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Challenges in Water Energy Development for Energy Security in Aceh

Razali Thaib[1,a*], Zulfan[1,b], Ichsan Setiawan[2,c], Ayana Rizki[3,d]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Syiah Kuala, Aceh, Indonesia

[2]Department of Marine Science, Marine Science and Fisheries Faculty, Universitas Syiah Kuala, Darussalam, Banda Aceh. Indonesia.

[3]Fishing and Navigation Vessel Laboratory, Marine and Fisheries Faculty, Universitas Syiah Kuala, Darussalam, Banda Aceh. Indonesia.

[a]razalithaib@usk.ac.id, [b]zulfanstmt@usk.ac.id, [c]ichsansetiawan@usk.ac.id, [d]ayanarizki1@gmail.com
*razalithaib@usk.ac.id

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Abstract. Aceh has great potential for the development of hydropower as a sustainable energy source. However, a number of challenges must be overcome to realize this potential and ensure energy stability in the region. The study was conducted through interviews using questionnaires, and literature studies from various sources. The main causes are deteriorating infrastructure, transportation difficulties, local technology and education problems, and environmental damage due to energy infrastructure development. In addition, weak regulations, varying community standards and limits, climate change, and political stability and security are obstacles to energy development in Aceh. The purpose of this study is to identify and analyze these challenges and provide strategic recommendations to mitigate the associated hazards. Hydropower development can be optimized to support energy security in Aceh with the government, private sector, local communities, and experts taking a collaborative approach.

Introduction

The potential for hydropower in Aceh is very large considering the geographical conditions, high rainfall, and the existence of large rivers that have the potential for the construction of Hydroelectric Power Plants. Most countries aiming to replace traditional energy sources with renewable ones have begun making large investments in this field. Since renewable energy requires significant investment, evaluating investment risks is crucial for making sound decisions [1]. Factors such as technological developments, industrialization, and population growth have caused the world's energy demand to continue increasing, while available resources are insufficient to meet these needs. Consequently, the search for alternative energy sources has accelerated, leading many countries to focus on renewable energy. In addition to research and development in new renewable energy technologies, building an effective socialization program is essential. This requires a solid decision-making framework, which this study provides by establishing criteria and evaluating their importance using the fuzzy analytical hierarchy process (AHP) method [2].

Renewable energy is one of the most popular alternatives to traditional energy sources. In Indonesia, renewable energy is available in the form of solar power, hydropower, geothermal energy, wind energy, and biomass. Each type of renewable energy has its own advantages and disadvantages, making it important to select the most appropriate source to maximize benefits. A selection methodology based on fuzzy AHP is proposed, which introduces a novel procedure for gathering expert opinions. Several selection criteria suitable for Indonesia are also presented. According to the analysis, hydropower is the best renewable energy source, followed by geothermal, solar power, wind power, and biomass [3].

The challenges in developing hydropower for energy security in Aceh are highly relevant, given the region's abundant water resources. With numerous rivers, lakes, and high rainfall, Aceh has

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significant potential to utilize hydropower as a solution for its energy security. However, this potential has not yet been fully realized, and Aceh continues to face major challenges, including a dependence on fossil fuels and an unstable energy supply. These issues underscore the urgency of developing renewable energy, particularly hydropower, which could play a crucial role in addressing the region's energy crisis.

On the other hand, the development of hydropower infrastructure in Aceh faces various obstacles. One major challenge is the limited technology and the high investment costs required to build the infrastructure, particularly in remote areas that are difficult to access. In addition to technical challenges, hydropower projects also pose environmental concerns, such as their impact on aquatic ecosystems and the risk of land use changes, which can affect local communities. Moreover, while renewable energy policies in Indonesia are still evolving, they are often insufficient to support the acceleration of hydropower development. As a region with special autonomy, Aceh also faces regulatory complexities in developing energy projects, including hydropower. Another significant challenge is the shortage of human resources and financing. Hydropower development requires experts and substantial funding, both of which remain significant obstacles in Aceh. However, the development of hydropower in Aceh is a crucial step toward achieving sustainable energy security. By diversifying energy sources and reducing dependence on fossil fuels, Aceh can establish a more stable and environmentally friendly energy supply. Therefore, it is essential to address these challenges to ensure that the potential of hydropower is fully harnessed, thereby strengthening energy security in the region.

