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Regional Case Study

Sustainability Strategy for Solar Power Plant: Integrating Sustainable Development and Rural Enviroment

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Abstract

The development of renewable energy is essential amid the global energy transition, yet the sustainability of solar power plants—both commercial and household—in Bali Province remains low. Access to electricity is a vital component of sustainable development, helping to bridge the gap between rural and urban areas in Indonesia. In 2016, solar power plants were established in Karangasem Regency to electrify rural communities that previously lacked access due to difficult geographical conditions. This study aims to identify and analyze the key factors influencing sustainable solar power growth in Karangasem while offering strategic recommendations. Employing a qualitative approach and the MICMAC method, it explores economic aspects such as job creation, poverty alleviation, and energy investment; social factors like energy access and community participation; environmental considerations including waste management and climate mitigation; and institutional elements involving local regulations and public-private collaboration. The findings highlight that fostering local economic development (ESD), sustainably managing resources (SNRU), and reducing air pollution (AP) are crucial for enhancing environmental quality (EQI) and attracting investment (EI). The study emphasizes the need for collaborative frameworks and robust policy measures to promote renewable energy, ensuring long-term sustainability and advancing rural development and environment in Karangasem Regency, Bali Province.

Keywords: Solar power plant; sustainable development; rural environment; MICMAC

1. Introduction

Energy is an essential component in meeting fundamental human needs, including healthcare, mobility, communication, and daily activities. Furthermore, energy plays a crucial role in promoting economic development and contributing to societal welfare (Shyu, 2021). Several factors, such as population growth, economic development, and technological advancements, have significantly increased global energy demand in recent years. Both Krishan and Suhag (2019) and Halkos and Gkampoura (2020) predict that this trend will continue in the future.

According to Sustainable Development Goal (SDG) 7, sustainable energy is central to achieving the 2030 Agenda (Gielen et al., 2019). The three primary goals of SDG 7 are: (1) ensuring that all people have access to affordable, reliable, and universal modern energy services; (2) significantly increasing the share of renewable energy in the global energy mix; and (3) doubling the rate of improvement in global energy efficiency (Mastrucci et al., 2019; Bertheau, 2020; Castor et al., 2020; Swain & Karimu, 2020). Progress toward a more sustainable and equitable global energy system requires achieving specific sustainable development objectives related to energy. According to Birol (2018), the International Energy Agency (IEA) supports this objective by pledging to ensure universal energy access by 2030.

Qazi et al. (2019) and Al-Shetwi (2022) emphasize that utilizing renewable energy sources is essential for developing sustainable power production systems globally. Jurasz et al. (2020) argue that renewable energy has emerged as a more cost-effective and environmentally friendly alternative to traditional electricity supply methods across national and regional grids. Currently, renewable energy sources contribute around 15–20% of the world's total energy supply (Amjith & Bavanish, 2022; Kumar, 2020). These sources include hydropower, wind, solar, biomass, ocean energy, biofuels, and geothermal energy.

Rural electrification is a critical component in providing electricity access to remote areas (Peters et al., 2019). Falk et al. (2021) regard electrification as a transformative achievement that has improved individual lives. Access to electricity has significantly enhanced the quality of life, facilitating communication, commerce, transportation, education, and household activities. In rural areas, where the population is often economically disadvantaged, electrification can reduce poverty, provide essential services, and foster social progress (Rachmawatie, 2024).

In Indonesia, extensive rural electrification efforts have resulted in an impressive national electrification ratio of 99.79%. However, 126 communities still lack access to electricity. The Ministry of Energy and Mineral Resources identifies the high cost of building grid infrastructure in remote areas as a major obstacle to achieving complete electrification. Therefore, electrifying rural and remote regions, particularly in Eastern Indonesia and the 3T regions (frontier, outermost, and underdeveloped areas), requires more cost-effective and innovative strategies. These strategies include incorporating renewable energy sources, such as solar power plant, while ensuring security and sustainability (Kementerian Energi dan Sumber Daya Mineral, 2023).

The Karangasem Regency in Bali, with its diverse geography comprising coastal, mountainous, and rural village areas, faces significant challenges in electrification due to its dispersed population and remote locations. Integrating renewable energy sources into the power grid offers numerous benefits, not only for the electricity sector but also for social, economic, and environmental development. According to Solaymani (2019), the power industry is a major contributor to carbon dioxide (CO_2) emissions, raising serious environmental concerns. Energy-related emissions are projected to increase by approximately 16% by 2040. This highlights the need for the electricity grid to play a crucial role in mitigating climate change and global warming. For a sustainable energy future, the electricity sector must adopt low-carbon power generation, heavily relying on renewable energy sources (Bogdanov et al., 2021), as it progresses toward decarbonization.

Figure 1. Solar power plant

Figure 1 illustrates the development of Solar Power Plant in Bali Province. Specifically, the 10 KWP Off-Grid Solar Power Plant in Karangasem provides a sustainable solution for expanding access to affordable, environmentally friendly electricity in the region (Kementerian Energi dan Sumber Daya Mineral, 2013). This solar power plant supplies electricity to 29 households and three temples (pura) used for worship, demonstrating its role in enhancing quality of life and supporting essential social infrastructure. As shown in Figure 1, the system harnesses solar energy to deliver stable and economical electricity for rural communities, consistent with the findings of Yadav et al. (2019).

Research on the sustainability of electrification systems and technologies has been extensive, including the development of various sustainability indices (Razmjoo et al., 2020). Although several studies have evaluated the impact of electrification in Kenya, Sub-Saharan Africa, and India, its influence on sustainable development from the end-user perspective remains underexplored (Akbas et al., 2022; Harrington & Hsu, 2024; Sarangi et al., 2019). It is essential to develop a sustainability impact assessment framework in the context of electrification. These assessments typically use monetary, biophysical, and indicator-based methods, with the latter being the most common due to its ability to measure the social, economic, and environmental dimensions of energy projects (Martínez-Martínez et al., 2023; Voegeli et al., 2019).

