

LAND EVALUATION TOWARD SUSTAINABLE LAND MANAGEMENT IN GEOTHERMAL FIELD IN SOUTHERN BANDUNG HIGHLAND

Herlinawati¹, Nendi Rohaendi¹, Iwan F Setiawan¹

¹Human Resource Development Center for Geology, Mineral and Coal

Email Penulis: kakilina82@gmail.com

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ABSTRACT

Indonesia has been recognized to have large geothermal potential, possibly up to 28 MW. However, the development of renewable energy has great impact on environmental degradation such as massive land use change. This research aims to apply land use management in geothermal area, to analyse the correlation between social economic development and environmental protection, and to align with several key sustainable development goals, demonstrating a commitment to enhancing social, economic, and environmental well-being. In addition, the study goals include to implement sustainable development goal (SDG) especially to support no poverty (SDG 1), good health (SDG 3), clean energy (SDG 7), good jobs and economic growth (SDG 8), sustainable cities and communities (SDG 11), protect the planet (SDG 13), and life on land (SDG 15). As case study area is Ciwidey area, the area has three geothermal deposits such as Patuha geothermal field, Cibuni geothermal field, and Ciwidey geothermal field. Installed electricity power Patuha geothermal field is produced since 2014. To analysis the relationship between social economic activities and the environment using based on data analysis and the model of Driving-Pressure-State-Impact-Response (DPSIR). Based on data analysis and DPSIR model, we conclude that the long-term driving force of land use change is geothermal development, population growth, and tourism growth caused pressures on the environment such as farmland loss and ecological degradation. Then, the pressures are directly reflected in the changes of land state such as residential and tourism area. It has an impact on the farmland loss and ecological degradation, to encourage policy maker to make a series of positive response measures to achieve the goal of sustainable development.

Keywords: Land evaluation, Sustainable Land Management, DPSIR

INTRODUCTION

Indonesia has been recognized to have large geothermal potential, possibly up to 28 MW. The resources are distributed at 331 geothermal areas and among of them, 45 locations are located in West Java Indonesia which is the highest locality in Java and Indonesia in general (Fauzia & Makarim, 2024). Sustainable energy is an emerging paradigm. Geothermal energy is usually considered a renewable energy source, but geothermal development and use can however have significant multi-dimensional sustainability implications (Shortall et al., 2015). The management and monitoring of land use in geothermal fields are crucial for the sustainable utilization of water resources, as well as for striking a balance between the production of renewable energy and the preservation of the environment (Utama et al., 2024). Efficient land use management is crucial for sustainably preserving water resources in geothermal areas. Land use management can support the regulation of surface water flow.

Land is the limited resources, which also habitat for natural entities, and critically depends on human activities (Pratiwi et al., 2019). Land-use defines as functioning land resources for various purposes in human activities, which also impacts on the land itself. In Indonesia, the

typical land use for instance is farming to produce goods whose land cover changes through different land use practices such as irrigation, harvesting, and selling the products (Maddalena, 2011). Land management is the way of the land user's to achieve this aim. Land use monitoring and management heavily rely on satellite imagery to obtain accurate spatial information crucial for effective planning such as high resolution image (Utama et al., 2024). Google Earth Engine (GEE) is a cloud-based computing platform that uses Google's infrastructure to facilitate access to geospatial data and its processing (Velasategui-Montoya et al., 2023).

Bandung basin area is one of the important economic areas in Indonesia. One of the economic sectors is tourism, especially in northern and southern Bandung, as mountainous area such as geotourism, agrotourism, water tourism, and forest tourism (Rohaendi et al., 2021). The development of tourism area and urban area, it need a lot of energy, one of energy source come from geothermal. However, there is conflict between tourism activities and environmental protection (Chen et al., 2022). One of geothermal field in Southern Bandung Highland is Patuha geothermal field which is located in west Java, Indonesia, about 50 km southwest of the city of Bandung (Ashat et al., 2019; Purwantoro et al., 2010). As case study area is Ciwidey area, the area has three geothermal deposits such as Patuha geothermal field, Cibuni geothermal field, and Ciwidey geothermal field. Installed electricity power Patuha geothermal field is produced since 2014. Patuha field is one of the best vapor-dominated geothermal system in Indonesia with liquid deep zone included and temperature about 210 – 230⁰ C covering 20 km², however, Cibuni and Ciwidey is categorize as green geothermal field (Ashat & Pratama, 2018).

