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Energy Poverty: Analysis of Infrastructure and Geographic Factors in Rural Areas of Indonesia

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ABSTRACT

This study aims to analyze the factors that influence the chances of energy poverty in rural areas of Indonesia, with a focus on the role of infrastructure and geographic conditions. The data used comes from the 2018 Village Potential Data Collection (PODES), which covers 3,293 selected villages through purposive sampling techniques. The analytical method applied is binary logistic regression with a quantitative approach, using the maximum likelihood (ML) method for model estimation. The results of the study show that education, health infrastructure, and renewable energy development play a significant role in reducing energy poverty. In addition, the geographical conditions of remote and coastal villages are the main obstacles in the distribution of modern energy. The conclusion of this study emphasizes the need for integrative and sustainable policies, which pay attention to aspects of infrastructure, economy, and geographic characteristics, in order to increase access to clean and sustainable energy in rural areas of Indonesia, especially in the 3T areas. This strategy is expected to support inclusive and sustainable socio-economic development at the village level.

Keywords: Energy Poverty, Rural Areas, Infrastructure, Geographic
JEL Classifications: O18, Q48

1. INTRODUCTION

Energy is essential for achieving a decent standard of living and meeting basic human needs. An assessment of the linkages between SDG goal seven and other SDGs has highlighted the central role of energy in achieving sustainable development (ESMAP Annual Report, 2020). This study focuses on the issue of energy poverty in rural areas of Indonesia, combining infrastructure factors and geographical aspects as the main analytical framework. In the Indonesian context, the government's efforts to increase access to electricity through the national electrification program have shown significant progress, with the electrification ratio increasing from 72.95% in 2011 to 99.20% in 2020. However, this achievement does not fully resolve the problems related to access to clean and affordable energy, especially those related to cooking needs and sustainable energy in the 3T (disadvantaged, frontier, and outermost) areas. This context emphasizes the importance of in-depth analysis to understand the dynamics of energy poverty at the rural level that are more specific and multifaceted (Figure 1).

Field phenomena show that even though the electrification rate has reached close to 100%, in reality many villages in Indonesia still face problems in fulfilling clean energy and the quality of energy services. These figures can give the impression that the problem of energy poverty has been formally resolved, whereas aspects such as fulfilling energy for cooking needs and the quality of energy used are still major challenges. Therefore, this study is important to investigate the factors causing energy poverty more comprehensively and in depth, and to examine why the electrification rate does not directly support the sustainability of decent and affordable energy at the village level (Sambodo and Novandra, 2019).

Previous studies focused more on the socio-economic impacts of energy poverty at the household level, this study attempts to examine more broadly the aspects of rural areas as a different entity from the framework of previous studies. This is important because the characteristics of rural areas, such as infrastructure, natural resource potential, and geographical conditions, have a major influence on community energy access and utilization (Adu and Anthony Miles, 2023).

Several previous studies have shown that energy poverty tends to be concentrated in certain groups of people located in remote areas and with low incomes. Existing data suggests that energy poverty is not only related to the lack of electricity supply, but also to the quality of fuel used and building conditions that do not support energy efficiency. In many countries including Indonesia, energy poverty is also often connected to social and economic inequality that worsens the sustainability of development, so it is important to integrate infrastructure and geographic aspects in this analysis (Piwowar, 2020).

