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Impacts of PT Pertamina Geothermal Sibayak's Exploration on Economic, Social, and Environmental Aspects: A Case Study in Semangat Gunung Village, Karo District

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ABSTRACT

This research explores the direct and indirect impacts of PT Pertamina Geothermal (Tbk) Sibayak's geothermal exploration on the economic, social, and environmental aspects of Semangat Gunung Village in Merdeka District, Karo Regency. The study surveyed 120 residents, achieving a 100% response rate. Using the Lilliefors test, the data were found to be normally distributed. The socioeconomic and environmental impacts were assessed by comparing pre- and post-exploration conditions. Findings indicate significant effects on various aspects: employment opportunities increased, though business opportunities remained unaffected by the geothermal activities. Community income saw a decline, primarily due to environmental disruptions such as floods impacting agriculture. Despite these economic shifts, the majority of the population continued working in agriculture, with a significant minority engaged in informal businesses. The exploration activities also affected community comfort and cultural heritage, with a substantial number of residents expressing discomfort and concerns over environmental degradation. The study underscores the need for a strategic environmental management approach, identifying key internal and external factors influencing the community. Recommendations include leveraging strengths and opportunities while mitigating weaknesses and threats, using a Livelihood Approach matrix for strategic planning. These findings provide crucial insights for policymakers and stakeholders in managing the socioeconomic and environmental impacts of geothermal exploration.

1. INTRODUCTION

The growing global demand for renewable energy sources has led to increased interest in geothermal energy due to its sustainability and low environmental impact. Geothermal energy, derived from the Earth's internal heat, offers a stable and continuous power supply, making it an attractive alternative to fossil fuels. However, the exploration and extraction of geothermal energy are not without consequences, particularly for the local communities and environments where such activities take place. This research focuses on the direct and indirect impacts of PT Pertamina Geothermal (Tbk) Sibayak's geothermal exploration on the economic, social, and environmental aspects of Semangat Gunung Village in Merdeka District, Karo Regency [1, 2]. Globally, geothermal energy is recognized as a critical component in the transition to sustainable energy systems. Countries like Iceland, the Philippines, and New Zealand have successfully integrated geothermal energy into their national grids, significantly reducing their carbon footprints. Indonesia, situated on the Pacific Ring of Fire, has abundant geothermal resources, ranking among the top countries in geothermal potential [3, 4]. The Indonesian government's push towards renewable energy has seen significant investments in geothermal projects, aiming to meet the nation's energy demands while adhering to international climate agreements [5].

PT Pertamina Geothermal Energy (PGE), a subsidiary of PT Pertamina (Persero), has been at the forefront of geothermal exploration in Indonesia. PGE's Sibayak geothermal field, located in North Sumatra, is one of the key projects contributing to the nation's renewable energy targets. However, the socio-economic and environmental ramifications of such projects need careful assessment to ensure that the benefits outweigh the potential adverse effects on local communities [6, 7]. Semangat Gunung Village, located in the Merdeka District of Karo Regency, is a community deeply intertwined with its natural environment. The village, with a population of 8,756 people spread across 9.22 km², relies heavily on agriculture for its livelihood. The geothermal exploration activities by PT Pertamina Geothermal (Tbk) Sibayak in the region have introduced both opportunities and challenges for the local population [8, 9].

The primary objective of this research is to analyze the

direct and indirect impacts of geothermal exploration on the economic, social, and environmental aspects of Semangat Gunung Village, using a livelihood approach. This involves assessing changes in employment and business opportunities, community income, comfort, cultural heritage, public perception, and community attitudes. The economic implications of geothermal exploration are multifaceted. On one hand, such projects can create job opportunities, boost local businesses, and enhance infrastructure [10, 11]. On the other hand, they can disrupt existing economic activities, particularly agriculture, which is the mainstay of Semangat Gunung Village. This study investigates the extent to which geothermal exploration has created employment opportunities for the local population and its impact on small businesses and household incomes [12]. The research findings reveal that while geothermal exploration has led to some job creation, the benefits are unevenly distributed. Employment opportunities have primarily emerged in the form of temporary or informal jobs, with limited long-term employment prospects [13, 14]. Furthermore, the influx of workers and construction activities have caused disruptions to agricultural activities, leading to reduced income for many households [15]. Socially, geothermal exploration can influence community cohesion, comfort, and cultural heritage. The activities associated with geothermal projects, such as drilling and infrastructure development, can lead to social upheaval, affecting the daily lives and comfort levels of residents. Additionally, the presence of a large-scale industrial project can alter the social fabric and cultural dynamics of the community [2, 16].

In Semangat Gunung Village, the research shows a significant impact on community comfort and social cohesion. Many residents have expressed concerns about noise, dust, and other disturbances caused by the exploration activities [17, 18]. The disruption of traditional practices and potential damage to cultural heritage sites have also been highlighted as critical issues. The study underscores the need for comprehensive social impact assessments and the implementation of measures to mitigate adverse effects on local communities [1]. Geothermal exploration, while generally considered environmentally friendly, can still have significant ecological consequences. The extraction of geothermal energy involves drilling deep into the Earth's crust, which can lead to land subsidence, contamination of water sources, and changes in land use patterns. The environmental impact assessment in this research focuses on these potential issues, examining both the immediate and long-term effects on the local ecosystem [19, 20].