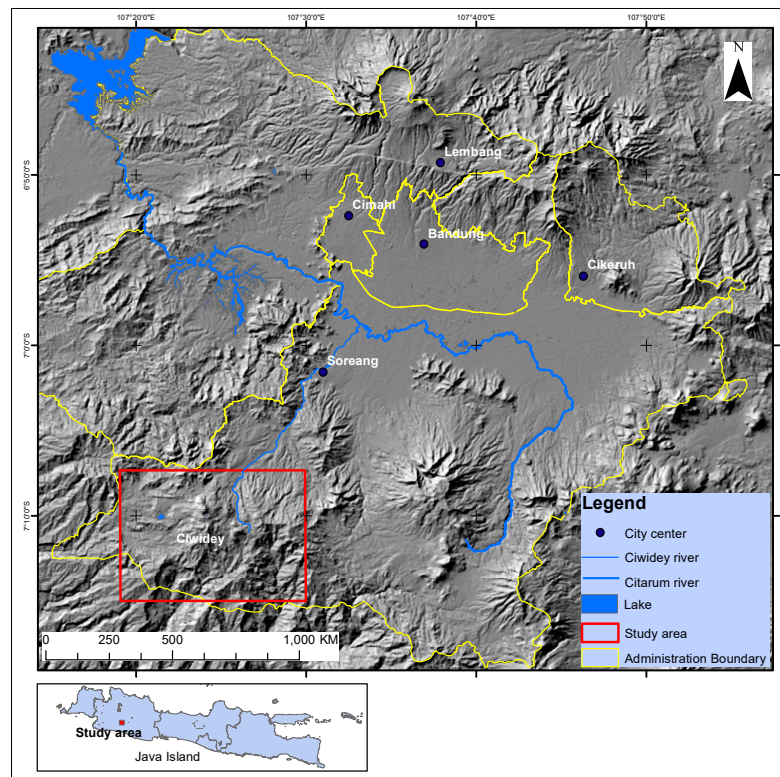


Figure 1 Location of study area (red square) in Ciwidey Highland in Bandung Regency

Research of geothermal in Java Island has been conducted since the 1900s and the studies mainly focus on the hydrothermal alteration and their structure control (Indarto et al., 2018). Most of studies conclude that the geothermal field either located around volcano or around fault. This research aims to align with several key sustainable development goals, demonstrating a commitment to enhancing social, economic, and environmental well-being. In addition, the study goals include to implement sustainable development goal (SDG) especially to support no poverty (SDG 1), good health (SDG 3), clean energy (SDG 7), good jobs and economic growth (SDG 8), sustainable cities and communities (SDG 11), protect the planet (SDG 13), and life on land (SDG 15) (Gill, 2017).

LITERATURE REVIEW

Land evaluation is widely used in many contexts, ranging from economical asset, business planning, and land use planning process (Belal et al., 2015). Land evaluation as ‘the process of predicting the use potential of land on the basis of its attributes’ as a tool for strategic land use planning. Moreover, land performance can be evaluated based on benefits and constraints, productive land use and environmental degradation will occur.