The primary objective of this study is to investigate the critical characteristics essential for the development of solar power plant on new and renewable energy at the household level in rural areas. This research aims to examine both the direct and indirect effects of various sustainability factors on the development of solar power plant. These factors include economic, social, and environmental variables that can influence the efficiency and viability of solar initiatives. By conducting a comprehensive analysis of these elements, the study intends to provide deeper insights into the strategic actions required to optimize the development and deployment of these renewable energy technologies. The findings are expected to lay a solid foundation for informed decision-making, and policies that support the broader growth of solar power plant are anticipated to emerge from this research. Furthermore, the study aims to encourage the adoption of environmentally friendly and sustainable energy solutions across various rural regions.

2. Methods

This study adopts qualitative research techniques to offer a thorough understanding of the development of solar power plant. The qualitative component includes an extensive literature review, utilizing various sources such as peer-reviewed journals, books, conference papers, reports, white papers, theses, and dissertations. The review focuses on examining key theories, practices, and challenges related to solar power plant development, identifying both best practices and existing gaps in the field.

To ensure the quality of the selected literature, a systematic selection process is used, which includes bibliometric analysis. This analysis quantitatively evaluates the relevance and impact of publications, taking into account factors like the publication's country of origin, research location, type of study, year of publication, and citation metrics. Bibliometric tools are also employed to identify key areas of expertise, research clusters, and collaborative networks within the field. Through this rigorous review, the study seeks to provide a comprehensive perspective on the opportunities, challenges, and strategies for advancing solar power plant development. The insights gathered will lay the foundation for developing sustainable and innovative solutions to promote the adoption of renewable energy, particularly in rural and underserved regions.

Four data collection techniques are applied in this study: document analysis, Participatory Rural Appraisal (PRA), questionnaire-based interviews, and Focus Group Discussions (FGD). Document analysis examines the socio-economic impacts of solar power plant by reviewing existing reports, policies, and research. PRA involves active participation from the local community, ensuring their needs and perspectives are considered in decision-making and project development (Mezmir, 2020; Rayesa et al., 2023). Questionnaire interviews gather data from additional respondents not included in the FGDs, while the FGDs engage key stakeholders, including (1) solar power plant service recipients, (2) village officials, (3) community leaders, and (4) relevant government agencies.

The research evaluates four key dimensions—economic, social, environmental, and institutional—as outlined in Table 1. The variables and characteristics incorporated into the questionnaires are based on insights gathered from interviews and FGDs, ensuring the data reflects both local knowledge and expert opinions, which are detailed in the Appendix.

Conducted in Karangasem, Bali, the study uses the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) method to identify key factors influencing the sustainability of solar power plant in Karangasem Regency, Bali Province. This analysis considers variables across the economic, social, environmental, and institutional dimensions, assessing their direct and indirect impacts on the sustainability of solar power plant. The study's findings aim to offer actionable insights for creating effective strategies to support sustainable solar power plant development in rural areas.

Applying the MICMAC method involves several stages to identify and map key variables. Stratigea and Papadopoulou (2013) outline two main stages of the MICMAC process. The first stage is understanding the scope of the problem and the system under study, which requires stakeholder involvement, including experts, specialists, and the community, typically through FGDs. The data analysis process uses MICMAC to convert the weight of each variable into a Matrix of Direct Influence (MDI), as presented in Table 2.

Table 2. Tabulation of the relationship between influence and dependence

	V 1	**V 2**	**V 3 …**	**V n**	**Influence (Y-Axis)**
V 1	0	(V1,V2)	(V1,V3) …	(V1,Vn)	∑ ($Var_{1\text{-}j}$)
V 2	(V2,V1)	0	(V2,V3)	(V2,Vn)	
V 3	(V3,V1)	(V3,V2)	0	(V3,Vn)	
..					
Vn	(Vn,V1)	(Vn,V2)	(Vn,V3)	0	
Dependence (X-Axis)	∑ ($Var_{j\text{-}1}$)				

Source: Rosalinda et al. (2022)

The results of the first round are then processed using MICMAC software (developed by LIPSOR) to identify the key variables, which is the main objective of the MICMAC analysis. This analysis is enriched by the initial information gathered by the researcher or planner. The results are then used in the second round of FGD to confirm the findings related to the studied system. The two stages of the process lead to the identification of the key drivers that influence changes within the system. The analysis flow of MICMAC is illustrated in Figure 2.

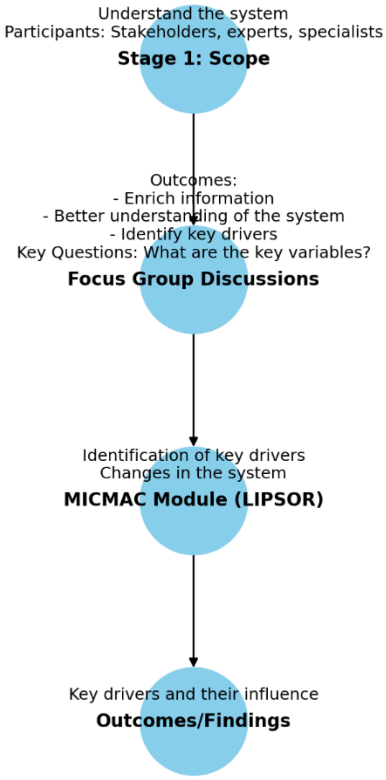

Figure 2. Framework of MICMAC modified from Stratigea (2013)
Source: Rachmawatie and Fauzi, (2024)

In the subsequent stage, the intensity of influence and dependence among variables is analyzed, based on their position on the quadrant map, as shown in Figure 3.

