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Sustainability Approach of Site Selection for Renewables Deployment in Indonesian Rural Electrical Grids

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***Abstract*— As Indonesia works up efforts to increase renewables penetration and inequality of electrification ratio across the country, rural electrical grids are growing in popularity. However, there are some uncertainties of its development in a rural area, especially in deploying resources and forming guidance for site selection. The complexity of many aspects that incorporate and impact many stakeholders must be considered to develop a sustainable energy project. A sustainability framework that assesses a site's qualification for renewables electrification project is created to address these concerns. This study has resulted in a framework for site selection by considering the primary stakeholders' inclusiveness with holistic assessment in technical, economic, environmental, and social aspects. The inclusion of different perspectives and different elements in this study creates the robustness of the sustainability framework. Life Cycle Assessment (LCA) studies may support the framework to understand the project's benefit towards a better environment. Willingness-to-pay-approach can help the community take ownership of the mini-grid instead of imposing it upon them a foreign solution. This holistic framework may still need to be evaluated in its application concerning the existing constraints and limited resources. Studies of regulation, policy, and incentives can support the implementation of such a systematic sustainability framework. Nevertheless, implementing this framework helps encourage policymakers, developers, communities, and energy service companies to understand better and accomplish further sustainable development.**

***Keywords*— rural electrification; site selection; sustainability assessment; sustainable development; sustainability framework.**

I. Introduction

This section describes the overview of renewables development and its deployment potential in Indonesia. The sustainability approach's importance to build a site selection framework in renewables project deployment is also described. Indonesia has been working on expanding renewable energy deployment to achieve its sustainable development goals in the national development agenda. In 2019, Indonesia had the growth of moderate renewable. In 2019, Indonesia added 385 MW of renewables, giving a total of 10.17 GW installed renewable power plant or an annual increase of 3% [1]. In terms of generation, renewables only contributed to 12.2% of the established capacity mix in 2019. The renewable generation mix has been stagnant since 2011, ranging around 11% to 13% of the electricity mix with hydropower and geothermal as the main contributors [1]. However, this percentage is not close enough to the national target and further plan. The National Medium Term Development Plan targets renewable capacity of 17 GW and renewables share in the primary energy mix at 16% by 2019 [1]. Meanwhile, in the national energy plan, the government aims to increase renewables capacity to 13.9 GW by 2019 or 17.5% of total capacity in that year. The government also set to put renewables at 23% of total capacity by 2025 [2]. All the targets mentioned above were set to harness large potential of renewables in Indonesia. Many renewables potential studies have been conducted by many organizations and verified by the Indonesian Ministry of Energy and Mineral Resources (MEMR). The renewables potentials and its implementation in Indonesia are shown in Fig. 1 [3]. Fig. 1 shows that Indonesia still has a lot of renewables potential to be utilized. The most considerable renewable potential comes from solar energy, which is accounted for around 208 GW. In comparison, hydro has the potential of 75 GW, wind energy has a potential of around 61 GW, and other renewables has a total potential of around 61.5 GW [3]. Being the largest renewable energy potential, solar energy has not even been quarterly utilized. The record shows that the total solar PV installed is just around 140 MWp [3]. Indonesia still has many tasks in harnessing renewables potential and meeting its electricity demands.