Research Methods

This research was conducted in several districts and cities in Aceh Province. The subjects of this study included the general public of Aceh, as well as several academics and experts in the field of renewable energy, together with companies and NGOs involved in the oil energy sector, to collect information related to a number of challenges that must be overcome to realize this potential and ensure energy stability in the Aceh region. This study involved 150 respondents. A sample size of 150 people is often considered representative enough for exploratory studies or surveys. Primary data were collected through structured interviews using questionnaires, which captured respondents' opinions on a number of challenges that must be overcome. The selection of respondents for interviews was carried out using the purposive sampling method. Secondary data were collected from previous studies, journals, and other publications relevant to this study.

Result and Discussion

Aceh, a province rich in natural resources, faces significant challenges in its efforts to achieve sustainable energy security, particularly from renewable energy sources. Despite its immense potential to harness clean energy, such as hydropower, wind, and solar, various obstacles hinder Aceh from fully optimizing this potential. These challenges include limited infrastructure, difficulties in financing, slow adoption of technology, and complex social and environmental issues. Furthermore, political and security dynamics, along with the impacts of climate change, add additional layers of complexity to the efforts to build a resilient energy sector. In this context, understanding and addressing these challenges are crucial for Aceh to ensure the sustainability of its future energy supply while fostering inclusive and environmentally friendly economic development. Below is a breakdown of the obstacles Aceh faces in achieving sustainable energy security (see figure 1).