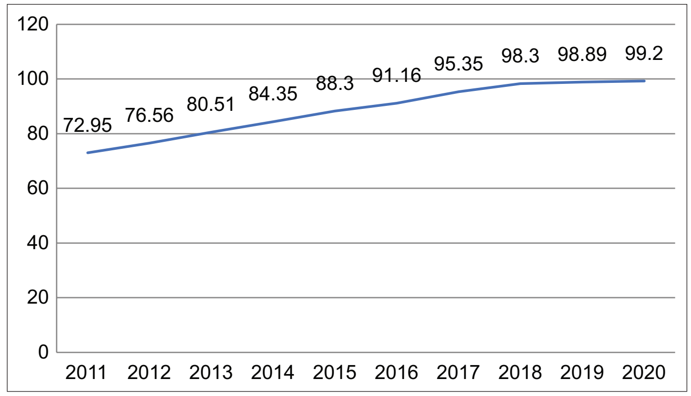
Stefan Bouzarovski and Petrova (2015) in his research shows that globally, the experience of various countries on energy poverty is not only a matter of access, but also related to economic factors and geographic location that affect the availability and quality of energy. For example, in Brazil and China, rural areas face major challenges in terms of clean energy distribution and air quality from non-environmentally friendly fuels. In China itself, the widespread use of biomass and coal causes indoor air pollution, which shows that rural energy conditions can have negative consequences for health and the environment. This international experience shows the need for a comprehensive approach to addressing rural energy poverty (Bezerra et al., 2022).

In the ASEAN region, including Laos and Cambodia, the issue of energy access in rural areas remains a major obstacle to socio-economic development. Low income and remote geographic locations are the main factors causing inadequate energy access, thus hampering the achievement of the SDGs (sustainable development goals). This global focus shows that energy poverty is a cross-border problem and requires regional and national solutions. Policy integration at the central and local government levels is essential so that all villages can obtain sufficient, sustainable and affordable energy (Oum, 2019).

Households in developing countries face difficulties in accessing adequate energy for their daily needs. This can be due to limited energy infrastructure, financial constraints, or specific geographic factors. In South Asia, particularly in countries such as India and Bangladesh, rural energy poverty continues to be a major barrier to economic development and social well-being. Infrastructure constraints, economic conditions, and geographic factors contribute significantly to low access to clean and affordable energy. Energy poverty is considered a major barrier to inclusive and sustainable development in the region. Therefore, energy subsidy programs and the development of renewable energy technologies are strategic steps to address these challenges (Abdoulaye Sy and Mokaddem, 2022).

Studies from various countries show that energy poverty is closely related to health conditions, environmental sustainability, and household social welfare. In Poland and China, for example, inequality in terms of access and quality of energy in villages has a direct impact on residents' health, such as the risk of diseases caused by smoke in the house, and also on the choice of environmentally friendly energy technologies. This experience shows that addressing energy poverty must include aspects of education, financial policies, and targeted infrastructure development (Shan et al., 2015).

Figure 1: Indonesia's electrification ratio 2011-2020 (percent)



Source: Badan Pusat Statistik, (2022)

Conceptually, this study confirms that energy poverty is a multidimensional problem involving economic, social, infrastructure, and geographical conditions. A holistic approach is needed that not only focuses on increasing electricity access quantitatively, but also pays attention to energy quality, environmental sustainability, and village community participation in the energy transition process. Strengthening local capacity and community education are the main pillars so that village communities are able to utilize the potential of renewable energy sources optimally and sustainably (Phoumin and Kimura, 2019).

Addressing energy poverty in rural Indonesia requires integrated and sustainable policies. The importance of developing appropriate infrastructure, government support, and increasing public energy awareness and literacy are strategic steps that must be prioritized. Energy poverty is not only an access issue, but also part of inclusive, equitable, and sustainable socio-economic development throughout rural Indonesia (Aristondo and Onaindia, 2023).

2. LITERATUR REVIEW

The concept of energy poverty can be measured using indicators such as LIHC, TPR, HEO, DCEN index, etc. (Antepara et al., 2020; Papada and Kaliampakos, 2020; Sokołowski et al., 2020). In general, energy poverty refers to a situation where there are problems with maintaining an appropriate (comfortable) temperature in a dwelling (heating in winter and cooling in summer) and other problems related to lighting, cooking, using appliances (Thomson et al., 2019).

Energy poverty is a serious socio-economic challenge not only in countries with relatively low levels of socio-economic development, but also in highly and extremely developed countries. Energy security theory emphasizes the importance of the ability of energy systems to withstand and recover from disturbances. In the rural context, this theory highlights how renewable energy development can enhance energy security and reduce energy poverty (Gilbertson et al., 2012).