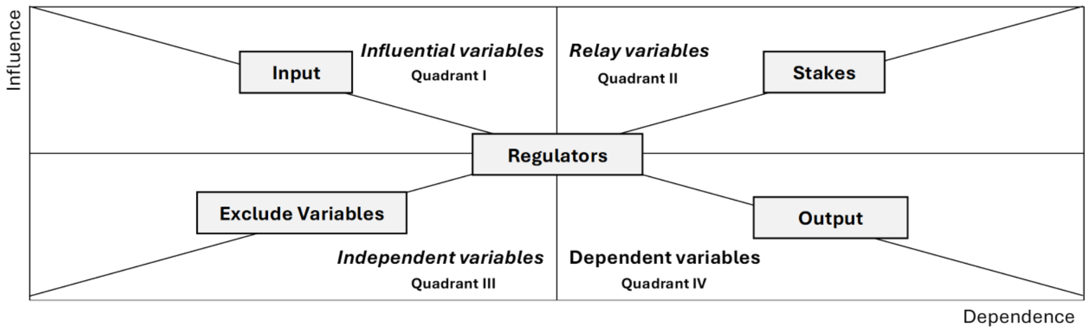

Figure 3. Illustration of MICMAC Analysis Results
Source: Rosalinda et al., (2022)

3. Result and Discussion

3.1 Publication by Country

Figure 4. Countries leading in renewable energy

Figure 4 presents a world map highlighting the distribution of publications related to renewable energy across various countries from 2014 to 2023. The map uses different colors to represent the number of publications from each country. The United States, marked in red, leads with 178 publications, indicating a significant focus on renewable energy research. China, shown in green, follows with 51 publications, reflecting its growing interest in this field. Spain, highlighted in yellow, has 26 publications, while Brazil and France, represented in blue and pink respectively, each have 23 publications. This map visually emphasizes the global landscape of renewable energy research, showcasing the countries that are most actively contributing to the field through academic and scientific publications.

3.2 An Overview of Renewable Energy

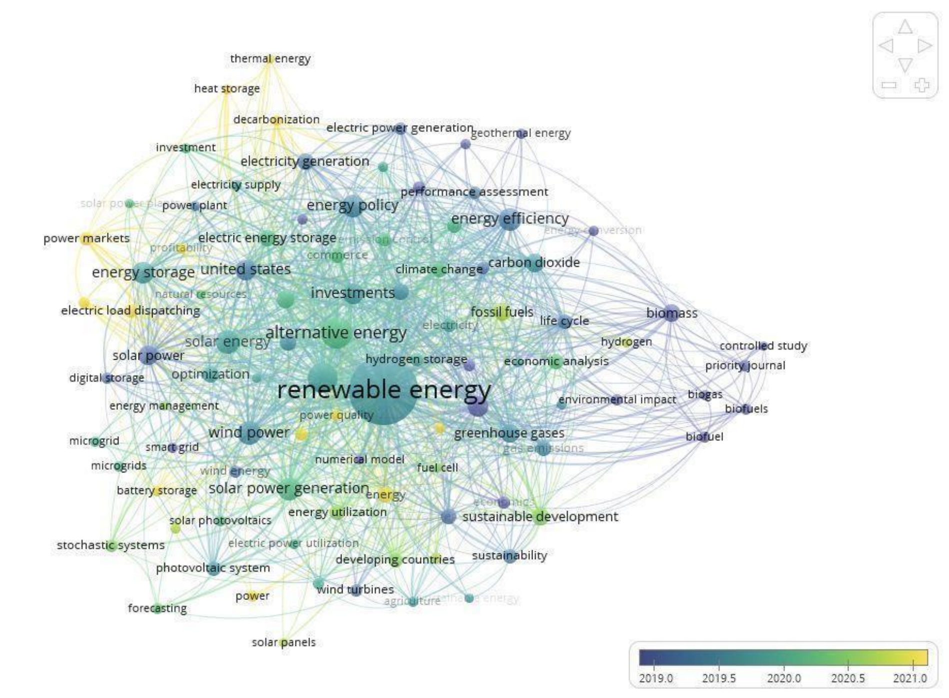

Figure 5. Portrait of the development of solar power plant

The development of research on renewable energy, particularly focusing on solar power, has evolved in recent years. As illustrated by the colors and years in the visualization, research between 2019 and 2020 emphasized themes such as energy storage, energy efficiency, and investment. From 2020 to 2021, research shifted toward optimizing renewable energy systems, with an increasing focus on solar power plant. Topics such as solar photovoltaics, solar panels, and solar power plant applications gained momentum. This research underscores the importance of efficiency, grid integration, and the role of solar energy in reducing dependence on fossil fuels. Based on this trend, a potential research novelty lies in exploring the integration of solar power. This direction offers a more comprehensive perspective by identifying the critical variables that support the successful implementation and sustainability of renewable energy projects. Such a combined approach provides new insights for future energy development models.

To analyze the relationships among key variables, Focus Group Discussions (FGD) and questionnaires were conducted, with data processed using the MICMAC method (Matrix of Crossed Impact Multiplications Applied to Classification). In the questionnaires, respondents assessed the interrelations between variables using the following scale:

0 = Non-existent influence
1 = Low direct influence
2 = Medium direct influence
3 = High direct influence
P = Potential influence

This structured approach classifies variables based on their influence and dependency, helping identify key factors crucial for enhancing solar power within sustainable energy systems. By categorizing variables into drivers, dependencies, linkages, and autonomous factors, the MICMAC method reveals how different elements interact.

This classification enables a strategic focus, ensuring that efforts target variables with the most significant impact on sustainable solar energy development. The insights gained provide actionable recommendations for policymakers and stakeholders, facilitating effective decision-making and resource allocation. By leveraging these critical factors, this approach supports the successful integration of solar power into broader renewable energy initiatives, promoting long-term sustainability.