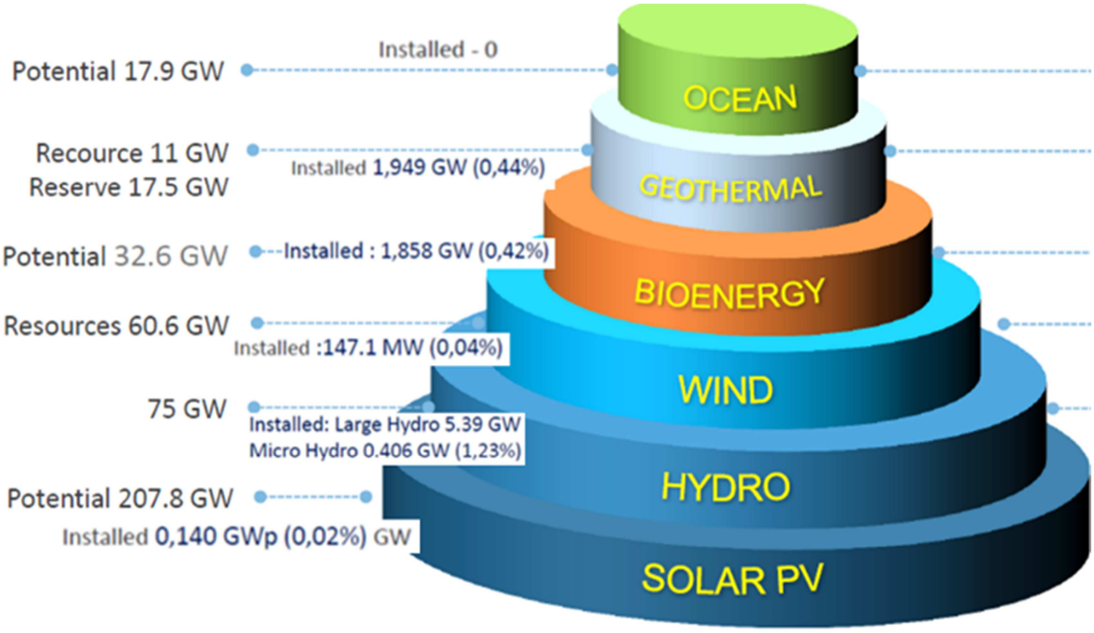

Fig. 1 Renewable energy potentials and implementation in Indonesia

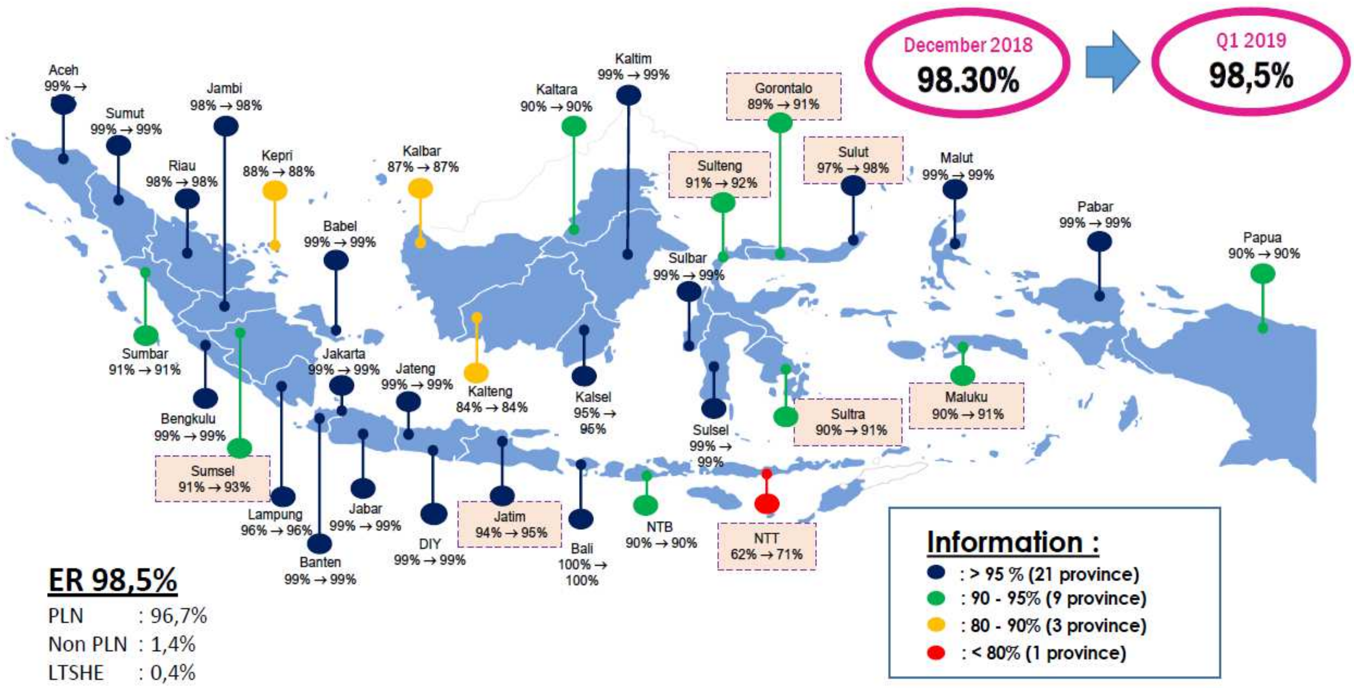

Fig. 2 Electrification ratio in Indonesia

Besides its commitment to meet the share of renewables target in the energy mix, Indonesia also needs to increase its electrification ratio. Indonesia's performance in the electricity sector is deficient when compared with other countries in the region. Indonesia's electrification ratio is one of the lowest compared to other ASEAN countries such as Malaysia, Philippines, Thailand, and Vietnam, which already achieve over 99% [4].