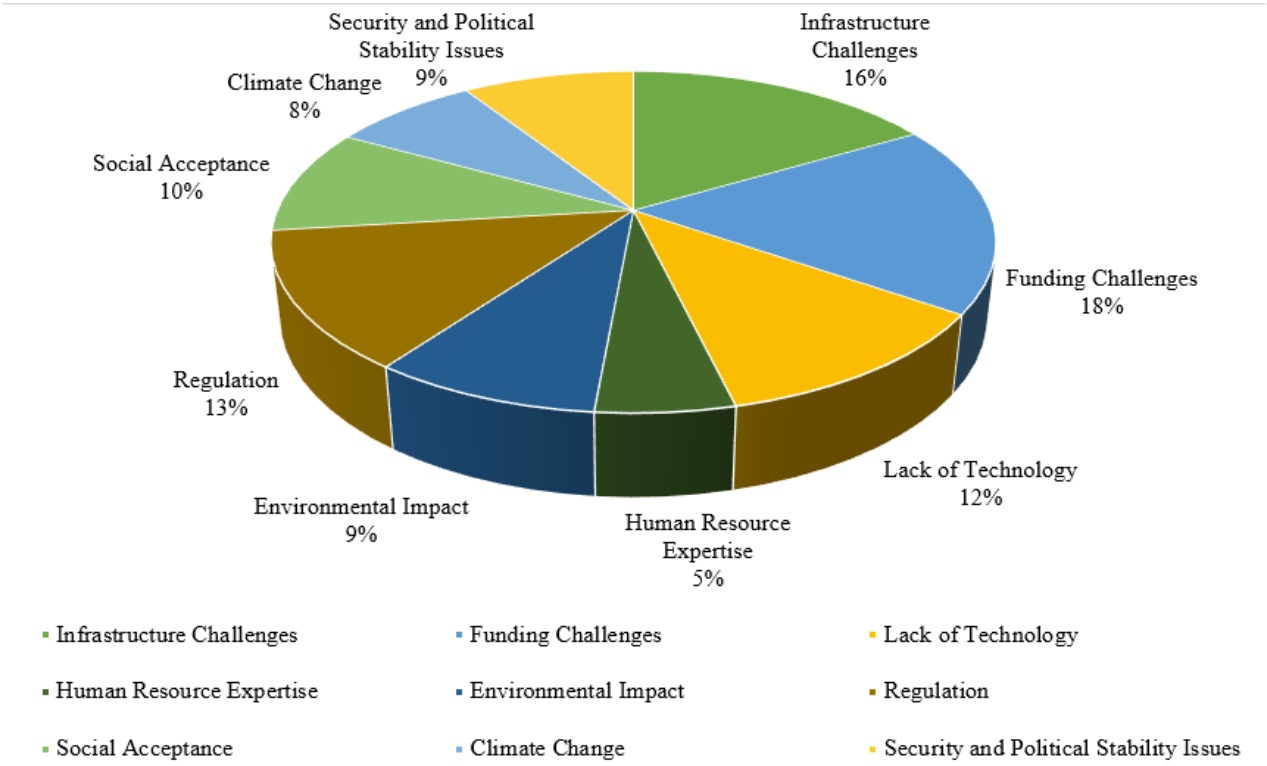

Fig. 1. Results of mapping challenges in Water Energy Development for Energy Security in Aceh.

a. Infrastructure Challenges

Energy infrastructure in Aceh still faces significant limitations, especially in remote and hard-to-reach areas [4]. One of the main issues is the uneven availability of electricity networks, with many rural areas and small islands still not well connected to the national grid. This forces people in these areas to rely on alternative energy sources, which are often inadequate and unstable, such as diesel generators that require expensive and hard-to-access fuel [5]. Additionally, fuel distribution in Aceh faces major challenges. Limited access to remote areas makes fuel delivery difficult and expensive, leading to inconsistent energy supplies. This issue is exacerbated by the lack of energy storage facilities, making fuel distribution inefficient and vulnerable to supply disruptions. The limitations in energy transportation—both electricity and fuel—add to the complexity of the problem, given Aceh's geographical terrain, which includes mountains, dense forests, and long coastlines.

To address these challenges, it is essential for Aceh to develop better and more reliable energy infrastructure. The construction of more efficient and environmentally friendly power plants, along with the expansion of the electricity distribution network to cover the entire region, are critical steps that must be taken. Additionally, strengthening energy storage facilities [6] for both electricity and fuel [7] is necessary to ensure better and more stable energy management. With adequate infrastructure, Aceh can improve access to and availability of energy, ultimately driving economic growth and enhancing the quality of life for people across the province.

b. Funding Challenges

Financing is one of the biggest challenges facing energy project development, particularly in a region like Aceh, which requires significant investment to upgrade its energy infrastructure and technology. Energy projects are often extremely costly, especially when they involve high-tech applications and complex infrastructure development [8]. Additionally, many of these projects are long-term, meaning that investments do not yield immediate returns, making investors hesitant to commit. This is particularly relevant in Aceh, where economic and political uncertainty can influence investor interest.

Budget constraints faced by local governments are also a major obstacle. While the central government may have larger financial resources, these funds are often not fully allocated to energy

projects in more remote or less developed areas. Local governments in Aceh, with their limited resources, struggle to finance large-scale projects, particularly those requiring substantial upfront investment before any economic benefits are realized. This situation is further exacerbated by the lack of alternative revenue sources and fiscal constraints, which limit the ability of local governments to support energy development [9].

c. Lack of Technology

Aceh continues to face various limitations regarding the mastery and adoption of energy technology, encompassing both the renewable and non-renewable energy sectors. These limitations not only affect the effectiveness of existing energy resource utilization but also hinder the overall development of the energy industry in the region. The technology currently available is often outdated, failing to keep pace with modern advancements, or is inadequate for meeting increasingly complex needs. For instance, existing power plants may still rely on old technology that has low efficiency and high emissions, rendering them not only less economical but also detrimental to the environment.

In the renewable energy sector—such as solar, wind, and biomass—the adoption of technology also lags behind. Although Aceh possesses great potential for developing renewable energy, the technology required to convert this potential into usable energy resources remains limited. For example, the solar panel and wind turbine technologies currently in use may not be efficient enough to generate large amounts of energy or withstand harsh environmental conditions. As a result, the utilization of renewable resources in Aceh is suboptimal, leading to significant energy potential being wasted.

