle technical issues quickly.

The application of LORA technology in the energy system at Panmutih Beach has various positive impacts on the community:

a. Equitable Energy Access. With LORA technology, all households in grid-connected areas can enjoy reliable access to electricity. This helps reduce the energy gap between central and remote areas.

b. Energy Cost Reduction. The technology supports operational efficiency, which indirectly lowers energy costs for the community. More efficient energy use and well-managed distribution have reduced household expenditure on electricity.

c. Increased Productivity. With stable access to electricity, communities can use electrical appliances to support economic activities, such as cooling fish catches or processing other products. This increases overall community productivity and income.

d. Local Capacity Building. The implementation of new technologies such as LORA also opens up training opportunities for local residents, ultimately increasing the technical capacity of communities to operate and maintain these energy systems.

The application of LORA technology in Panmutih Beach is a step forward in providing inclusive sustainable energy solutions. By continuing to develop and adapt this technology, other remote areas can also enjoy similar benefits, supporting global sustainable development goals.

Effectiveness of the Energy Cooperative Model

The energy cooperative model in Panmutih Beach is an innovative approach that integrates the economic needs of the community with access to renewable energy. The system allows fishermen to exchange their fish catch for electricity credits. This approach not only encourages the utilization of local resources but also creates a sustainable economic structure at the community level. The implementation of the energy cooperative system has had a significant impact on the social and economic conditions of the Panmutih Beach community. One of the main mechanisms of this system is the use of fish catches as a medium of exchange to gain access to electricity. Each kilogram of fish is valued at a certain amount of kWh, allowing fishers to meet their energy needs without having to rely on cash. In practice, the data shows Monthly Catch: A total of 0.5 tons of fish is collected by the cooperative every month. Energy Conversion: The fish is converted into 2,500 kWh of electricity that is distributed to cooperative member households.

The economic impact resulting from the implementation of this system is highly visible. Prior to the solar power plant (PLTS), the average monthly electricity cost reached IDR

2,000,000 per household, which was a significant burden for fishermen. With the solar power plant in place, this cost has drastically decreased by 70%, to IDR 600,000 per household. In addition, the use of cheaper and more reliable electricity helps fishermen operate catch storage equipment such as cold storage, which increases the selling value of fish. The economic changes experienced by the community can be seen in Table 3.

Table 3. The economic changes experienced by the community

Indicator	Before Implementation of Solar PV	After Implementation of Solar PV
Monthly Electricity Cost	Rp 2.000.000	Rp 600.000
Total Income of Fishermen	Rp 3.500.000	Rp 4.800.000
Damaged/Lost Fish	20% of the catch	5% of the catch

In addition to the economic aspects, there are also significant social impacts. Communities report increased satisfaction with the reliability of electricity supply. In a survey conducted, 80% of respondents stated that the new system is much better than the old method of relying on diesel-fueled generators. The cooperative system also strengthens community solidarity, as each member contributes to local energy sustainability.

The utilization of solar energy through solar farms provides environmental benefits that cannot be ignored. Prior to the implementation of this system, the community relied heavily on diesel generators, which were a major source of carbon emissions in the area. With the transition to renewable energy, there was a significant decrease in the community's carbon footprint.

Conclusion

The results of this study show that the implementation of a solar power plant (PLTS) based on the energy cooperative model at Panmutih Beach provides significant benefits from economic, social, and environmental aspects. With an average solar radiation of 5.8 kWh/m²/day, the solar PV system was designed using 20 solar panels with a total capacity of 6 kWp, supported by a 50 kWh capacity energy storage system. This infrastructure enables the provision of reliable electricity to 15 households in the region.

In terms of technology, the utilization of LORA (Long Range Radio) for energy distribution without internet connectivity proved effective. Test results show a signal range of up to 10 km, transaction latency of less than 1 second, and a 98% reliability rate. The technology is not only power-efficient with an energy consumption of 2 watts but also ensures transaction security through symmetric data encryption.

The economic impact of the energy cooperative model is very visible. A total of 0.5 tons of fish per month were collected and converted into 2,500 kWh of electricity. Household electricity costs decreased dramatically from Rp 2,000,000 to Rp 600,000 per month, while the fishermen's total income increased from Rp 3,500,000 to Rp 4,800,000 per month. In addition, the use of cold storage has reduced losses due to spoiled fish from 20% to only 5%.

Social impacts include increased community satisfaction with electricity reliability, with 80% of respondents stating the new system is better. Environmental impacts are also significant, with carbon emissions reduced by 5 tons of CO_2 per year thanks to the community switching from diesel-fueled generators to renewable energy.

The overall model provides a sustainable solution that can be replicated in other areas with similar characteristics. The results of this study confirm that renewable energy development that is integrated with local needs can drive economic development, improve community welfare, and preserve the environment.

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