The national electrification ratio and each province's ratio in Indonesia can be seen in Fig. 2 [3]. The Indonesian electrification ratio has been improved from 86% in 2015 to 94.9% in 2017 [4]. In 2018, it reached 98.3% and 98.5% in early 2019 [3], [5]. Most of the provinces in Indonesia (i.e., 21 provinces) have reached more than 95% electrification ratio, aiming to electrify the whole nation.

A. Renewables Deployment Potential in Rural Areas

While the Indonesian government has committed to electrifying the whole country by 2020, there are still more than one million households without electricity, particularly in rural areas [1]. As it is shown in Fig. 2, there is clear information of inequality across provinces in the country, with eastern provinces having a much lower electrification ratio. The electrification ratio in East Nusa Tenggara, for instance, was only 62% in 2018, the lowest in Indonesia.

Many rural areas experience a low electrification ratio that increases the deployment of power plants. It would increase the national electrification ratio effectively. The private sector needs to be stimulated to invest in geographically remote areas [6]. Village grids are widely regarded as more promising in terms of a developmental impact because they allow for the productive use of the generated electricity [7]. The system size is needed to be considered, as well. Large-scale centralized power plants may not meet the needs of rural areas. Instead, small-scale off-grid renewable generation systems can help electrify these areas cost-effectively [1].

Solar energy resource is the most considerable renewables potential in Indonesia, and it surely can be harnessed to meet the urgent needs in increasing the electrification ratio in rural areas. It has also been studied that most small grids (i.e., in rural areas) rely on solar PV technology [8]. This trend is supported by solar panels' falling costs and their growing penetration in the developing market [8].

Despite its deployment potential, some challenges have been faced by renewable energy projects. Time, cost, and the development of own best practices for project planning and implementation are critical challenges that need to be tackled [4], [6]. The developers must manage risks for electricity projects, and the time period is not adequately considered in the design of renewable energy targets. It took 3 years from the policy design to detailed action plans launched in 2017 [4]. Similarly, the financing sources and implementation mechanisms are not considered in the renewable energy target design. Besides, there is still a lack of standards, certification, and knowledge transfer on project implementation and management practices. Their own best practices are significant and needed to be scaled-up from pilot projects [9].

Best practices in many project stages are needed in renewables power plant deployment. Those would include best practices in site selection, feasibility study, grid impact study, operation & management, and other supporting studies [9], [10]. This paper will focus on the formulation of a site selection framework for renewables projects in rural electrical grids.

B. Issues in Site Selection for Renewables Project in Rural Areas

Whereas the need to improve rural access to electricity services is well established, the optimal way for achieving this target is still imprecise. Some studies claim that it is difficult to make financing economically viable for rural electrification projects [6], [11]. Building electricity infrastructure in remote areas is not financially feasible, even for the national electricity company, PLN, subsidized by the government [4]. As financial resources on the local and national levels are tight, private companies or international investors are encouraged to support renewables projects.

However, some barriers can be expressed into investment risks or uncertainties in the planning or feasibility study, bringing deterrence to investors from investing [12], [13]. Despite the more than 900 renewable energy-based village grid projects and pilots across Indonesia, there is still a lack of standards, certification, and knowledge transfer on the best practices of planning and management [6]. One of the critical challenges is the lack of a systemic and commonly accepted framework for site selection and planning [8].

Many issues may arise in conducting site selection. Finding a particular site, land acquisition, and involving rural communities as consumers is a challenge [8], [14]. Land acquisition issues are common due to a lack of clarity regarding land ownership in many locations. The process of acquiring land is often costly and time-consuming. Community members in the rural area are also needed to be involved in the decision-making and implementation process. The developers may also need to assess the willingness-to-pay of the community in determining electricity prices. All these issues should be taken into a broader sustainability context to give a proper site selection framework for project deployment.

C. Sustainability Assessment Framework for Project Deployment

Nowadays, policies and frameworks have been developed with concern for sustainable development goals. The three main purposes of sustainable development are economic, social, and environmental purposes [15], [16]. The economic purpose is subject to improve equity in resource distribution across and within societies. The social purpose aims to improve human well-being. The environmental purpose seeks to develop a project that stays within environmental constraints.