These limitations are also connected to a lack of knowledge and skills among the local workforce in operating and maintaining more advanced energy technologies. Many workers may not have received adequate training in the latest technologies, which means that even when new technologies are adopted, their use is not always maximized. This lack of capacity further slows down the technology adoption process, as additional time and resources are needed to train the local workforce.

d. Human Resource Expertise

The lack of skilled and professional personnel in the energy sector is one of the main obstacles hindering the implementation and management of energy projects in Aceh. This challenge is critical, given that energy projects typically require high technical expertise, effective management, and a deep understanding of applicable technologies and regulations. However, Aceh currently faces a significant shortage in both the number and quality of competent human resources in the energy sector. These limitations include a scarcity of engineers with specialized expertise in energy and a shortfall in the number of trained technicians. Technicians are essential to the day-to-day operations of energy infrastructure, as they are responsible for running, maintaining, and repairing various systems and equipment. The absence of experienced and trained technicians means that many technical issues that arise in daily operations cannot be resolved quickly or efficiently, leading to significant downtime or even permanent damage to the energy infrastructure.

To address this challenge, developing human resource capacity is crucial. This can be achieved through various strategies, including enhancing formal education in energy engineering at universities and other educational institutions in Aceh. These educational programs need to be tailored to meet the demands of the modern energy industry, with curricula that cover the latest technologies, regulations, and best practices in the energy sector. Additionally, ongoing training is essential to ensure that the workforce can continuously improve its skills as technology advances.

e. Environmental Impacts

Although renewable energy sources such as solar, wind, and hydroelectric power are considered more environmentally friendly than fossil fuels, their development is not without environmental impacts. For instance, the construction of wind turbine farms can disrupt the migration patterns of birds and bats, as well as alter the natural landscapes that are vital for various species. Similarly, the construction of hydroelectric power plants can lead to changes in river flows, which in turn can disrupt

aquatic ecosystems, reduce fish populations, and destroy wetlands essential for biodiversity. Additionally, the production of solar panels and batteries requires raw materials that are often obtained through environmentally damaging mining practices [10].

These impacts illustrate that energy development cannot proceed without careful consideration of the environment. This necessitates the implementation of strict, environmentally friendly policies that must be integrated into every stage of energy development, from planning and construction to operation. These policies should include comprehensive environmental impact assessments, the use of clean technologies that minimize emissions and waste, and mitigation measures designed to reduce negative impacts on ecosystems. Moreover, mitigation efforts must be an integral part of every energy project. Such efforts can encompass a variety of actions, including rehabilitating degraded land, improving waste management, and employing emission-reducing technologies. For example, in fossil-fueled power projects, the use of carbon capture and storage (CCS) technology can help reduce CO_2 emissions released into the atmosphere. In renewable energy projects, appropriate site selection and environmentally friendly design can help minimize disturbances to natural [11]. Furthermore, compensation and rehabilitation programs, such as replanting degraded forests or restoring river ecosystems, can help restore the environmental balance disrupted by energy development.

Overall, the environmental challenges faced in energy development in Aceh require a holistic and sustainable approach. The government, industry, and communities need to collaborate to ensure that energy development not only meets current energy needs but also considers its impacts on the environment and future generations. With the right policies, environmentally friendly technologies, and effective mitigation efforts, Aceh can develop its energy sector sustainably, preserving its natural environment while continuing to support the welfare of its people [12].

f. Regulation

Unclear or overlapping regulations often pose a significant obstacle to the licensing and implementation of energy projects, and this issue is particularly pronounced in Aceh. The regulatory process, which is intended to govern and ensure that energy projects are executed in accordance with standards and the public interest, frequently becomes a substantial barrier for industry players and investors. One of the main challenges faced is the lack of harmonization between central and regional regulations. Aceh, with its special autonomy status, has regional regulations that sometimes differ from or even conflict with national regulations. Additionally, unclear regulations are often related to varying interpretations of the law by the different agencies involved. In many cases, there is overlapping authority among various government agencies, both at the central and regional levels, each of which has different perspectives or approaches to the implementation of energy projects. Slow bureaucracy is also a significant inhibiting factor; the process, which requires numerous stages and approvals from various agencies, can take months or even years before the necessary permits are obtained.

g. Social Acceptance

One of the main issues that often triggers community resistance is displacement. Energy projects, especially large-scale ones such as power plants or mining operations, frequently require extensive areas of land. This can mean that people living in the area may have to be relocated from their homes, leading to dissatisfaction and resistance. For many communities in Aceh, land is not only viewed as an economic asset but also holds deep cultural and spiritual significance. This displacement is often perceived as a violation of their rights, especially if the process is conducted without adequate consultation or fair compensation.