The findings indicate that geothermal exploration in Semangat Gunung Village has led to notable environmental changes. There have been reports of water contamination, changes in soil quality, and increased erosion in the vicinity of the exploration sites [21, 22]. These environmental changes have, in turn, affected agricultural productivity and the overall health of the local ecosystem. The study calls for stringent environmental monitoring and the adoption of best practices to minimize ecological damage.

2. MATERIAL AND METHODS

This study employs a mixed-methods approach to comprehensively assess the economic, social, and environmental impacts of PT Pertamina Geothermal (Tbk) Sibayak's geothermal exploration activities on Semangat Gunung Village [23]. The research methodology integrates both quantitative and qualitative data collection and analysis techniques to provide a holistic understanding of the impacts on the local community. Semangat Gunung Village, located in Merdeka District, Karo Regency, was chosen as the study area due to its proximity to the geothermal exploration site [24, 25]. The village has a population of 8,756 people and covers an area of 9.22 km². The community relies heavily on agriculture, making it an ideal location to study the impacts of industrial activities on traditional livelihoods [26-30].

2.1 Data collection qualitative approach

2.1.1 Surveys and questionnaires

A structured questionnaire was designed to gather information on various aspects of the respondents' livelihoods, including employment, income, community comfort, and perceptions of the geothermal exploration activities. The survey was administered to 120 households in Semangat Gunung Village, achieving a 100% response rate. The high response rate was facilitated by the direct distribution and collection of questionnaires by the researchers.

2.1.2 Interviews

In-depth interviews were conducted with key informants, including local leaders, community members, and representatives from PT Pertamina Geothermal (Tbk) Sibayak. These interviews provided qualitative insights into the community's experiences and perceptions of the geothermal exploration activities.

2.1.3 Focus Group Discussions (FGDs)

FGDs were organized to facilitate a deeper understanding of community dynamics and collective perceptions. Participants included a diverse group of villagers, ensuring a comprehensive representation of different demographics and viewpoints.

2.1.4 Statistical data

Data from the Central Statistics Agency (2023) was used to provide background information on the demographic and economic characteristics of Semangat Gunung Village. Historical data on employment, income levels, and business activities were also obtained from this source. Environmental impact assessment (EIA) reports and UKL-UPL documents related to the geothermal exploration activities in the Sibayak WKP area were reviewed. These documents provided baseline data and helped identify potential environmental risks and impacts. Relevant literature on the socioeconomic and environmental impacts of geothermal exploration was reviewed to contextualize the findings and support the analysis.

2.2 Data analysis quantitative approach

2.2.1 Quantitative analysis

Descriptive statistics were used to summarize the demographic characteristics of the respondents and the key variables of interest. Measures such as mean, median, standard deviation, and frequency distributions were calculated.

2.2.2 Normality test

The Lilliefors test was applied to assess the normality of

the data distribution. This test is suitable for datasets with more than 50 observations. The data was deemed normally distributed if the highest value (L_0) was less than the table value (L_t) at a significance level of $\alpha = 0.05$.

2.2.3 Impact assessment

The impact assessment was conducted by comparing conditions before (Q_{tp}) and after (Q_{dp}) the geothermal exploration activities. The difference between Q_{dp} and Q_{tp} values was used to quantify the magnitude of the impact, with a scale ranging from very small (1) to very large (4).

2.2.4 Thematic analysis

The qualitative data from interviews and FGDs were analyzed using thematic analysis. Key themes and patterns were identified, coded, and categorized to understand the community's perceptions and experiences.

2.3 Livelihood approach framework

The livelihood approach framework was employed to analyze the impacts on the five key capitals: human, social, natural, physical, and financial. This framework provided a comprehensive lens to evaluate how geothermal exploration activities influenced the overall well-being of the community.

2.3.1 Human capital

Changes in skills, health, and education levels of the community members were assessed. The impact on employment opportunities and workforce development was examined.

2.3.2 Social capital

The effects on community cohesion, social networks, and collective activities were explored. Community attitudes and perceptions towards the geothermal exploration were analyzed.

2.3.3 Natural capital

The study assessed changes in natural resources, including land, water, and biodiversity. Environmental degradation and its impact on agricultural productivity were examined.

2.3.4 Physical capital

The research evaluated improvements or damages to infrastructure and public services. The development of facilities related to the geothermal project and its impact on the community was analyzed.

2.3.5 Financial capital

Changes in household income, access to credit, and economic opportunities were assessed. The study analyzed the economic benefits and costs associated with the geothermal exploration activities. The research adhered to ethical standards to ensure the rights and well-being of the participants were protected. Informed consent was obtained from all respondents, and confidentiality was maintained throughout the study. The research was conducted with respect for local customs and norms, ensuring that the community's interests were prioritized.

2.4 Mathematical approaches

The Livelihood Approach Framework evaluates the impacts on the five key capitals: human, social, natural, physical, and financial. Each capital can be quantitatively assessed using various indicators. The general equation for calculating the Livelihood Impact Score (LIS) is as follows:

$$LIS = \frac{\sum_{i=1}^{n} W_i . I_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

where, W_i is the weight assigned to the i -th indicator, I_i is the value of the i -th indicator, and n is the number of indicators.