A sustainable framework has changed the ‘value’ or impact definition in the conventional business model into a broader and more holistic approach. The traditional model of business frameworks usually assumes that the primary goal of firms is to maximize profit and use the term ‘value’ as profit-related [17], [18], [19]. In sustainable frameworks, a business model is part of a complex system where the value to individuals, organizations, society, and the environment emerges from the interaction between different components on the broader system and context [16]. This can be illustrated by the torchlight framework in Fig. 3 [16].

The torchlight framework is designed to describe the business model constituents and their interactivity, leading to the emergence of value (light) for different stakeholders: individuals, organizations, society, and the environment. The analogy demonstrates that part of the value is apprehended by individuals and organizations (the yellow) and goes to broader society and the environment (blue). Essentially these shades of light (yellow and blue) will be larger or smaller depending on the nature of the business model and its functioning [16]. ‘Value’ incorporates the value created and apprehended for different stakeholders. The holistic approach would consider the value created to the individual, organization, society, and environment.

Findings from previous research on the sustainability of energy systems show some indicators that can be used to notice the defined ‘value’ deliverables. Those indicators are technical, economic, environmental, and social indicators [20]–[23]. The framework for integrated sustainability assessment of energy systems with its indicators is shown in Fig. 4 [23].

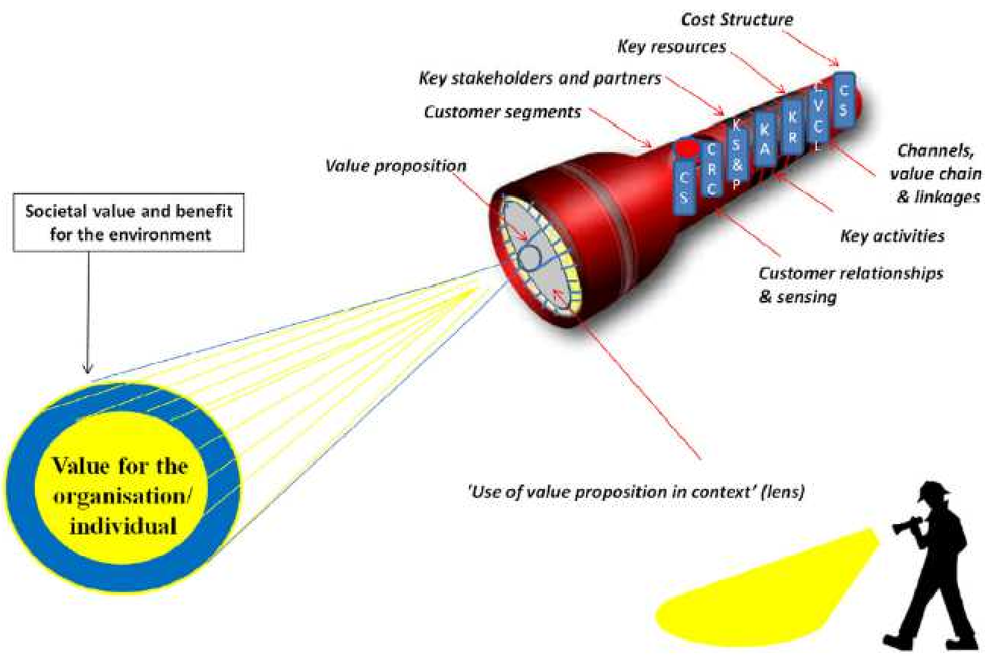

Fig. 3 Torch light framework

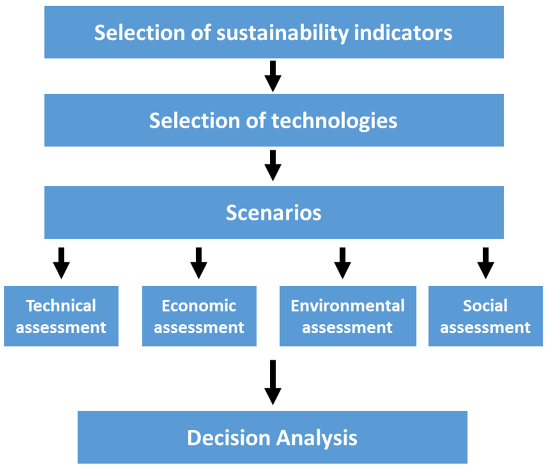

Fig. 4 Sustainability indicators and framework for sustainability assessment of energy systems.