	1 : NEP	2 : ESD	3 : LFA	4 : UR	5 : PR	6 : EI	7 : CS	8 : EIF	9 : ER	10 : AC	11 : CI	12 : QL	13 : HDI	14 : RIR	15 : LWP	16 : AP	17 : EQI	18 : SNRU	19 : FFR	20 : CCI	21 : LC	22 : LCR	23 : SP	24 : LEI	25 : EIC	26 : GPC	27 : REPS	28 : EDN
1 : New Economic Potential	0	3	3	2	2	3	2	1	1	1	1	2	1	1	1	1	2	1	2	1	2	1	2	2	2	2	2	2
2 : Economic Sector Development	3	0	3	2	2	3	3	2	2	1	1	2	1	2	1	1	2	1	1	1	1	1	2	2	2	2	2	2
3 : Labor Force Absorption	3	3	0	3	3	3	3	2	2	2	2	3	2	2	1	1	3	2	2	2	2	1	2	3	3	3	2	2
4 : Unemployment Reduction	2	2	3	0	3	3	2	2	1	1	1	2	1	2	1	1	2	2	2	2	2	1	1	2	2	2	2	2
5 : Poverty Reduction	2	2	3	3	0	3	2	2	1	1	1	2	2	3	2	2	2	2	2	2	2	1	1	2	2	2	2	2
6 : Energy Investment	3	3	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
7 : Competitiveness	2	3	3	2	2	3	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2
8 : Energy Infrastructure	1	2	2	2	2	3	2	0	3	3	3	3	3	3	2	2	3	3	3	3	3	2	2	3	3	3	2	2
9 : Electrification Ratio	1	2	2	1	1	3	2	3	0	3	3	3	3	3	2	2	3	3	3	3	3	2	2	3	3	3	2	2
10 : Accessibility	1	1	2	1	1	3	2	3	3	0	3	3	3	3	2	2	3	2	2	2	2	3	2	2	2	2	2	2
11 : Community Involvement	1	1	2	1	1	3	2	3	3	3	0	3	3	3	3	2	3	2	2	2	2	3	3	3	3	3	3	3
12 : Quality of Life	2	2	3	2	2	3	2	3	3	3	3	0	3	3	3	2	3	2	2	2	2	3	3	3	3	3	3	3
13 : Human Development Index	1	1	2	1	2	3	2	3	3	3	3	3	0	3	3	2	3	2	2	2	2	3	3	3	3	3	3	3
14 : Regional Inequality Reduction	1	2	2	2	3	3	2	3	3	3	3	3	3	0	2	2	3	2	2	2	2	3	3	3	3	3	3	3
15 : Liquid Waste Pollution	1	1	1	1	2	3	2	2	2	3	3	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	2
16 : Air Pollution	1	1	1	1	2	3	2	2	2	3	3	3	3	3	2	0	2	2	2	2	2	3	2	2	2	2	2	2
17 : Environmental Quality Index	2	2	3	2	2	3	2	3	3	3	3	3	3	3	3	2	0	3	3	3	3	2	3	3	2	2	2	2
18 : Sustainable Natural Resource Use	1	1	2	1	2	3	2	3	3	3	3	3	3	3	2	2	3	0	2	2	2	2	2	2	2	2	2	2
19 : Fossil Fuel Reduction	2	1	2	2	2	3	2	3	3	3	3	3	3	3	3	2	3	2	0	2	2	2	2	2	2	2	2	2
20 : Climate Change Impact	1	1	2	2	2	3	2	3	3	3	3	3	3	3	2	2	3	2	2	0	2	2	2	2	2	2	2	2
21 : Land Conservation	2	2	2	2	2	3	2	2	2	2	2	3	2	3	2	2	3	2	2	2	0	2	2	2	2	2	2	2
22 : Local Customary Regulations	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	3	2	2	2	2	2	0	2	2	2	2	2	2
23 : Stakeholder Participation	2	2	2	2	2	3	3	2	2	3	3	3	3	3	3	2	3	2	2	2	2	2	0	2	2	2	2	2
24 : Local Economic Incentives	2	2	2	2	2	3	2	2	2	3	3	3	3	3	2	2	3	2	2	2	2	2	0	2	2	2	2	2
25 : Energy Institutional Capacity	2	2	3	2	2	3	2	2	2	3	3	3	3	3	2	2	2	2	2	2	2	2	2	0	2	2	2	2
26 : Government-Private Collaboration	2	2	3	2	2	3	2	2	2	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	0	2	1	2
27 : Renewable Energy Policy Support	2	2	2	2	2	2	2	2	2	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0	2
28 : Energy Distribution Network	2	2	2	2	2	2	2	2	2	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0

Figure 6. Illustration of MICMAC analysis results: solar power plant sustainability in Karangasem, Bali Province (2024)