Research by Chodkowska-Miszczuk et al. (2021) shows that it is necessary in rural areas to manage electricity and heat more ecologically. In conclusion, the authors emphasize that institutional support and strengthening of local social capital are important. The development of energy infrastructure must be accompanied by good planning and community participation to ensure that the projects are in line with local needs and are sustainable (Marans, 2021).

Rural infrastructure includes the analysis of various types of educational, health, communication, energy and other infrastructure in the context of social, economic and environmental development. Educational infrastructure has an important relationship with energy poverty. According to Pachauri and Spreng (2011), educational infrastructure has a negative impact on energy poverty, where good educational infrastructure will enable people to gain access to education that improves their understanding of the benefits and how to use modern energy. According to Sovacool and Drupady (2011), education infrastructure has a negative impact on energy poverty, where areas with poor education infrastructure often also experience energy poverty.

Health infrastructure in rural areas often experiences limitations in terms of physical facilities, health workers, and geographic accessibility. According to Pachauri and Spreng (2011), health infrastructure has a negative impact on energy poverty, where good health infrastructure will support public health, so that they are more productive in their work. According to Sovacool and Drupady (2011), health infrastructure has a negative impact on energy poverty, where there are several cases experienced by people with low incomes who will prioritize health sector investment over investment in modern energy.

Rural communication infrastructure is very important to support economic growth, education, and health. According to Wilson and Symons (2020), communication infrastructure has a negative impact on energy poverty, where communication infrastructure, such as internet signal strength and the number of Base Transceiver Stations (BTS), has a significant impact on energy poverty. According to Sovacool (2012), communication infrastructure has a negative impact on energy poverty, where areas with minimal BTS or weak internet signals also tend to experience increased energy poverty. Complementary energy infrastructure in rural areas includes alternative energy sources, such as solar, wind, and biomass, which aim to provide affordable energy.

According to Sovacool (2012), complementary energy has a negative impact on energy poverty, where kerosene is a fossil fuel that is not environmentally friendly and has negative health impacts, especially if used in closed spaces. Rural geography encompasses an understanding of the physical, social, economic, and cultural characteristics of the area. Rural geography is also concerned with social resilience, which encompasses the ability of communities to cope with challenges such as natural disasters, climate change, and socioeconomic change (Barriers and Peterson, 2018). According to Pachauri and Spreng (2011), geography has a positive influence on energy poverty, where the mountainous slopes are difficult to reach by energy infrastructure, such as electricity networks or fuel transportation, due to difficult terrain and minimal road access.

3. METHODS

This research is a descriptive study with a quantitative approach. This study was conducted in Indonesia using secondary cross-section data from the Indonesian Village Potential Data Collection (PODES) issued by the Central Statistics Agency (BPS). The population in this study included all villages in Indonesia, while the sample used was 3,293 villages, selected using purposive sampling techniques. This study used a binary logistic method where the logit model estimation was carried out using the maximum likelihood (ML) method.

The basic equation in this study is as follows:

$$P_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_n x_n + \varepsilon$$

Thus, the empirical model of the research is as follows:

$$P_i = \beta_0 + \beta_{1\tau i}\,\text{primarydis1}_i + \beta_{2\tau i}\,\text{primarydis2}_i + \beta_{3\tau i}\,\text{seconddis1}_i + \beta_{4\tau i}\,\text{seconddis2}_i + \beta_{5\tau i}\,\text{highscholdis1}_{1i} + \beta_{6\tau i}\,\text{highscholdis2}_{1i} + \beta_{7\tau i}\,\text{unidis}_i + \beta_{8\tau i}\,\text{hosp1dis}_i + \beta_{9\tau i}\,\text{momchilddis}_i + \beta_{10\tau i}\,\text{healthunit1dis}_i + \beta_{11\tau i}\,\text{healthunit2dis}_i + \beta_{12\tau i}\,\text{healthunit3dis}_i + \beta_{13\tau i}\,\text{docdis}_i + \beta_{14\tau i}\,\text{midwivedis}_i ++ \beta_{15\tau i}\,\text{bts}_i + \beta_{16\tau i}\,\text{sigdis}_i + \beta_{17\tau i}\,\text{oildis}_i + \beta_{18\tau i}\,\text{sea}_i + \beta_{19\tau i}\,\text{peak}_i + \beta_{20\tau i}\,\text{roads\_surface}_i + \varepsilon$$