2.4.1 Economic impact assessment

To quantify the economic impact, we compare pre- and post-exploration conditions using the following equation:

$$\Delta E = Q_{dp} - Q_{tp} \quad (2)$$

where, ΔE is the change in economic condition, and Q_{dp}, Q_{tp} respectively are the economic condition after and before the geothermal exploration.

2.4.2 Social impact assessment

The social impact can be measured using the change in community comfort, perceptions, and attitudes. For example, the community comfort index can be calculated as:

$$CCI = \frac{\sum_{i=1}^{n} S_i}{n} \quad (3)$$

where, CCI is the community comfort index, S_i comfort score of the i-th respondent, and n is the number of respondents.

2.4.3 Environmental impact assessment

Environmental impact can be assessed using various environmental quality indicators. One common method is the environmental quality index (EQI):

$$EQI = \frac{\sum_{i=1}^{m} E_i}{m} \quad (4)$$

where, EQI is the environmental quality index, E_i value of the i-th environmental indicator, and the m is the total number of environmental indicators.

2.4.4 Normality test using Lilliefors test

The Lilliefors test is used to assess the normality of data distribution. The test statistic is given by:

$$L_0 = \max \left| F(z) - S(z) \right| \quad (5)$$

where, L_0 is the Lilliefors test statistic, $F(z)$ is the cumulative distribution function of the standard normal distribution, and $S(z)$ is the empirical cumulative distribution function of the sample.

To determine if the data is normally distributed, we compare L_0 with the critical value L_t from the Lilliefors table at a given significance level α. The data is considered normally distributed if $L_0 < L_t$.

2.4.5 Employment and business opportunity impact

The impact on employment and business opportunities can be assessed using the following equations:

$$\Delta Em = \frac{N_{new} - N_{old}}{N_{total}} \times 100\% \quad (6)$$

$$\Delta B = \frac{B_{new} - B_{old}}{B_{total}} \times 100\% \quad (7)$$

where, N_{new} is the number of employed individuals after exploration, N_{old} is the number of employed individuals before exploration, N_{total} is the total population, B_{new} is the number of businesses after exploration, B_{old} is the number of businesses before exploration, and B_{total} is the total number of businesses.

2.4.6 Income impact assessment

Income impact can be measured by comparing the average income before and after the exploration:

$$\Delta In = \frac{I_{post} - I_{pre}}{I_{pre}} \times 100\% \quad (8)$$

where, ΔIn percentage change in average income, I_{post} is the average income after exploration, and I_{pre} is the average income before exploration. These equations form the basis for quantitatively assessing the impacts within the Livelihood Approach Framework. By applying these methods, we can systematically evaluate the effects of geothermal exploration on the economic, social, and environmental aspects of Semangat Gunung Village.

3. RESULT AND DISCUSSIONS

This study's data normality testing findings are shown in Table 1. From the given data distributions, the average value ($\bar{x}$) was 6.43 with a standard deviation (S) of 0.53. When entered into the Lilliefors normality test formula, $|F(z)-S(z)|$ ranges from 0.1152 to 0.458. Overall, data is normally distributed. This is due to the highest normality test number (L_0) of 0.1152, which is lower than the Lilliefors test quantile value $\alpha = 0.05$ with N = 45 of 0.1321.

Table 1 presents the results of a normality test on a dataset consisting of 45 observations. The Table 1 displays specific data points X_i along with their corresponding standardized scores Z, empirical cumulative distribution function values $S(z)$, theoretical cumulative distribution function values, and the absolute differences between $F(z)$ and $S(z)$, denoted as $|F(z)-S(z)|$. The data points have an average ($\bar{x}$) of 6.43 with a standard deviation S of 0.53. The maximum difference observed is 0.1152, which is lower than the critical Lilliefors test value L_t of 0.13, and the calculated L_0 is 0.12. This suggests that the data is normally distributed, as indicated by the consistent "Normal" description in the Table 1.

Table 1. Location description and research data

No.	X_i	Z	S(z)	F(z)	|F(z)-S(z)|	Description
1	7	-2.037	0.021	0.067	0.0458	Normal
2	7	-2.037	0.021	0.067	0.0458	Normal
3	7	-2.037	0.021	0.067	0.0458	Normal
4	6	-1.746	0.04	0.156	0.1152	Normal
5	6	-1.746	0.04	0.156	0.1152	Normal
6	6	-1.746	0.04	0.156	0.1152	Normal
7	6	-1.746	0.04	0.156	0.1152	Normal
N = 45		-	-	-	-	-
$\bar{x}$ = 6,43	L_0 = 0,12	-	-	-	-	-
S = 0,53	L_t = 0,13	-	-	-	-	-

3.1 Socioeconomic environmental impact of geothermal exploration activities at WKP Sibayak Karo Regency

The socio-economic-environmental impact is assessed using impact analysis, which involves comparing the conditions before the activity (Q_{tp}) with the conditions after the activity (Q_{dp}). The discrepancy between $Q_{tp} - Q_{dp}$ figures represent the quantitative measure of the amount of the impact that had place. A discrepancy with a numerical value of 1 indicates a negligible impact, a discrepancy of 2 falls into the moderate range, a discrepancy of 3 falls into the substantial range, and a discrepancy of 4 or more falls into the significant range. This research identifies 7 impact components. The factors encompass work prospects, entrepreneurial prospects, communal earnings, communal well-being, cultural ambiance, society perceptions, and societal attitudes.