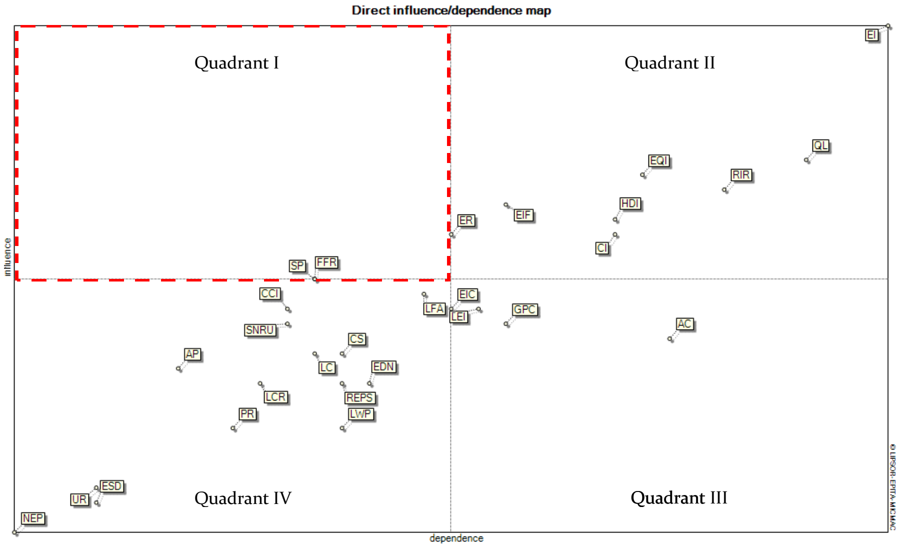

Figure 7. Map of sustainability variables by influence and dependence

The results of these assessments were classified into four MICMAC quadrants, depicting the position of variables based on their influence and dependence on other variables. In the quadrant of direct influence, the variables are categorized into four types. Quadrant I consists of influence variables, which have a significant impact on the system but are not heavily dependent on other variables. Quadrant II includes relay variables, which are both influential and highly dependent, acting as intermediaries that influence other variables while being significantly affected by them. Quadrant III comprises dependent variables, which exhibit high levels of dependency but have low influence within the system. Lastly, Quadrant IV contains autonomous variables, which demonstrate both low impact and low dependency, operating independently without significantly affecting or being influenced by other variables.

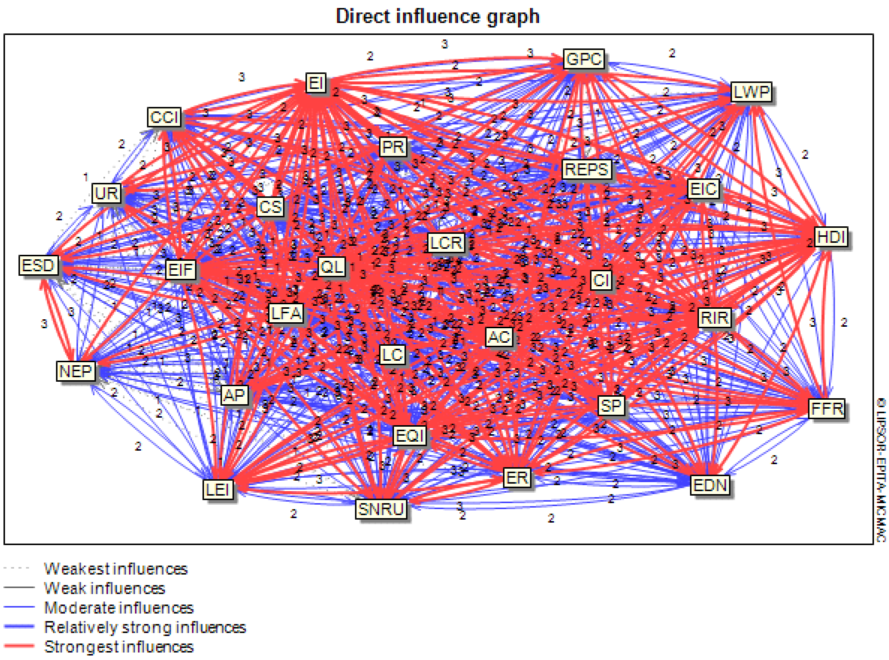

Figure 8. Graph of direct influence relationships between variables

In the context of the development of Solar Power Plant in rural areas, some variables act as primary drivers, while others depend more on external factors. Variables such as ESD (development of existing economic sectors), AP (reduction of air pollution), SNRU (increased sustainable use of natural resources), and PR (reduction of poverty) have a strong influence on other variables. These variables are directly linked to economic development and environmental sustainability in rural areas, making them critical drivers of significant changes in community life.

For example, the development of the local economy (ESD) can increase community income, attract renewable energy investments, and enhance well-being, ultimately improving the environmental quality index (EQI) and reducing poverty (PR). This situation is expected to boost group participation levels (Rachmawatie, 2024), which will, in turn, raise public awareness of the importance of environmental preservation. Increased awareness is likely to have a positive impact on the rural environment in villages across Karangasem Regency, particularly as communities begin to benefit from electricity produced by solar power plants. For example, the residents of Kubu Village only gained access to electricity from solar power plant in 2016, meaning that from Indonesia's independence until 2015, they had no access to modern electricity. During this time, the community maintained a traditional lifestyle, using firewood for cooking and oil lamps for lighting. This extended period without electricity highlights the limited living conditions before the arrival of solar power plant. With the development of solar power plant, the rural environment is expected to improve, becoming cleaner, more sustainable, and free of emissions, as the reliance on firewood for basic energy needs will no longer be necessary.

Conversely, variables such as EQI (Environmental Quality Index), EI (Energy Sector Investment), SP (Local Stakeholder Participation), and RIR (Regional Inequality Index) are more influenced by primary driving variables. For instance, improving the environmental quality index (EQI) relies heavily on the reduction of air pollution (AP) and the sustainable use of renewable energy (SNRU). Similarly, growth in energy sector investment (EI) depends significantly on the development of existing economic sectors (ESD) and supportive policies. Local stakeholder participation (SP) and the reduction of regional inequality (RIR) are closely linked to poverty reduction (PR) and sustainable resource utilization (SNRU).

These interconnections demonstrate that driver variables like ESD, AP, SNRU, and PR create the foundation for other variables to develop. Meanwhile, dependent variables such as EQI, EI, SP, and RIR are significantly influenced by these external factors. The combination of influence and dependency creates a complex dynamic where the development of solar power plant in rural areas can act as catalysts for broader economic, social, environmental, and institutional changes, with all variables supporting and reinforcing one another.