Where the dependent variable in this study is Pi (Energy poverty) with the independent variables are primarydis1 (Distance to the nearest elementary school), primarydis2 (Distance to the nearest MI), seconddis1 (Distance to the nearest junior high school), seconddis2 (Distance to the nearest MTS), highscholdis1 (Distance to the nearest high school), highscholdis2 (Distance to the nearest MA), unidis (Distance to the nearest college academy), hosp (Nearest distance to the hospital), momchilddis (Nearest distance to the maternity hospital), heallthunit1 (Nearest distance to the health center with inpatient care), heallthunit2 (Nearest distance to the health center without inpatient care), heallthunit3 (Nearest distance to the assistant health center), docdis (Nearest distance to the doctor's practice), midwifedis (Nearest distance to the midwife's practice), bts (Number of BTS towers), sigdis (Mobile phone internet signal), oildis (Existence of kerosene sales agent bases), sea (Existence settlements on the slopes of the peak), peak (village/sub-district that borders directly on the sea), roads_surface (Widest type of road surface).

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Final estimation of logistic model

This study was conducted to determine the probability of energy poverty in rural Indonesia. The estimation results are presented as follows:

Table 1: Coefficients of the estimation results of the energy poverty probability model

Variable	(1)	(2)
	Logit	Probit
Main		
Primarydis1	0.0129	0.00614
	(0.0137)	(0.00593)
Primarydis2	0.000870	0.000749
	(0.00291)	(0.00164)
Seconddis1	0.00621	0.000606
	(0.0107)	(0.00471)
Seconddis2	0.0150***	0.00787***
	(0.00334)	(0.00185)
Highschooldis1	0.0119**	0.00552**
	(0.00528)	(0.00270)
Highschooldis2	0.00487*	0.00322**
	(0.00276)	(0.00162)
Unidis	−0.0000926	0.000456
	(0.00248)	(0.00137)
Hosp1dis	−0.0137***	−0.00759***
	(0.00292)	(0.00158)
Momchilddis	0.00327*	0.00191*
	(0.00193)	(0.00110)
Healthunit1dis	0.00186	0.000697
	(0.00335)	(0.00175)
Healthunit2dis	0.000333	−0.000581
	(0.00271)	(0.00147)
Healthunit3dis	0.00224	0.00192
	(0.00389)	(0.00204)
Docdis	0.0152***	0.00894***
	(0.00300)	(0.00164)
Midwivedis	0.0172***	0.00974***
	(0.00236)	(0.00132)
Roads_surface	0.222**	0.130**
	(0.0917)	(0.0515)
Bts	−0.133**	−0.0728**
	(0.0578)	(0.0316)
Sigdis	0.485***	0.276***
	(0.0651)	(0.0365)
Oildis	−0.686***	−0.398***
	(0.115)	(0.0656)
Peak	0.435***	0.257***
	(0.103)	(0.0584)
Sea	1.049***	0.590***
	(0.134)	(0.0764)
_cons	−1.826***	−1.068***
	(0.291)	(0.165)
Aic	2461.4	2463.9
ll	−1209.7	−1211.0
N	3293	3293
LR (20)	2059.692	2057.208
Prob>Chi2	0.0412	0.0002
McFadden's R2	0.460	0.459
AIC	0.754	0.755
BIC	−1897.878	−1895.394
Goodness-of-fit test Chi2	0.837	0.835
Prob>Chi2	0.0412	0.0002