In addition, to conducting an assessment of the extent of the effects to identify the specific impacts resulting from the geothermal exploration activities of WKP Sibayak in Karo Regency, this study also performs an analysis of the characteristics of these effects to establish their level of significance. The parameters for determining substantial effects on the environment under consideration are:

- Total population impacted
- The extent of the impact's distribution
- The magnitude and duration of the collision
- Numerous additional living components are impacted.
- The cumulative nature of impact
- Reversibility or irreversibility of the impact
- Additional requirements align with advancements in science and technology.

3.2 Employment opportunity

According to the Central Statistics Agency's (2020) data, the majority of the population in Semangat Gunung Village is employed in the agricultural sector, with a total of 3,096 individuals. The number of jobless individuals is 48. Unemployment is caused by a disparity between the increase in the number of people of working age and the availability of job possibilities, resulting in a gap known as unemployment. The Q_{tp} value for the impact of work

possibilities in the Sibayak WKP, Karo Regency, is derived from the number of unemployed individuals in Semangat Gunung Village, based on secondary sources. If the number of unemployed individuals in Semangat Gunung Village is 48, which accounts for 0.45% of the total population, then the Q_{tp} given that the unemployment rate is less than 10%. The Q_{dp} value regarding the impact of employment opportunities resulting from geothermal exploration activities in the Sibayak WKP, Karo Regency, is derived from the number of unemployed individuals in Semangat Gunung Village, as determined by primary data gathering. According to the data obtained from distributing questionnaires to all responders, the percentage is 35.56%. The occupation with the highest employment rate is farming, followed by entrepreneurs/traders and artisans/odd laborers. Civil servants, members of the TNI, and police officers are considered public employees, whereas private employees refer to individuals working in the private sector. 11.11% of the respondents were unemployed. The Q_{dp} value is rated as scale 4, indicating an unemployment rate of 10% to 30%.

Figure 1 shows that the geothermal exploration activities in the Sibayak WKP, Karo Regency, have been analyzed to determine their impact on employment opportunities. According to Article 22 of Law 32 of 2009, these activities meet all five criteria for significant impacts. Therefore, the cumulative value (ΣP) of the impact on employment opportunities from these activities is 71.4%. Job opportunities are classified as being in scale category 4, which is considered more essential. The requirement for this classification is that the sum of the probabilities (ΣP) falls between 60% and 79%.