On the economic context, there are two basic standards to evaluate the use of land, i.e. efficiency and equity. Land should be used in optimum manner. The use of land is justified as inefficient and unjust, because land also has an internal nature to distribute wealth. Rossiter (1996) proposed the use of economic land evaluation for land resources management in rural area (Baja et al., 2001). Economic evaluation is more useful than using only physical evaluation. The economic value of land will be affected by the physical condition of the land and these effects can be quantified using economic terms. Land evaluation is necessary to minimize the risk of decision, physical evaluation is needed to classify the capability of the land and economical evaluation is used to maximize the profitability of the land. In the land use planning process, the evaluation of land is to find the suitability of land based on specific land use requirements. The aim of land-use suitability analysis is to identify the most appropriate spatial pattern of future land uses according to specific requirements such as for rural planning (Rohaendi & Agustine, 2014).

a. Qualitative and Quantitative Methods

Qualitative and quantitative evaluation methods are generally used in combination to evaluate suitability of land for a particular land use. Qualitative land evaluation methods describe suitability of land for particular land uses in the descriptive way based on expert knowledge. This method is generally used when the availability of data is limited. The principle of this method is proposed by FAO (1993). The suitability of land is presented as well suited, moderate suited and unsuited land. This method is primarily used to define land utilization type (LUT). Land is screened based on obvious constraints such as soil, climate, topography, and hydrology. This method is particularly suitable for screening process or matching process. Land use requirements match with land characteristics to produce land suitability. In the screening process only two classes are defined, unsuited land and potential land, then, the potential class will be classified into more detailed classes in quantitative methods. On the other hand, quantitative land evaluation methods expressed the quality of land in quantitative way such as

crop production. For instance, the production of wheat is described as ton of dry matter per unit of area. This method is generally used after qualitative method. This method needs some calculation to produce suitability index of land.

b. Land Evaluation Models

Rossiter (2003) defined land evaluation model as computer program to predict performance of land use of land area by given information on that land characteristics. Rossiter (2003) explained land evaluation models based on physical characteristics of land as follows;

1. Expert Knowledge Models

Automated Land Evaluation System (ALES) is a specialized program for physical and economic land evaluation based on in situ land characteristic, using land qualities. This computer program allowed the user to use their own expert knowledge to suit local needs and objectives. There is no fixed list about land use type (LUT) or land use characteristics.

2. Empirical-Statistical Models

This method tried to make a model based on correlation between specific objective and land characteristic using a statistical approach. For example, predicting crop production of maize with several land parameters. However, the lack of empirical method is expensive and time consuming. MicroLEIS system is one of the computers programs based on this approach.

3. Dynamic Simulation Model

This computer programme is trying to simulate crop growth along with the factors that influence crop growth such as water etc. There are several dynamic simulation models such as WOFOST, DSSAT, APSIM, EPIC, and GAPS.

c. Multiple Criteria Evaluation

The land evaluation method is also carried out based on Geographical Information Systems (GIS) and Multi Criteria Evaluation (MCE). GIS is a powerful tool in several planning process phases because the easiest to create, to modify and to analyse data. MCE is used to describe, evaluate, rank, and select among different alternatives in decision-making problem, according to set of criteria (Madurika & Hemakumara, 2017). MCE is widely used because the ability to combine between spatial and non-spatial and also can handle a lot of type of data.

Firstly, fuzzy set methods are to overcome imprecise judgments and preferences indefinable way (Baja et al., 2001). Fuzzy methods can manage complex and large number of variables considered in analysis based on the weighting systems for the decision criteria. Generally, as multiple criteria methods, the objectives are expressed both in qualitative and quantitative terms. In this method, sets a framework that provides a natural way of dealing with ambiguity and vagueness problems is developed for effective analysis. Secondly, Analytical Hierarchy Process (AHP), this method is developed by Saaty in 1980 and is a powerful decision-making method in order to determine the priorities among different attributes. The purpose of the AHP is to select the most appropriate land use to meet optimal requirement and increase profitability. The goal is placed on the first hierarchy and two strategic factors – cost and operational requirement are identified to achieve this goal. The cost is divided into two criteria – capital cost and operating cost. The operational requirement is divided into two criteria – natural factor and cultural factors. The next step is the measurement and data collection, which involves

forming a team of evaluators from stakeholders assigning pairwise comparison to the strategic factors, criteria and sub-criteria used in the AHP hierarchy.