The selection of indicators considered here is driven by global energy policy discussed in some papers [20]–[23]. The indicators may somehow be changed depending on the aims of the study. In electricity systems, the technical assessment considers the power plant and electricity grid's technical design. General economic indicators assessed would be capital costs, total annualized costs, and levelized costs. Taking a life cycle approach, the environmental indicators included in the framework are those typically considered in life cycle assessment. The social indicators considered can be classified into some categories such as public acceptability, health and safety, and social issue [23]. All these indicators are crucial to be considered for the preferred decision analysis in deploying and planning a long-term renewables project.

D. The objective of This Paper

The global transition towards sustainable development is now driving many projects deployed to follow the sustainability framework. The feasibility study will be needed to fulfill the economic, social, and environmental requirements. This paper aims to build a sustainability approach on-site selection framework for renewables projects. The framework is also explicitly designed to be used for renewables deployment in rural electrical grids in Indonesia.

II. MATERIAL AND METHOD

In this chapter, the methodology in developing a site selection framework for the study is explained. References used and the identification of stakeholders and sustainability assessment needed for site selection are described and elucidated.

A. Sources and References

In this paper, the site selection framework is constructed based on a literature review of sustainability assessment studies and the authors' experiences as professionals in developing renewable power plant projects in Indonesia. Concept and context that have been explained in previous sub-chapters are used as the reference in the study. The value created to different stakeholders and sustainability indicators is considered in developing the site selection framework.

B. Identification of Stakeholders in Site Selection Framework

Site selection in a renewable deployment project brings values to many different stakeholders [8], [16], [23]. A holistic approach in the sustainability assessment framework considers project impacts given to the stakeholders. The related stakeholders in site selection are described in Fig. 5 [8], [16], [23].

The scheme in Fig. 5 shows the key stakeholders strongly affected by site selection in a renewable project from a developer perspective. The value created from the site selection can impact the developers, Perusahaan Listrik

Negara (PLN), government, regional or local administrators, landowner, and consumers or rural community. PLN is a state-owned electricity company in Indonesia. PLN operates as a monopolistic corporation responsible for managing all grid-connected power plants and electricity distribution to all customers in the country. Site selection activity would also need to consult government and administrators to get permission and advice (e.g., information about local or regional spatial planning, the most suitable location, etc.). Landowner is one of the main stakeholders, as the developers would buy the land for power plant deployment. The final product of electricity from the power plant project will also significantly value rural communities or consumers' development.