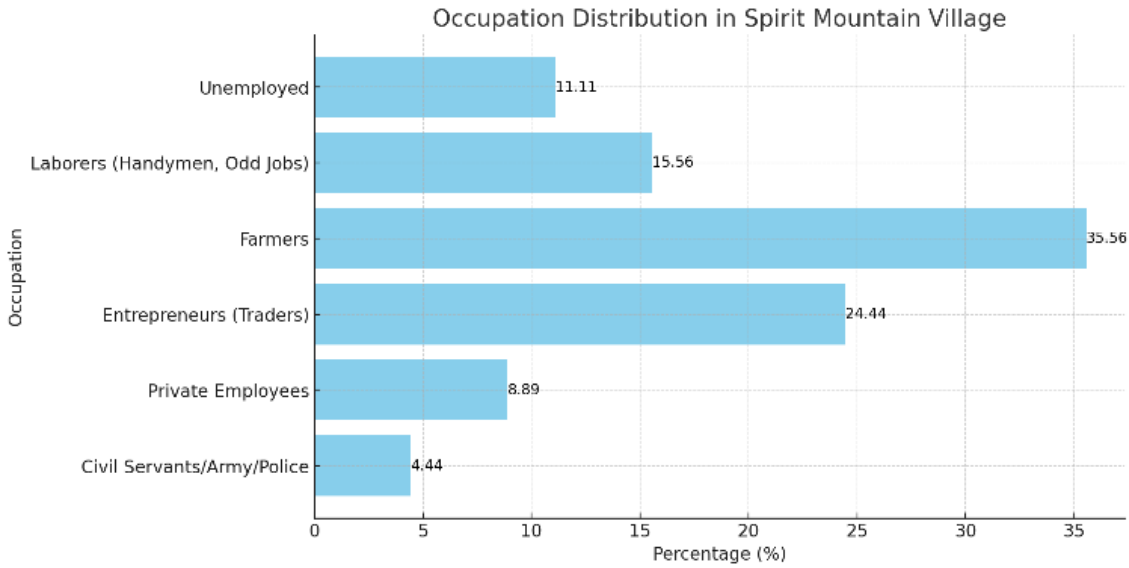

Figure 1. Types of work in the community

3.3 Business opportunities

Based on records from the Central Statistics Agency (2020), the number of small industrial businesses in Semangat Gunung Village is 3 with the capacity to absorb 16 workers. The Q_{tp} value on the impact of business opportunities without geothermal exploration activities in the Sibayak WKP, Karo Regency comes from the number of businesses in Semangat Gunung Village according to secondary data. If the number of businesses in Semangat Gunung Village. If the number is 3, then the Q_{tp} value. The Q_{dp} value for assessing the impact of geothermal exploration activities in the Sibayak WKP Karo Regency is determined based on the number of informal businesses in Semangat Gunung Village, as obtained from primary data gathering. Field observations indicate a significant presence of informal commercial activities, including grocery booths, workshops, accommodation and fish farming. Recently, Semangat Gunung Village has been maximizing its capabilities in areas such as tourism and agriculture. The establishment of these enterprises is naturally occurring in conjunction with the growth of tourist destinations in the Semangat Gunung Village. Nevertheless, the initiatives mentioned are unrelated to the geothermal exploration endeavors taking place in the Sibayak WKP area of Karo Regency. This is due to the fact that the entrance to the Sibayak WKP Area, located in Karo Regency, is not situated in Semangat Gunung Village. The Q_{dp} value, ranges from 0 to 2 for enterprises resulting from geothermal exploration activities in the Sibayak WKP, Karo Regency. After analyzing the significance of the impact on business opportunities resulting from geothermal exploration activities in the Sibayak WKP, Karo Regency, it meets two important impact criteria. Therefore, the total value (ΣP) of the impact on business opportunities from these activities is 28.5%. Job opportunities are classified as being in scale category 2, which is considered fairly important. This classification is based on the condition that the sum of the probabilities (ΣP) falls within the range of 20-39%.

Figure 2 illustrates the income distribution in Semangat Gunung Village, indicating that a significant majority of the population (77.28%) has an income range between 1,000,000 and 2,000,000 IDR. A smaller proportion, 15.56%, earns between 2,000,000 and 3,000,000 IDR, while only 6.67% of the population falls within the 3,000,000 to 4,000,000 IDR income range. There are no residents earning above 4,000,000 IDR. This data highlights a concentration of income within the lower range, suggesting potential economic challenges and a need for economic development initiatives within the village.

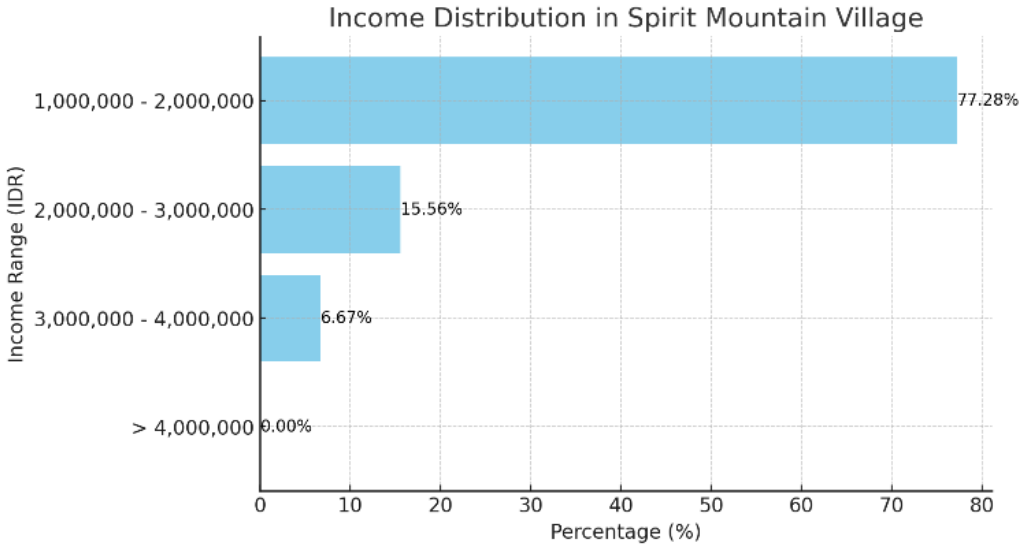

Figure 2. Income of the Semangat Gunung Village community

3.4 Community convenience

The Q_{tp} value on the impact of community comfort without geothermal exploration activities in the Sibayak WKP, Karo Regency comes from a description of the condition of the community in Semangat Gunung Village according to secondary data. For these conditions, an analogous approach was used from previous research which described the conditions of the people of Semangat Gunung Village. The community of Semangat Gunung Village is dominated by the Karo tribe.

The chart has been fixed and translated to English. Figure 3 illustrates the impact on comfort in Semangat Gunung Village, showing that 77.27% of respondents feel that their comfort is disrupted, while 22.73% do not feel that their comfort is disrupted. This indicates that the majority of the population experiences a significant disturbance to their comfort in the village.