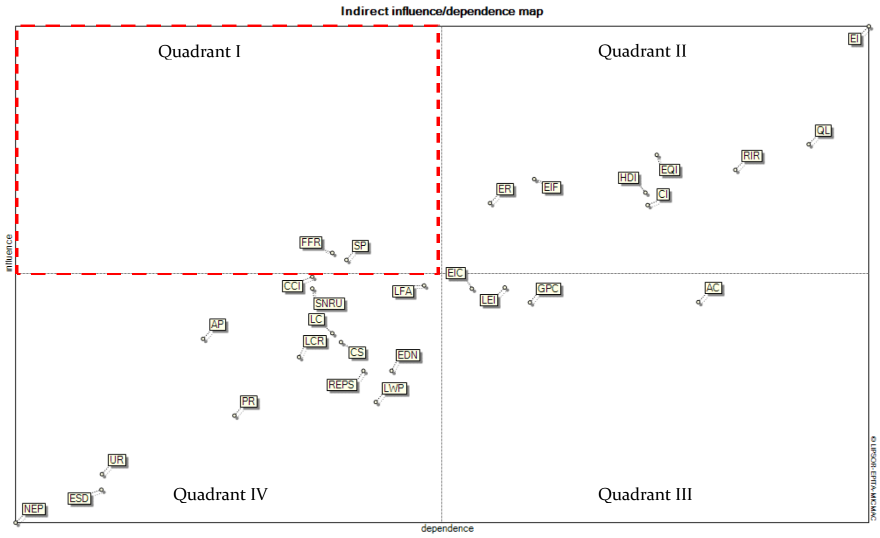

Figure 9. Map of sustainability variables according to indirect influence and dependence

Figure 9 illustrates the quadrants that depict the indirect influence of various variables. Based on the figure, some variables remain in the same quadrant when compared to the direct influence map, while others may experience positional shifts. In Quadrant I (High Influence Variables), the variables FFR (Fossil Fuel Reduction) and SP (Stakeholder Participation) are positioned due to their strong influence on the sustainability of solar power resources in Bali, while exhibiting low dependence on other variables. This position highlights their pivotal role in driving the development and effectiveness of solar energy initiatives in the region.

The variable FFR is crucial as it directly impacts the overall environmental sustainability of energy production in Bali. By reducing reliance on fossil fuels, the adoption of solar power resources contributes to lower greenhouse gas emissions and less environmental degradation, aligning with global sustainability goals. This transition not only enhances the ecological integrity of the region but also promotes energy independence, as solar energy harnesses a renewable resource that is abundant in Bali. On the other hand, SP underscores the importance of stakeholder participation in the success of solar power projects. Engaging local communities, government agencies, and private sectors fosters a collaborative environment that can address concerns, share knowledge, and enhance the acceptance of solar technologies. Stakeholder participation ensures that the needs and aspirations of the community are considered, leading to more effective implementation and maintenance of solar power resources. This collaborative approach also strengthens the resilience of the energy system by building local capacity and promoting social equity.

Overall, the strong influence of FFR and SP, combined with their low dependence on other variables, suggests that these factors can significantly shape the trajectory of sustainable solar power development in Bali, facilitating the transition to a cleaner and more sustainable energy future. Their roles as independent yet impactful variables highlight the importance of both environmental considerations and community involvement in achieving sustainability in the region's energy landscape.

In Quadrant II (Relay Variables), the variables have high influence but also depend heavily on others. The direct influence map indicates that ER (Electrification Ratio), EIF (Energy Infrastructure), HDI (Human Development Index), CI (Community Involvement), EQI (Environmental Quality Index), RIR (Regional Inequality Reduction), QL (Quality of Life), and EI (Energy Investment) reside here. These variables act as intermediaries, influencing others while being significantly affected by external factors.

Quadrant III (Dependent Variables) includes variables that are highly dependent on others but have low influence. Variables such as LEI (Local Economic Incentives), EIC (Energy Institutional Capacity), GPC (Government-Private Collaboration), and AC (Accessibility) fall into this quadrant, indicating that they are affected by many other variables but do not significantly influence the overall system.

Lastly, Quadrant IV (Autonomous Variables) comprises those with both low influence and low dependence. These variables, including LFA (Labor Force Absorption), CCI (Climate Change Impact), SNRU (Sustainable Natural Resource Use), LC (Land Conservation), CS (Competitiveness), REPS (Renewable Energy Policy Support), EDN (Energy Distribution Network), LWP (Liquid Waste Pollution), LCR (Local Customary Regulations), PR (Poverty Reduction), AP (Air Pollution), UR (Unemployment Reduction), ESD (Economic Sector Development), and NEP (New Economic Potential), operate relatively independently within the system.

This comprehensive map provides a detailed perspective on how direct and indirect influences function within the system and how these variables interact concerning their influence and dependence. By understanding these dynamics, stakeholders can better identify strategies for enhancing the sustainability of solar power resources in Bali, focusing on high-influence variables and ensuring that relay variables are effectively supported by relevant policies and practices.