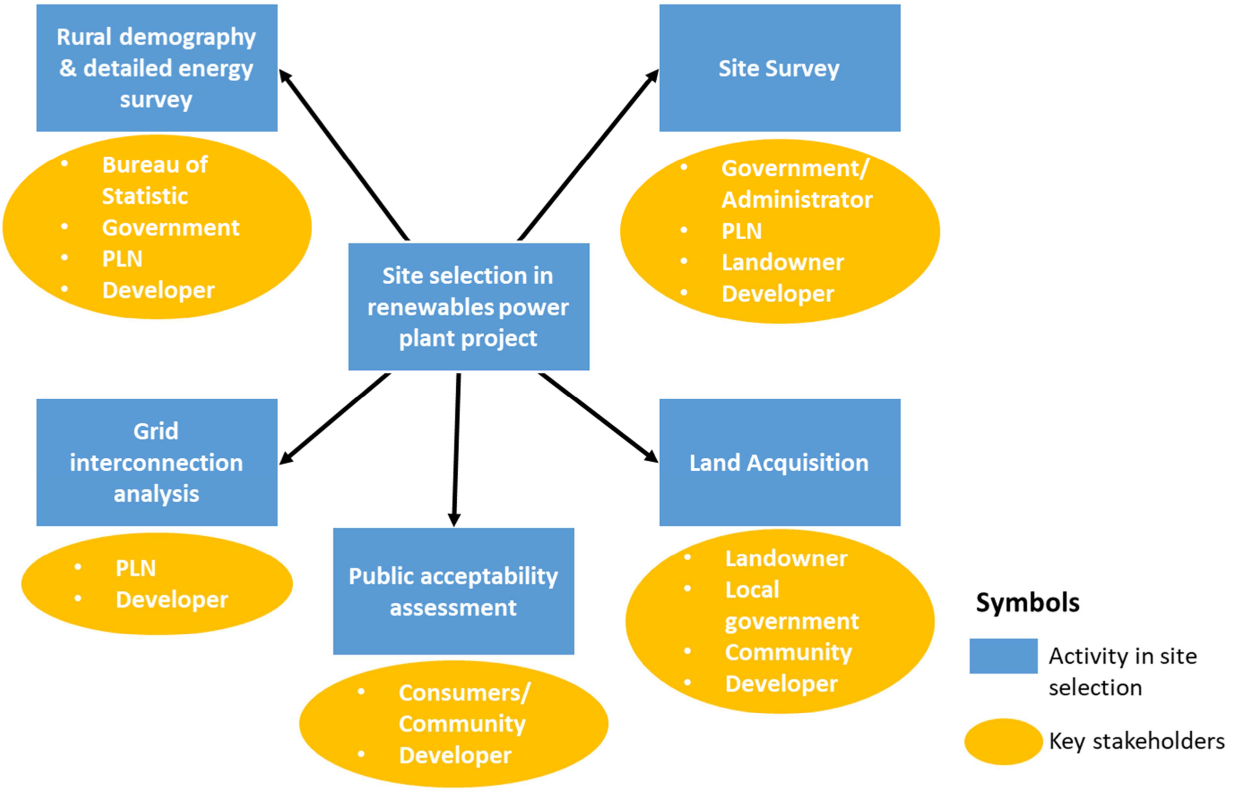

Fig. 5 Key stakeholders in site selection activity

C. Identification on Sustainability Assessment of Site Selection

Based on the framework for sustainability assessment of energy systems described in Fig. 4, general stages of site selection study are arranged and shown in Fig. 6.

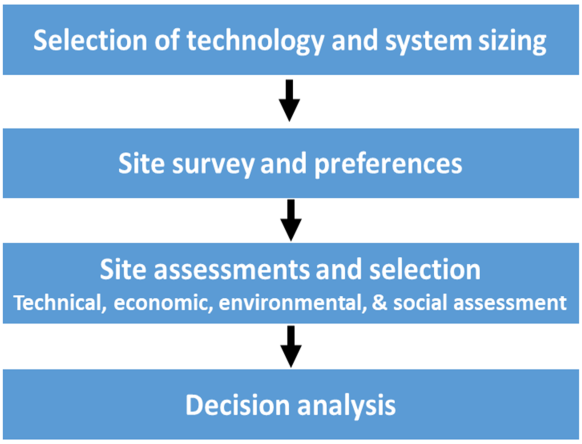

Fig. 6 Stages for site selection in power plant project

After the developer has chosen the capacity or size of the power plant and consulted the state-owned company about the plan, site selection can be improved to find the best location for a project. As the conducted study needs to be done in a sustainability framework, selected sites can then be evaluated in the technical, economic, environmental, and social assessment. This holistic approach for an evaluation will support the developer to bring out good and robust decisions. Decision analysis can be done with a technique (e.g., analytic hierarchy process, multiple criteria decision analysis, etc.) depending on its preference.

Technical, economic, environmental, and social indicators are used in the sustainability assessment of site selection. Key indicators that represent technical, economic, environmental, and social assessment for site selection are shown in Fig. 7. Main assessments expounded in Fig. 7 are needed for site selection, which considers its impact on stakeholders within a sustainable approach. Key assessments and affected stakeholders are summarized in the following sub-chapters.

1) Technical Assessment: Main technical assessments for site selection are energy demand, grid impact, site topography study, and the land acquisition plan. State-owned electrical companies and developers would need energy demand and grid impact study as they want to know how much the power plant's required capacity is and how it will affect the electricity distribution and quality in the whole grid system. Technical assessment in the land profile is also required concerning power plant layout specification. The most feasible site is then selected for further land acquisition plans.

2) Economic Assessment: Economic assessment in site selection is generally any estimation that may affect the capital cost. Key economic assessments for site selection in this study are total land cost and additional transmission cost. Total land cost is important to be assessed for developer financial performance. The further transmission cost is also needed to be estimated for the developer and the state-owned company for a financial assessment concerning their contract. Nevertheless, the assessment may not be limited to these two indicators. The economic assessment would be the evaluation of any costs in site selection that can affect the total capital cost.

3) Environmental Assessment: Main environmental assessments for site selection are identifying environmental impact and the environmental impact of land preparation. The identification of environmental impact may include the recognition of, for instance, the reserved forest that may be seen in the spatial planning by the government. The environmental impact of the land preparation process can also be estimated in the assessment (e.g., its global warming potential). Environmental assessment is important because environmental quality will affect all stakeholders.

4) Social Assessment: Main social assessments for site selection are community acceptability and social impact identification. Community acceptability (e.g., willingness-to-pay) in the rural grid is needed to be assessed because they are directly affected by the new electrical facility. This facility is also planned to be installed to support the economic development of rural communities. Social issues that may arise in deploying a new power plant is also needed to be evaluated in the sustainable framework.