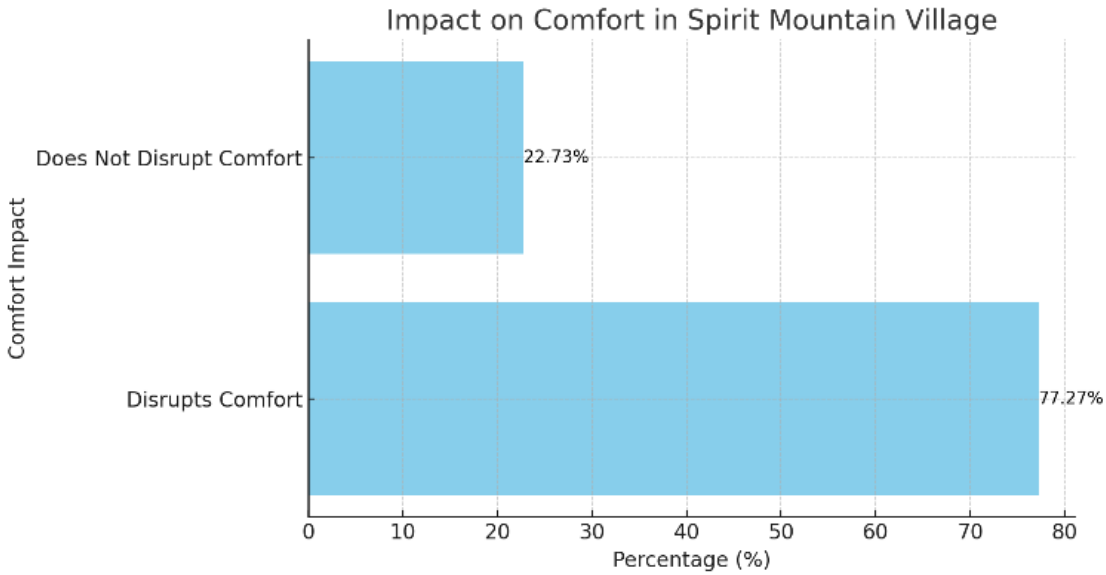

Figure 3. Village community comfort

3.5 Public perception

The Q_{tp} value regarding the impact on community attitudes in the absence of geothermal exploration activities in the Sibayak WKP, Karo Regency is derived from the overall perception of the community in Semangat Gunung Village, using an analogous approach. Before WKP's geothermal prospecting endeavors.

Figure 4 illustrates the perceived impacts in Semangat Gunung Village. The most significant concern is that 35.59% of respondents believe that activities in the village make the river water muddy. Other notable impacts include providing employment opportunities (13.56%), improving the local economy (10.17%), and concerns about fishing failure (dead fish) at 10.17%. A smaller percentage of respondents expressed concerns about changing water discharge (8.47%), reducing income (3.39%), flash floods (1.69%), and the fear of Mount Sibayak erupting (3.39%). Additionally, 13.56% of respondents are supportive as long as the activities do not disturb the community.

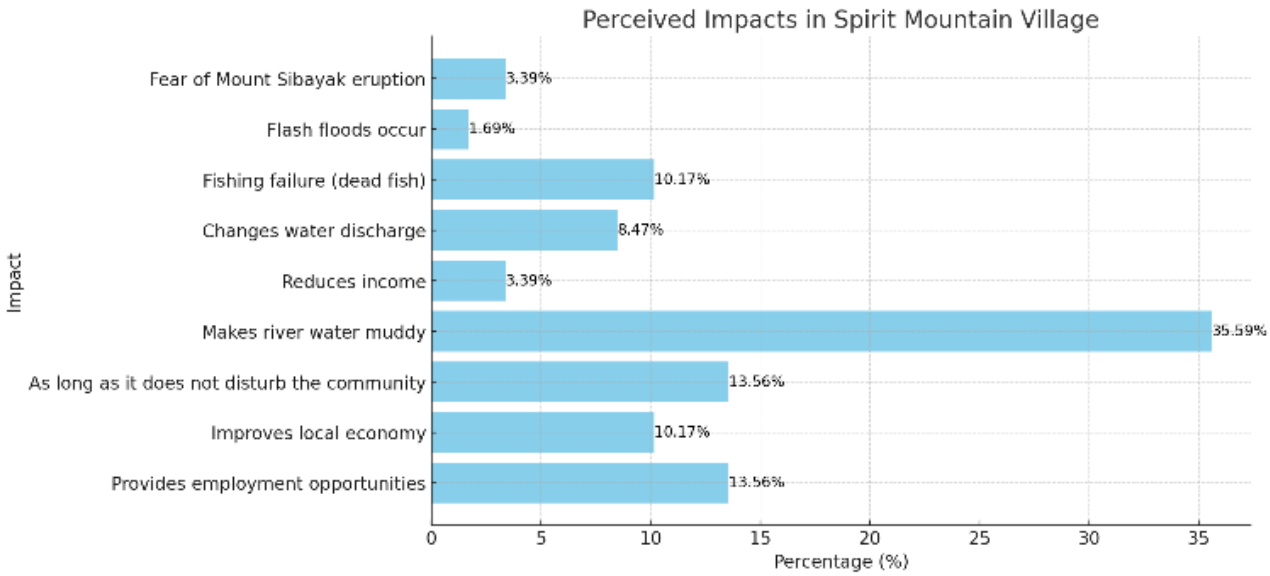

Figure 4. Perceived impacts

3.6 Environmental management strategy socio-economic-environmental components

Strategic planning is a process that seeks to define the goals and objectives of an organization or firm. It involves making decisions about policies, resource allocation, and formulating guidelines. When doing a strategic environmental analysis, there are two processes that can be undertaken these steps include:

- Determine the key strategic factors. Determine the internal factors and conditions analyses internal characteristics of the organization, such as strengths, shortcomings, and the existing plan. Determine the external environment. Identify external elements that may impact opportunities and pose dangers to the organization, such as the communities or other stakeholders involved.
- Employing the Livelihood Approach technique matrix for matching. The analysis conducted using the Livelihood Approach matrix is rooted in the principle of maximizing strengths and opportunities while minimizing weaknesses and dangers.