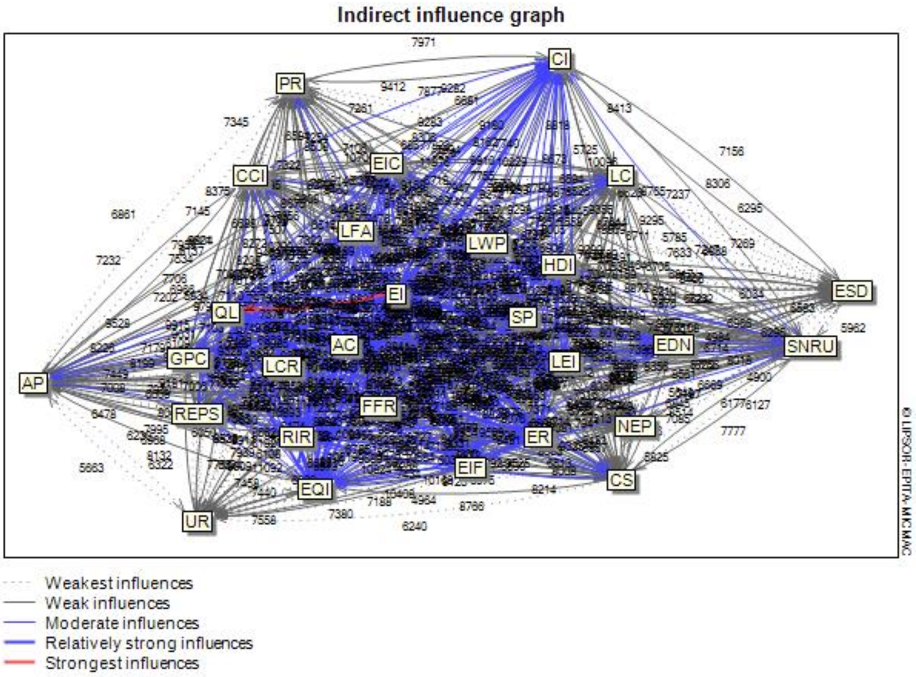

Figure 10. Graph of indirect influence relationship between variables

The image illustrates an indirect influence graph, which depicts the relationships between various variables with moderate to strong impacts on others. According to Figure 10, most variables are primarily affected by weak to moderate influences. However, the graph also indicates that the variables representing the growth of energy sector investment in the local village, town, or region (EI) and the improvement in the quality of life for the local community (QL) have the most substantial influence, as shown by a thick red line.

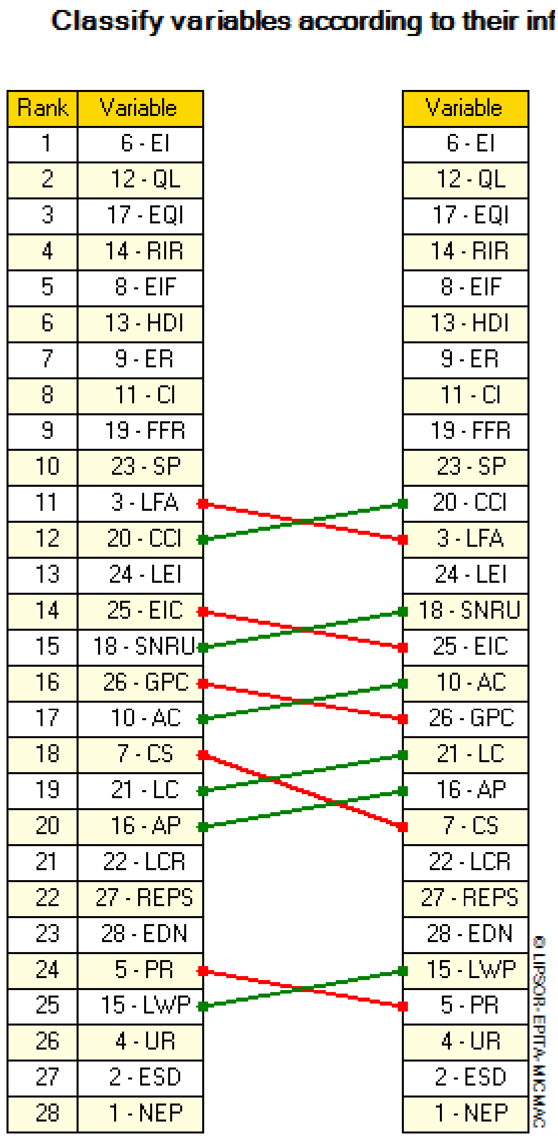

Figure 11. Rank of variables based on dependencies

Figure 11 shows the changes in the ranking of variables based on their influence. The changes illustrated in the figure indicate that the ranking positions of variables shift from their initial state in the MDI (Matrix of Direct Influence) to the updated state after the Boolean iteration with MII (Matrix of Indirect Influence). Based on Figure 8, it is evident that several variables experienced a drop in ranking after accounting for indirect influence. For example, the variable LFA dropped from rank 11 to 12, EIC from 14 to 15, GPC from 16 to 17, CS from 18 to 20, and PR from 24 to 25. Meanwhile, some variables saw an increase in ranking after considering indirect influence, such as CCI, which rose from rank 12 to 11, SNRU from 15 to 14, AC from 17 to 16, LC from 19 to 18, AP from 20 to 19, and LWP from 25 to 24.