Standard errors in parentheses. *P<0.1, **P<0.05, ***P<0.01

Based on the test results that have been carried out on both the logit and probit models, prob > Chi^2 shows a significance level value of <0.05. This means that all independent variables simultaneously affect the probability of energy poverty in rural Indonesia. Based on Table 1, both using logit or probit show consistent results, meaning that the model can be said to be robust. In addition, the BIC value can be seen which shows that the best logit and probit models cover the probability of energy poverty which can be seen from the smallest BIC value. Based on the BIC value seen, the smallest BIC value is probit. Therefore, the best model for predicting the model is the probit regression model. When viewed from the diagnostic and post-estimation tests carried out on the three models, the table concludes that it is statistically significant because the Prob > Chi^2 value is <0.05. While the statistical value of the Pearson Chi^2 goodness-of-fit test for all models is also >0.05, it can be stated that the model is accepted and worthy of analysis.

Based on the results in Table 1, in the probit results, it can be seen that in the education infrastructure variable group, the variables seconddis2, highschooldis1. highschooldis2 have a significance value <alpha. The seconddis2 variable has a seconddis2 coefficient of 0.00787, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the distance to the seconddis2 school is further. The highschooldis1 variable has a highschooldis1 coefficient of 0.00552, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the distance to the highschooldis1 school is further. The highschooldis2 variable has a highschooldis2 coefficient of 0.00322, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the distance to the highschooldis2 school is further.

Based on the results in Table 1, in the probit results, it can be seen that in the health infrastructure variable group, the variables hosp1dis, momchilddis, docdis, and midwivedis have a significance value <alpha. The hosp1dis variable has a hosp1dis coefficient of −0.00759, meaning that villages with an average energy user of 1 (poor) have a lower chance of energy poverty than families with an average energy user of 0 when the hosp1dis distance is further. The momchilddis variable has a momchilddis coefficient of 0.00191, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the momchilddis distance is further. The docdis variable has a docdis coefficient of 0.00894, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the docdis distance is further. The midwivedis variable has a midwivedis coefficient of 0.00974, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the midwivedis distance is further.

Based on the results in Table 1, in the probit results, it can be seen that in the communication infrastructure variable group, the bts and sigdis variables have a significance value <alpha. The bts variable has a bts coefficient of −0.0728, meaning that villages with an average energy user of 1 (poor) have a lower chance of energy poverty than families with an average energy user of 0 when the number of bts is large. The sigdis variable has a sigdis coefficient of −0.276, meaning that villages with an average energy user of 1 (poor) have a lower chance of energy poverty than families with an average energy user of 0 when the sigdis internet signal is stronger.

Based on the results in Table 1, in the probit results, it can be seen that in the complementary energy infrastructure variable group, the oildis variable has a significance value <alpha. The oildis variable has an oildis coefficient of −0.398, meaning that villages with an average energy user of 1 (poor) have a lower chance of energy poverty than families with an average energy user of 0 when there are oildis sellers.

Based on the results in Table 1, in the probit results, it can be seen that in the group of topographic geography variables of the village and sub-district areas, the peak and sea variables have a significance value < alpha. The peak variable has a peak coefficient of 0.257, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when peak settlements exist. The sea variable has a sea coefficient of 0.590, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when sea settlements exist. The roads_surface variable has a roads_surface coefficient of 0.257, meaning that villages with an average energy user of 1 (poor) have a higher chance of energy poverty than families with an average energy user of 0 when the widest road surface type roads_surface is good.

The variables primarydis1, primarydis2, primarydis3, unidis, healthunit1dis, healthunit2dis and healthunit3dis have P > alpha. Based on this, the variables primarydis1, primarydis2, primarydis3, unidis, healthunit1dis, healthunit2dis and healthunit3dis have no differences in conditions in the 2 (two) groups.

4.2. Discussion

4.2.1. Education infrastructure to opportunities of rural energy poverty conditions in Indonesia

Educational infrastructure plays an important role in determining the level of energy poverty in rural areas. Villages that are far from secondary schools such as MTS, SMA, or MA tend to have a higher likelihood of experiencing energy poverty. This is due to the isolation of the area which not only limits access to education, but also access to transportation, health services, and energy. When access to education is limited, villagers have difficulty getting decent jobs, so incomes remain low and it is difficult to switch to more sustainable modern energy sources.