The Sustainable Livelihoods Framework (SLF) is an analytical framework designed to elucidate the methods of comprehending, examining, and delineating the aspects that impact the sustenance of impoverished individuals. SLF defines livelihood as the combination of skills, resources, and actions necessary for sustaining one's way of life. According sustainable lifestyle is defined as a means of living that is capable of dealing with and recovering from pressures and unexpected events, while also maintaining or improving its abilities and resources in the present and future, without harming the natural resources on which it relies. The model highlights that livelihoods are seldom confined to a single activity, but rather encompass a multifaceted, varied, context-dependent, and ever-evolving set of methods that households devise to fulfil their requirements. The conventional SLF model positions impoverished individuals at the focal point of a pentagon consisting of five distinct categories of resources referred to as capitals. The central argument posits that individuals of low socioeconomic status construct their means of subsistence by utilizing this specific collection of resources. The initial classification of resources is human capital, which encompasses elements such as workforce, expertise, intelligence, proficiency, and ingenuity. The second category of resources is natural capital, which includes land, pastures, woods, and water. The third category is physical capital, which includes assets such as dwellings, machinery, tools, cattle, jewelry, and food stock. The fourth category is financial capital, which include resources such as savings or a loan/credit facility. Social capital is the last category of resources, which pertains to the quality of relationships among individuals. For example, if a household can rely on the assistance of neighbors, it is regarded as having a significant amount of social capital. The SLF approach to livelihood assessment centers around evaluating the degree to which individuals structure their lives based on the five resource categories. For example, those living in rural areas are anticipated to rely more heavily on natural resources such as land, pasture, and water. Conversely, urban residents are predicted to rely more on human resources and have access to a diverse array of physical assets such as roads, power, and housing. The approach acknowledges that contextual factors, such as climate and government restrictions, have an impact on how individuals utilize the five capitals to structure their livelihoods. Contextual elements, such as climate, have an influence on natural capital, such as water and pasture. According to the idea, intervention policies and programmers, such as W.E.F, should priorities addressing these circumstances in order to reduce the vulnerability of people's livelihoods. This theory was valuable for the current study since it offered a structure for evaluating the livelihoods of households located near the Geothermal Project. Impacts on the environment and society resulting from the growth of geothermal energy. Evaluations in the industry show that most of the geothermal capacity is situated within or near forested regions, and its exploitation would necessitate the removal of forests and the construction of roads. Due to the challenging and rugged topography, Indonesia will likely need to undertake around double the amount of road development compared to other nations. The development and construction activities, as well as other activities facilitated by roads such as hunting, illegal logging, and use of fire, will have substantial effects on the environment, wildlife, and the indigenous population residing in these areas. These impacts may include land loss, restricted access to forest products, negative effects on their livelihoods, a perception of inequitable distribution of

benefits, encroachment by outsiders into their traditional territory and way of life, and potential conflicts with in-migrants, including the construction workers. Another crucial evaluation pertains to the indigenous population of Indonesia, with a specific emphasis on the obstacles they encounter during the process of development. Below is a concise summary of the key elements. These factors contributed to the development and enhancement of this IPPF.

The environmental conditions can impact individuals' sense of comfort. Inadequate environmental conditions can adversely affect the mental health and well-being of individuals, often resulting in violent. The geothermal exploration activities of the Sibayak WKP in Karo Regency had a significant negative influence on the comfort of Semangat Gunung Village, falling into the highest magnitude category with a weight of -4. The decrease in comfort experienced at Semangat Gunung Village is attributed to socio-cultural factors. The originator or corporate actor of geothermal exploration activities in the Sibayak WKP, Karo Regency should priorities environmental management by considering the influence on community comfort.

The activity initiator must effectively address the community's expectations regarding the geothermal exploration activities of the Sibayak WKP in Karo Regency. The involvement of the community in planning an activity is governed by Minister of the Environment Regulation Number 17 of 2012 in a normative manner. Community participation seeks to cultivate passion and a feeling of ownership towards a development endeavor through their active engagement in it. Community expectations are utilized as a strategic element in developing environmental management plans for the social, economic, and environmental aspects of this research's setting.

Figure 5 illustrates the considerations for development in Semangat Gunung Village. The most critical factor, as indicated by 43.33% of respondents, is ensuring that the development does not harm the community. Other significant considerations include providing employment opportunities (23.33%) and ensuring that the development does not damage the environment (16.67%). Additionally, respondents emphasized the importance of no longer causing muddy water (6.67%) and compensating affected communities (3.33%). Some respondents also mentioned the need to consider the land clearing process (3.33%) and suggested that the development should not be continued (3.33%).