METHODOLOGY

There are two types of data in the research, collecting primary data is from field work and DEM from Information Geospatial Agency of Indonesia, Google Earth Engine, and secondary data from government offices such as statistical centre of agency, district office, and research national agency. We are also conducting of interview with stakeholders and community. Stakeholders or community involvements based on European Commission in 2003 stated there are three degrees of stakeholder involvement in the decision making process including; co-operating is when stakeholders actually participate or active involvement in and contribute actively to the process; co-thinking is when stakeholders who have input (technical knowledge and/or useful information) with respect to content and are sources of expert knowledge or consultation; co-knowing is stakeholders who do not play an active role in the process but should be kept informed about its progress (Geneletti, 2010).

From previous basic data, we analyse policy analysis, geology, and social economy. Then, to understand correlation between economic activities and environmental protection for research area, we apply DPSIR (Driving-Pressure-State-Impact-Response) frameworks (Chen et al., 2022; Qu et al., 2020). In comparison with the other model, the framework is systematic, comprehensive, and logical approach to deal with research problem.

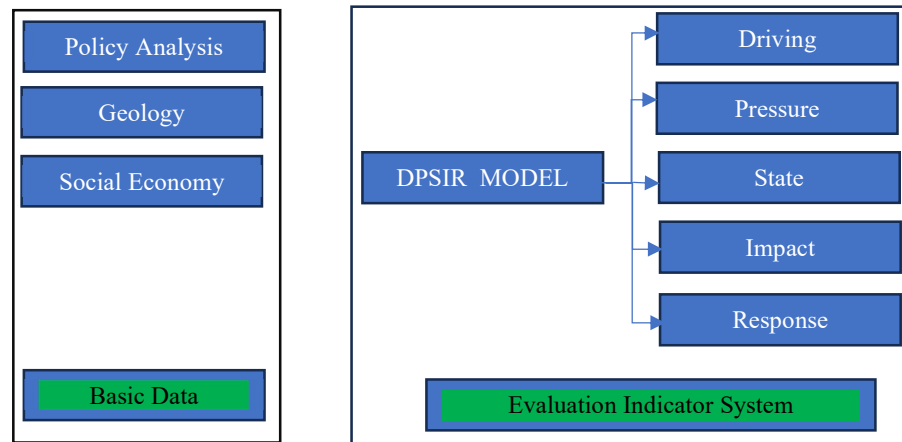


Figure 2 Methodology of the research

RESULT AND DISCUSSION

a. Regulation and Policy Analysis

From Law of Republic of Indonesia No. 30 of 2007 about Energy stated that the formulation of the national energy policy is guided by the principles of equity, sustainability, and environmental considerations, aimed at fostering energy self-reliance and ensuring national energy security. As a result of this policy, there are rises a necessity for diversifying the energy sources to fulfil domestic energy requirements, with a particular emphasis on the development

of novel renewable energy solutions. Under the perspective of energy as development capital, renewable energy plays an important role in driving a green, sustainable and low-carbon economic system.

The Indonesian government has National Energy Policy (RUEN), is focused on enhancing the utilization of renewable energy, with a particular emphasis on geothermal energy. Indonesia boasts one of the largest geothermal potentials globally, across approximately 331 geothermal sites scattered throughout the archipelago. The country ranks second in the world for installed geothermal capacity, following the United States. Should development proceed as anticipated, geothermal energy could serve as the cornerstone of Indonesia's clean energy strategy, playing a crucial role in achieving the goal of net-zero emissions by 2060. Furthermore, geothermal energy offers solutions for energy diversification in remote areas that are difficult to connect to conventional electricity grids.

Presidential Regulation No. 22 of 2017 about the national energy general plan, Indonesia has set specific goals for incorporating renewable energy into its national energy mix. By 2025, the target is to achieve a 23% share of renewable energy, which translates to a capacity of 45.2 GW. The remaining energy requirements will be met through biofuels, biomass, biogas, and coal bed methane. However, in the electricity sector, Indonesia faces a significant challenge. As of March 2017, the installed capacity of new renewable energy power plants stood at a mere 8.80 GW, accounting for just 2% of the total renewable energy potential of 443 GW available in the country. As per the findings of the Indonesia National Energy Council (2017), the country possesses a significant renewable energy capacity of 443 GW for electricity generation, encompassing geothermal, hydropower, solar, wind, and ocean wave sources. Among these, solar energy exhibits the largest potential, exceeding 207 MW, while water and wind sources also hold substantial promise.