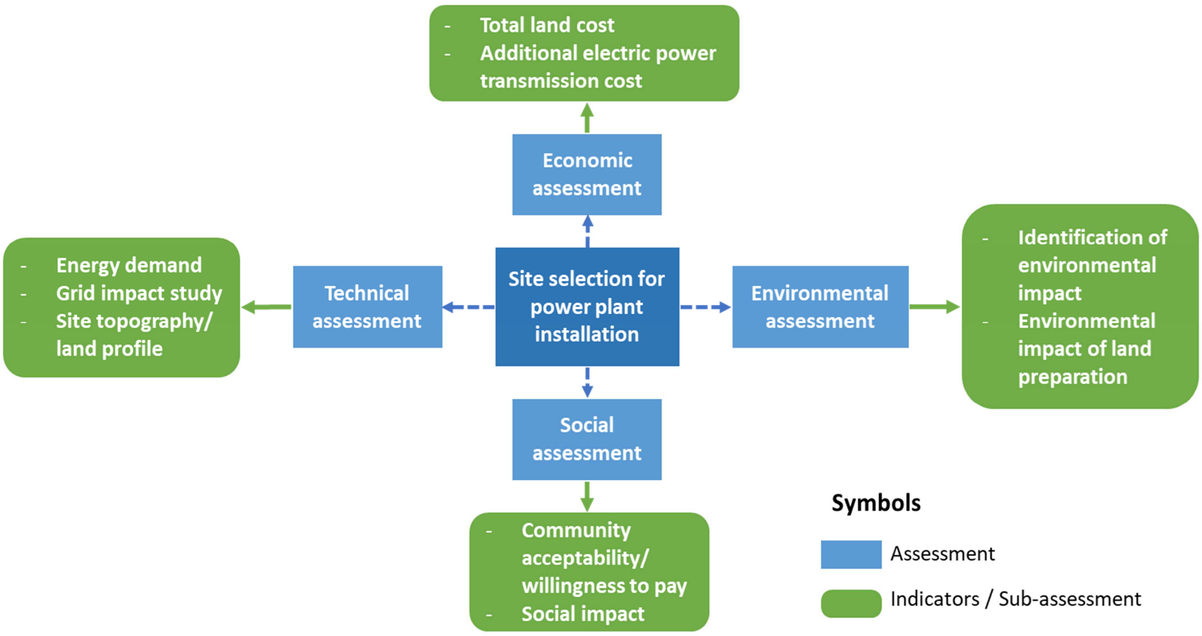

Fig. 7 Assessments in site selection

D. Developing a Site Selection Framework

Identification of stakeholders and sustainability assessment in site selection has been explained in the previous sub-chapters. The assessment is required to evaluate the impact that can affect the associated stakeholders. After stakeholders and sustainability indicators in site selection have been identified, an elaborate framework for site selection is then developed for the study in this paper.

Site selection in a feasibility study of the renewables project involves some assessment stages: desk research, preliminary site survey, detailed site survey and assessment, and further assessment for site selection. These stages of study are conducted within a sustainable framework explained in previous sub-chapters. The site selection framework then results in the next chapter.

III. Results and Discussion

A. Site selection framework

Identifying and evaluating all aspects mentioned in the previous chapter for site selection is essential to developing a sustainable electrification project. Those aspects are then considered through some stages in site selection.

B. Desktop Study

In this phase, a desk study for possible locations that may benefit from such an electrification project is conducted. A particular location's potential may still not be assessed in a detailed manner; however, it does form a basis further to analyze the early suitability for future study. The information resulting from the desktop study can be used to guide site surveys and identify potential locations. Several parameters may be used to obtain a site based on desktop research are as follows:

- Population information from any reliable governmental source
- Electricity development status in electrical state-owned company plan report
- Proximity to grid infrastructure and potential renewable resources
- Village/rural economic development.

C. Site Survey

In this stage, a detailed survey is carried out in person to analyze the selected sites further. Preliminary assessments are conducted here to support the feasibility study, grid impact study, and project development.

1) Land Profile Assessment and Land Acquisition: It is essential to assess the site's topography and elevation profile and compare it to the power plant requirements and specifications. The technical information of land structure and characteristics will be required to ensure its suitability with the civil engineering of power plant design, for instance, soil robustness for wind turbine foundation or solar PV mounting structure. The site elevation profile information will also be required to estimate the civil works of land preparation (e.g. cut and fill) and how much it will cost.