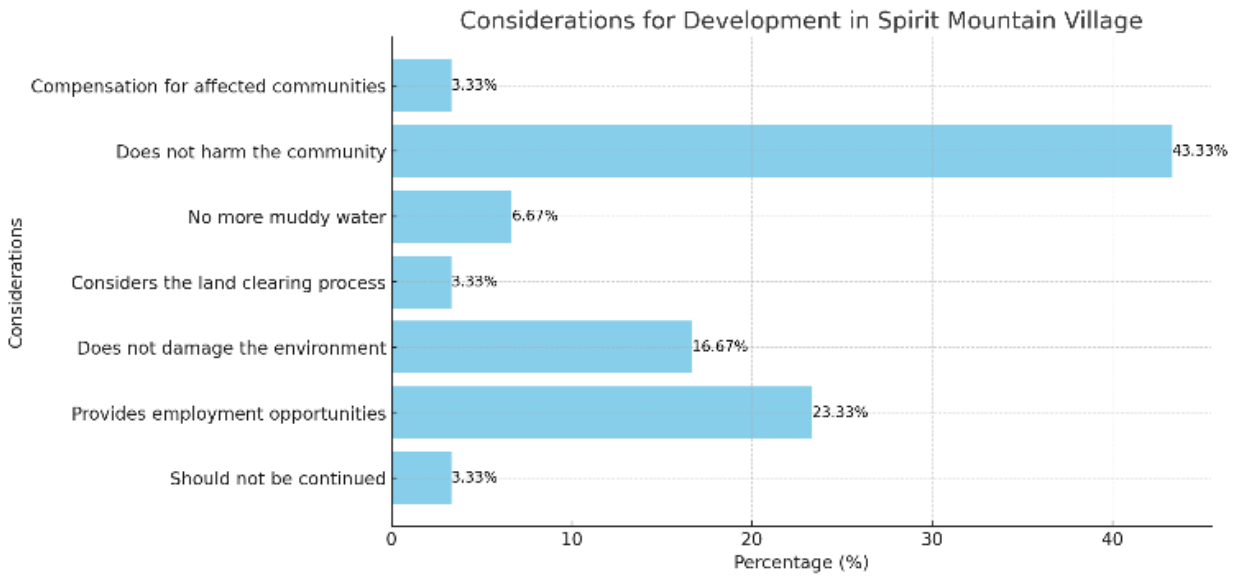

Figure 5. Considerations for development

4. CONCLUSIONS

The geothermal exploration activities by PT Pertamina Geothermal (Tbk) Sibayak have both positive and negative impacts on Semangat Gunung Village. The study emphasizes the importance of involving local communities in decision-making processes and ensuring that development projects are aligned with their needs and aspirations. Recommendations include enhancing community engagement, improving environmental management practices, and developing strategies to mitigate social disruptions. This research contributes to the broader discourse on the sustainable development of geothermal energy in Indonesia and provides valuable insights for policymakers, industry stakeholders, and local communities. Future research should continue to explore the long-term impacts of geothermal exploration and identify best practices for balancing economic development with environmental and social sustainability. Despite its contributions, this study has several limitations that should be acknowledged. First, the scope of the research was limited to a single village, which may restrict the generalizability of the findings to other contexts. Second, the data collection relied heavily on self-reported information from surveys and interviews, which may introduce response biases. Additionally, the study did not include certain environmental factors, such as detailed assessments of air and water quality or the impact on local wildlife, due to resource and data access constraints. The absence of a formal pre-test for the survey instrument is another limitation that could affect the validity of the results.

To build on the findings of this study, future research should consider expanding the geographical scope to include multiple communities affected by geothermal exploration, allowing for comparative analysis across different contexts. Additionally, integrating more robust environmental data, such as air and water quality measurements, and conducting longitudinal studies could provide deeper insights into the long-term

impacts of geothermal projects. Researchers could also explore the social dynamics and cultural shifts resulting from prolonged exposure to such projects, as well as investigate the role of community engagement in mitigating adverse impacts. Finally, future studies might benefit from developing and pre-testing more refined survey instruments to enhance data accuracy and reliability.

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NOMENCLATURE

n	The sample size or the total number of observations or respondents.
W	A weight assigned to a particular indicator or factor in the analysis.
I	An indicator or a specific variable that is being measured.
LIS	A composite score calculated to assess the overall impact of a particular factor on the livelihood of a community.
Q_{tp}	The post-exploration condition of a particular economic, social, or environmental variable.
Q_{dp}	The pre-exploration condition of a particular economic, social, or environmental variable.
L_0	The observed value of the Lilliefors test statistic, used to assess the normality of the data distribution.
L_t	The critical value from the Lilliefors table at a given significance level, used to determine if the data follows a normal distribution.
$\bar{x}$	The mean or average value of the observations in the dataset.
S	The standard deviation of the observations in the dataset, representing the dispersion or spread of the data around the mean.
$S(z)$	The empirical cumulative distribution function value for a given z-score, representing the proportion of observations less than or equal to a particular value.
$F(z)$	The theoretical cumulative distribution function value for a given z-score under the assumption of a normal distribution.
$\|F(z)-S(z)\|$	The absolute difference between the theoretical and empirical cumulative distribution functions, used in normality testing.
t_p	A term that might represent a time period or a condition during the post-exploration phase.
t_d	A term that might represent a time period or a condition during the pre-exploration phase.
ΔQ	The change in a specific variable or indicator.
CI	Community Impact or Comfort Index
EQI	Environmental Quality Index