There are two types of geothermal energy utilization according to Presidential Regulation No. 7 of 2017, the first one is indirect utilization that can be described as the activity of exploiting geothermal utilization through the process of converting heat energy and or fluid into electrical energy. The other one is through direct utilization is the activity of exploiting geothermal utilization directly without conducting the process of converting heat energy and or fluid into other types of energy for non-electric purposes. The implementation of geothermal for indirect utilization in all regions of Indonesia is the authority of the national government which is carried out and or coordinated by the Minister of energy and mineral resources of Indonesia.

The implementation of geothermal activities has been changed by Law No. 6 of 2023 on Job Creation (Omnibus Law), through Article 41, amends Law Number 21 of 2014, which has the objective to regulate geothermal exploitation endeavours with the aim of bolstering energy security and independence, promoting sustainable development, and maximizing the welfare and prosperity of the population. This includes enhancing the use of geothermal energy as a renewable resource to meet the country's energy requirements, as well as promoting the utilization of clean and eco-friendly energy to reduce greenhouse gas emissions. Geothermal resources are regarded as a national asset under the control of the state, intended for the benefit of the people. The governance of geothermal resources involves the collaboration of the

national government, provincial governments, and local governments at the regency or city level, with each entity exercising their respective authority and adhering to principles of responsible utilization.

b. Geological Analysis

Physiography of South Bandung is composed of mountainous area, hilly area, and high plain of Pangalengan and Bandung itself (Bronto et al., 2006). Based on volcanic stratigraphy, volcanic rocks there are divided into four rock units, three of them are identified their volcanic sources, having Miocen to Quaternary ages including QTv (Pyroclastic deposit), Ql (Quarter Kendeng product), Qv (Quarter Patuha product) and Tmcs (pumices, tuff sandstone and breccia) (Koesmono et al., 1996).