Land acquisition plan became an important consideration in deploying renewables in a rural area. The confluence of territorialization, property rights, and commoditization of land, resources, and space-making enables spatial and more complex enclosure forms [24]. Especially in a rural area, there is a lack of clarity regarding land ownership in many locations. The proper approach for regulation of National Land Agency and spatial planning and involving the local community must be done in converting the status for land acquisition.

2) Grid Connection Plan and Impact: As the identified sites in the renewables project might contribute considerable amounts of intermittent power, it is essential to consider their integration to the existing power system and their connection to the grid [25]. The data of load or electricity demand, existing generators, and electrical infrastructure must be obtained to study the grid connection plan. The projection of electricity demand and supply is considered in planning point of connection from the selected site to design a reliable power system while giving electricity access for the community. The implementation of a storage system would also be required in some remote islands. In a more extensive system, examining peak demand reduction by inspecting population density or estimating maximum distance from human settlements can also help policymakers balance urban development costs with energy transition infrastructure costs [26].

In developing an electrification project, a new power plant's injection must improve the existing grid system. It must benefit power quality and maintain the system frequency to provide a reliable power system for the community. The voltage drops in such a system (i.e., reactive power) is estimated by the vectorial sum below [27].

$$\Delta V = R \times I\,active + X \times I\,reactive \qquad (1)$$

A grid impact study can be conducted by using software or simulation tools. Further research in assessing possible fault and system stability is required before implementing the renewable power plant to the grid.

3) Identification of Environmental Impact: Project development, especially the one that will involve construction and operation for an extended period, must comply with environmental regulation and responsibility. The location selection is essential to know whether it is a protected forest area or any specified prohibited area (e.g., heritage area) stated in the spatial planning. In this sustainable framework, the development of a project must not harm the existing biodiversity.

The environmental impact assessment of renewables project may also be conducted to accelerate further innovation and understanding. Some studies of using a well-known tool, life cycle assessment (LCA), on different renewables project have ever been done and compared [28]. It will also be interesting, for instance, to conduct an environmental impact assessment in the case of converting the non-productive land into a renewables power plant site.

Whilst, it is correct that the LCA studies may be done in different quality and project technology. This study may have varying results and may bring confusion in the initial stage. It does form a foundation to create a larger database. Further, complete the analysis and data harmonization can bring more understanding of the environmental impact of different projects, especially in a specific place (i.e., Indonesia).

4) Community Acceptability: The authors' experience working with communities across Indonesia, especially in rural areas, has highlighted the need for entailing local communities in the decision-making and project execution. The electrification is implemented to support the economic development in the region; it is also important to understand the willingness-to-pay of the community. The support from Energy Service Company (ESCO) may be helpful in this matter.

ESCOs must appreciate the significance of justifying the high cost of rural grid to the users. Front-line staff including surveyors should undertake such training and consider the economics of supply and demand with local communities. Apart from studying the need for reliable electricity, a particular assessment should also ascertain the price that the user may be willing to pay for a facility of continuous renewable energy supply [29]. Despite assisting the ESCO in effective pricing of electricity, the willingness-to-pay assessment will also help the community understand the need for circular systems. The framework would then address decentralized electricity production and distribution in a systems-level viewpoint.

IV. Conclusion

In this study, the sustainability approach has been utilized to create a holistic framework for site selection in the deployment of renewables projects in Indonesia’s rural area. The framework developed in this study used the sustainability assessment concept to evaluate the technical, economic, environmental, and social aspects. The assessment results of each site can be compared, and the importance of particular aspect can be weighted on the stakeholder' preference. The most feasible site can then be selected for further acquisition.

The inclusion of different perspectives and different aspects of this study creates the robustness of the sustainability framework. Further LCA studies may support the framework to understand the project's benefit towards the environment better. Willingness-to-pay-approach can be utilized to help the community take ownership of the mini-grid instead of imposing it upon them as a foreign solution.

This holistic framework may still need to be evaluated in its application concerning the existing constraints and limited resources. Studies of regulation, policy, and incentives can support the implementation of such a systematic sustainability framework. Nevertheless, implementing this framework helps encourage policymakers, developers, communities, and energy service companies to better understand and accomplish further sustainable development.

NOMENCLATURE

ΔV	voltage drop	V
R, X	electrical resistance & reactance	ohm
I active	electric current (active power)	A
I reactive	electric current (reactive power)	A

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