Research Fakayode et al. (2008) supports these findings by highlighting the importance of educational infrastructure in improving agricultural productivity and community welfare. In Indonesia, many farmers in remote areas lack access to quality education, which limits their knowledge and skills. School construction, teacher training, and education programs relevant to local needs can encourage the adoption of new technologies and efficient agricultural practices, thereby increasing incomes and enabling communities to shift from traditional to more modern energy sources.

However, Bezerra et al. (2022) put forward a different view that economic factors such as income and market access are more important in reducing energy poverty than educational infrastructure. Although education is important, its impact will be limited if it is not balanced with economic growth and quality of education. Even when education is available, people still use traditional energy due to limited access to technology or ingrained habits. Therefore, educational interventions must be accompanied by adequate economic support and energy infrastructure to effectively address energy poverty.

4.2.2. Health infrastructure to opportunities of rural energy poverty conditions in Indonesia

Access to health infrastructure has been shown to have a significant impact on energy poverty in rural areas. The distance of a village to a hospital, maternity hospital, doctor's practice, and midwife is an important indicator: the farther the distance, the more likely the village is to experience energy poverty. This is because remote villages tend to have limited infrastructure, including access to energy. Although some villages far from the main hospital appear to be unaffected due to their low energy consumption lifestyles, in general, limited access to health reflects the limitations of other infrastructure such as electricity and health technology. This condition shows the importance of an integrated approach in developing basic infrastructure. Villages that have closer access to health facilities usually also have better energy infrastructure. Development policies such as village electrification and the provision of basic health services in remote villages can simultaneously reduce energy poverty and improve community welfare.

Study conducted by Gilbertson et al. (2012) also emphasized that improving health and housing infrastructure can help reduce psychosocial stress and improve the health of people affected by energy poverty, for example by improving home ventilation or providing adequate energy for household needs.

However, research by Oihana Aristondo and Onaindia (2023) provide a different view. They emphasize that the main focus for reducing energy poverty should be on the development of energy infrastructure itself, not health. They argue that economic factors, such as income and employment, are more important than access to health services. In addition, changes in energy consumption patterns are also highly dependent on social and cultural norms, not solely on the availability of health facilities. Therefore, the development of health infrastructure must be accompanied by economic growth and social change in order to have a real impact on reducing energy poverty.

4.2.3. Communication infrastructure to opportunities of rural energy poverty conditions in Indonesia

Communication infrastructure such as BTS towers play an important role in reducing energy poverty in rural areas. The more BTS towers in a village, the higher the level of connectivity, both for access to information, education, digital health services, and economic opportunities. Good connectivity paves the way for people to find out about energy assistance programs, alternative energy technologies, and online job opportunities. Thus, villages that have strong internet signals and adequate communication infrastructure tend to have lower levels of energy poverty than villages with limited infrastructure. However, this success depends on the availability of energy itself. BTS towers require stable electricity to operate, so in areas without adequate electricity access, connectivity is disrupted. Therefore, the use of renewable energy such as solar panels for BTS towers is an important solution. This step not only provides stable communication services, but also encourages people to be more connected and economically independent. Research such as by Szabó et al. (2013) emphasized that the relationship between energy and communication is very close and mutually supportive to overcome energy poverty.

However, a different view was expressed by Fakayode et al. (2008), who considers that education and economic infrastructure are more fundamental than communication. Without adequate education, communities may not be able to utilize existing communication technology. The quality of communication services is often low in remote villages, so its benefits are limited. In other words, even though communication infrastructure is available, its impact on reducing energy poverty is not optimal if it is not supported by increasing human resource capacity through education and strengthening the community's economy.