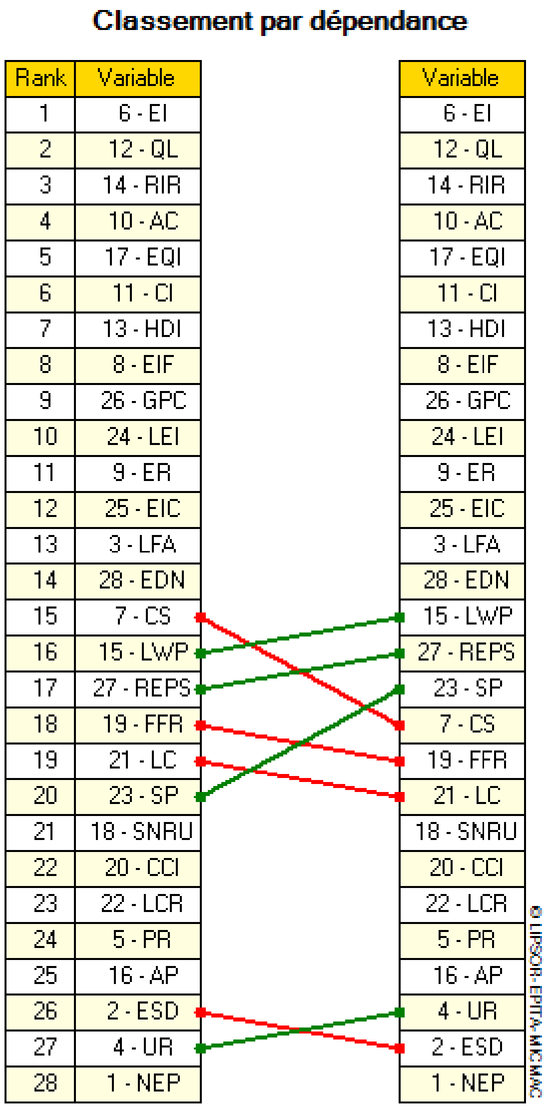

Figure 12. Rank of variables based on dependencies

Figure 12 illustrates the ranking changes due to dependency influences. The variables CS, FFR, LC, and ESD experienced a decline in ranking because they were affected by dependency factors. Conversely, the variables LWP, REPS, SP, and UR improved their rankings in terms of dependency. For example, CS dropped from rank 15 to 18, FFR from 18 to 19, LC from 19 to 20, and ESD from 26 to 27. On the other hand, some variables improved after accounting for indirect influence, such as LWP rising from rank 16 to 15, REPS from 17 to 16, SP from 20 to 17, and UR from 27 to 26. The variable related to energy sector investment growth in local villages, towns, or regions (EI) consistently held the top rank in the MDI (Matrix of Direct Influence) as a dependent variable. This indicates that the sustainability of solar power plant development is significantly influenced by other variables.

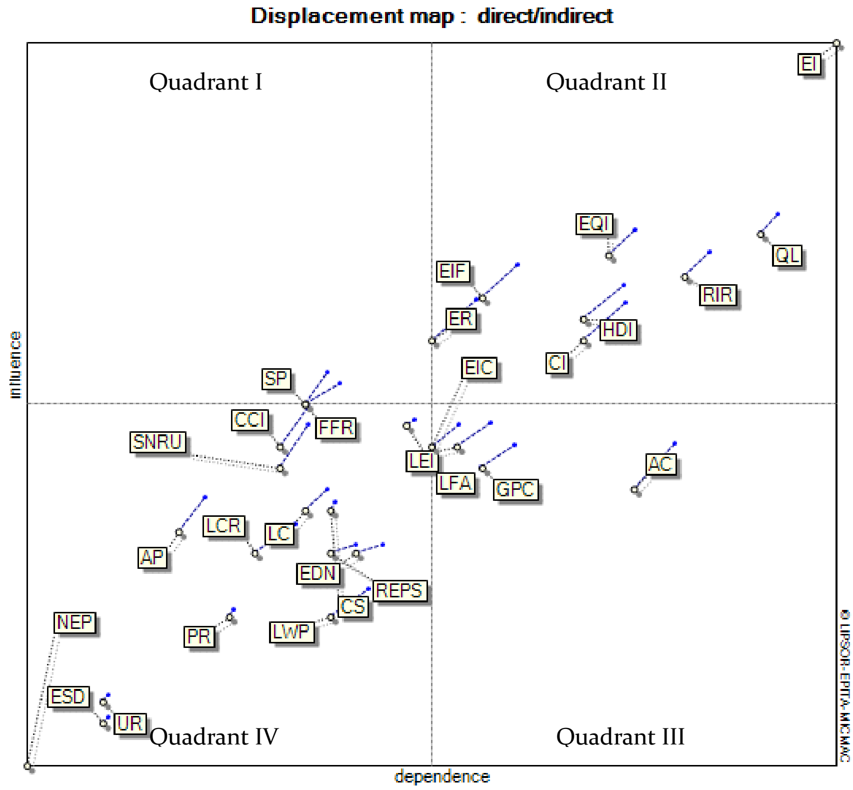

Figure 13. Intervariable displacement map from direct to indirect influence

Figure 13 presents a displacement map that visualizes shifts in variable positions due to indirect influences. This analysis provides essential insights into how policymakers can leverage these relationships to enhance renewable energy programs in rural contexts, ensuring that findings are relevant not only to Karangasem but also to similar regions globally facing energy access challenges.

4. Conclusions

This research provides essential insights into the development of Solar Power Plants in rural areas, focusing on the social, economic, and environmental factors that influence sustainability. Through the application of the MICMAC method, the study identifies key variables shaping renewable energy development in remote regions like Karangasem Regency, Bali. The findings highlight those crucial elements such as Local Economic Sector Development (ESD), Sustainable Natural Resource Utilization (SNRU), and Air Pollution Reduction (AP) have a direct impact on the sustainability of these energy systems. These factors also play a significant role in influencing dependent aspects like Environmental Quality (EQI) and Energy Sector Investment (EI).

The analysis reveals that several variables shifted positions when indirect influences were considered, underscoring the dynamic nature of sustainability efforts. Solar power plant initiatives have been shown to directly improve local livelihoods, enhance social well-being, and contribute to better environmental conditions. The study emphasizes the importance of establishing comprehensive policies and fostering collaborative efforts among governments, communities, and private stakeholders to fully realize the benefits of renewable energy programs in rural areas.

While the findings focus on Karangasem, they offer valuable lessons for rural communities worldwide facing similar energy-related challenges. Regions with difficult terrain or limited access to conventional energy infrastructure often depend on costly and unsustainable sources like kerosene and diesel, which hinder economic growth and social welfare. By applying the insights from this study, policymakers and stakeholders can develop tailored renewable energy strategies that promote sustainable development, reduce environmental harm, and enhance the quality of life in these communities.

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