Additionally, access to natural resources is also a sensitive issue. In many areas of Aceh, communities depend on natural resources for their livelihoods, such as agriculture, fisheries, and forestry. Concerns about environmental impacts often drive community resistance as well. To overcome these challenges and gain better social acceptance, it is essential for the parties involved in energy projects to build trust with the communities [13]This can begin with early community involvement in the project planning process. Engaging communities in discussions and consultations can help them understand

the goals and benefits of the project and provide them with the opportunity to voice their concerns and expectations. This process not only increases transparency but also gives communities a sense of ownership, which can reduce resistance and enhance support [14].

h. Climate Change

Climate change is a global challenge increasingly felt in various parts of the world, including Aceh. This phenomenon not only affects ecosystems and daily life but also has serious implications for energy security in the region. In Aceh, climate change has caused significant alterations in weather patterns, including erratic rainfall, an increased frequency of storms, and extreme temperatures that occur more often than before. All of these changes have a direct impact on energy production and distribution, especially from renewable energy sources that are highly dependent on natural conditions, such as hydroelectricity and wind energy.

Hydroelectric power sources, which harness the flow of water from rivers or dams, are highly susceptible to changes in rainfall patterns. In Aceh, which has a large number of hydroelectric power plants, the dependence on stable rainfall is very high. When rainfall becomes erratic, for example during prolonged periods of drought or heavy rains that cause flooding, the electricity production capacity of hydropower plants can drop dramatically. Droughts can reduce the flow of water needed to drive turbines, while floods can damage infrastructure and force temporary shutdowns to prevent further damage. This of course has an impact on energy availability, which can be unstable and unpredictable.

Adaptation to climate change must also be a priority in the planning and management of energy infrastructure. Governments and industry need to develop comprehensive adaptation strategies, including planning for infrastructure that is resilient to extreme weather events and developing early warning systems to mitigate the impacts of natural disasters on energy infrastructure. For example, constructing dams designed to withstand major floods or strengthening electricity distribution networks to endure strong winds could be part of these adaptation efforts. Furthermore, it is essential to develop policies that support innovation and investment in technologies that can enhance the resilience of energy systems to climate change [15].

i. Security and Political Stability Issues

Political security and stability are crucial factors in the success of energy sector development in Aceh. As a region with a history of conflict and complex political dynamics, Aceh requires a stable environment to ensure the sustainability of energy projects that are currently being developed or will be in the future. Conflicts, whether internal, such as disputes between political groups or communities, or external, such as threats from armed groups, can hinder various stages of energy projects, from planning to operations. Political instability can create uncertainty for investors and project developers, ultimately leading to project delays or cancellations.

Creating a stable and secure environment is not only the responsibility of the government but also requires the active participation of various stakeholders, including the community, security forces, and energy industry players. The government must ensure that the policies implemented support political stability and security by creating a clear legal framework, enforcing the law fairly, and facilitating dialogue between groups with differing interests. Communities must also be empowered to play a role in maintaining security, for example, through community security programs or partnerships between communities and security forces [16].

Conclusion

Aceh faces complex challenges in its efforts to achieve resilience in renewable energy resources. Despite its significant potential in harnessing clean energy sources such as hydro, wind, and solar, several major barriers continue to hinder the optimization of this potential. Infrastructure limitations, difficulties in obtaining adequate funding, slow adoption of new technologies, and a shortage of renewable energy experts are some of the main factors obstructing the development of this sector. Additionally, social issues such as low public understanding of renewable energy, complex regulatory

challenges, and political and security conditions that are not yet fully stable further complicate the situation. The impacts of climate change also add to the burden of ensuring sustainable energy resilience in the region.

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