4.2.4. Complementary energy infrastructure to opportunities in Indonesia's rural energy poverty Conditions

Complementary energy infrastructure such as the presence of kerosene sellers has been shown to have a significant impact on reducing energy poverty in Indonesian villages. The presence of kerosene sellers provides alternative energy access for people who do not yet have an electricity network or experience high energy costs. Kerosene is used for basic needs such as cooking and lighting, allowing poor families to still have access to energy even in limited conditions. Thus, villages that have kerosene sellers show lower levels of energy poverty than villages that do not.

However, this solution is short-term and not fully sustainable. The use of kerosene has an environmental impact and low efficiency if used continuously. The government has indeed encouraged an energy conversion program to LPG and renewable energy, but in many remote villages, distribution and price are still major obstacles. Therefore, although kerosene sellers play an important role today, long-term policies are still needed. This includes the development of renewable energy infrastructure, such as solar energy or bioenergy, as well as support for distribution policies and subsidies for energy poor communities.

Research conducted by Bhattacharya et al. (2021) supports this finding, that complementary energy infrastructure can improve energy accessibility in rural areas. However, criticism from Piwowar (2020) shows that dependence on kerosene is not a permanent solution to energy poverty. He emphasized the importance of transitioning to cleaner and more sustainable energy and investing in education, purchasing power, and other supporting infrastructure. In other words, complementary energy infrastructure such as kerosene sellers is important for short-term solutions, but cannot stand alone without a more comprehensive and sustainable energy development strategy.

4.2.5. Topographic geography of the region on the opportunities of rural energy poverty conditions in Indonesia

Complementary energy infrastructure has different impacts on rural energy poverty depending on its geographical conditions. Villages located on slopes, peaks, or cliffs tend to have higher chances of energy poverty due to challenges in accessing and distributing modern energy. Electricity grids and fuel distribution are difficult to build in such areas due to costs and technical constraints. As a result, communities rely on traditional energy sources such as firewood, which are inefficient, time-consuming, and have negative impacts on health. The same thing happens in coastal villages that are prone to abrasion and extreme weather, so energy infrastructure is more vulnerable to damage and energy distribution is more disrupted.

The type of surface and quality of inter-village roads also play an important but not always linear role in energy poverty. Wider roads do not always guarantee smooth energy distribution if they are of poor quality, unpaved, or impassable during the rainy season. Poor roads increase the cost of energy distribution, making energy prices more expensive for remote rural communities. In fact, wider inter-village roads can mean longer distances and more challenging distribution. As a result, communities become more dependent on expensive and inefficient local energy, exacerbating energy poverty.

Research conducted by Bezerra et al. (2022) emphasized the importance of taking into account geographical conditions and infrastructure in overcoming energy poverty, as is the case in Brazil and is also relevant in Indonesia. However, a different view was expressed by Primc et al. (2019), which states that geography is not the only key factor. Good infrastructure, policy support, and community empowerment can reduce the negative impacts of geographic location. Therefore, the development of weather-resilient and geographically friendly infrastructure such as solar energy with battery storage, improved road access, and energy efficiency education are very important. A holistic approach that combines technical, geographic, social, and policy aspects will be more effective in addressing energy poverty in rural Indonesia.

5. CONCLUSION

This study confirms that eradicating energy poverty in rural Indonesia requires a holistic approach by integrating various aspects of key infrastructure. Good education infrastructure can improve the quality of life by increasing productivity and public awareness of the importance of safe and affordable energy. Meanwhile, adequate health infrastructure is essential because energy poverty has a direct impact on people's physical and mental health, so improving access to health services will also improve general welfare. Communication infrastructure such as BTS towers also play an important role in expanding access to information about energy, education, and health services, which helps people face various challenges. In addition, the development of complementary energy, especially renewable energy, is a crucial solution to reduce dependence on polluting traditional energy, and policies that support this development must be tailored to local needs. No less important, geographical factors such as the location of remote villages or coastal areas are obstacles in energy distribution, so policy formulation must consider geographical and social conditions as a whole. With a coordinated, data-based approach that takes into account local contexts, it is hoped that equitable and sustainable energy access can be realized for rural communities who have been vulnerable to energy poverty.

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