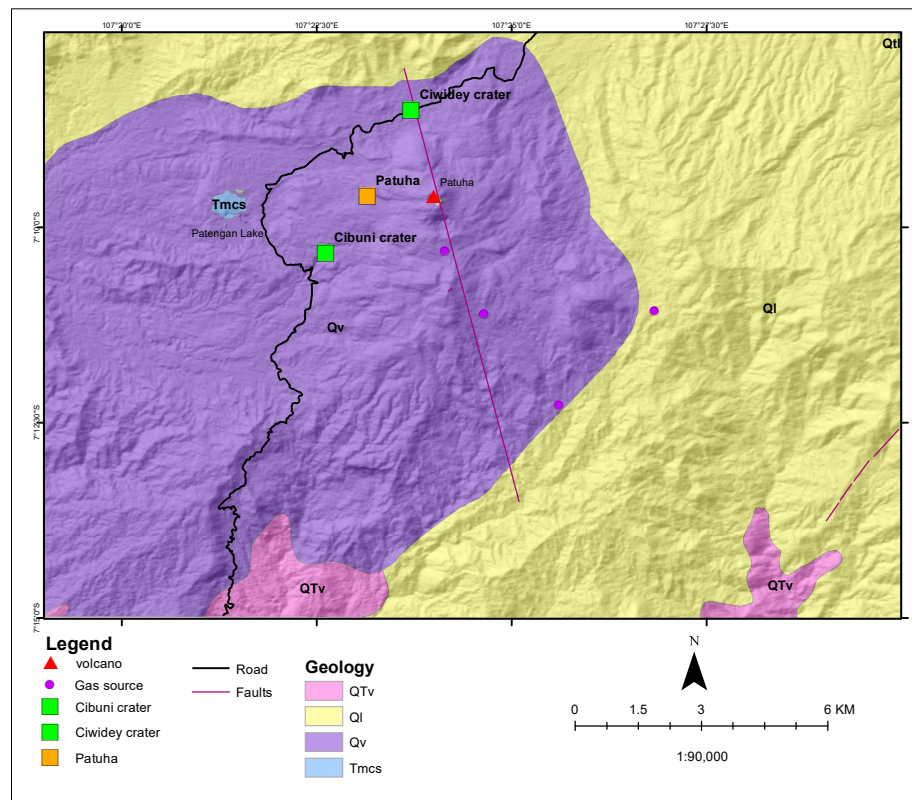


Figure 3 Geology map of study area (source: (Koesmono et al., 1996))

The research area is the boundary of northern and southern watershed. The northern watershed led to Citarum river or famous as upper Citarum watershed. One of centre tourism in this area is Patengan Lake, its forming from volcanic crater. The surrounding area of Patuha, Cibuni, and Ciwidey crater is tourism area either local or foreign tourists. The development of tourism is one of driving factor for land use change in the area.

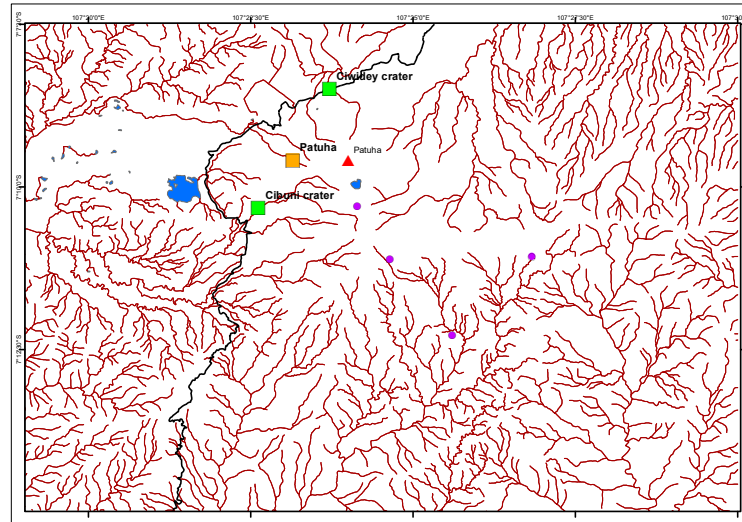


Figure 4 Drainage pattern of study area

c. Social and Economic Analysis

There is significant population growth in district such as Ciwidey, Rancabali, and Pasir Jambu, as we can see from table. Beside geothermal development, the population and tourist growth either international tourist or domestic tourist is driving factor for land use change di study area.

Table 1 Population number in three sub district in Bandung regency

Subdistrict	Population by subdistrict (individuals)		
	2020	2021	2022
Ciwidey	86.445	87.815	89.436
Rancabali	51.096	51.403	51.846
Pasirjambu	91.191	92.302	93.667

Table 2 Tourist number in regency and cities in Bandung basin

Regency	Number of Tourist Visits to Tourist Attractions (people)								
	International Tourist			Domestic Tourist			Total		
	2021	2022	2023	2021	2022	2023	2021	2022	2023
Bandung	100	1.746	15.833	1.836.575	3.782.823	1.014.251	1.836.675	3.784.569	1.030.084
Sumedang	-	11.410	12.023	648.004	1.292.992	1.803.403	648.004	1.304.402	1.815.426
Bandung Barat	-	21.241	3.996	2.202.146	4.447.943	3.476.351	2.202.146	4.469.184	3.480.347
Kota Bandung	-	1.841	12.639	393.223	2.404.708	2.910.645	393.223	2.406.549	2.923.284
Kota Cimahi	-	120	426	29.533	74.689	110.341	29.533	74.809	110.767

d. Sustainable Land Use Management

- Existing Land Use

There are seven classes including built-up, bush, farming, plantation forest, primary forest, rice field, and water body. The development of geothermal industry, tourist area, and population growth.

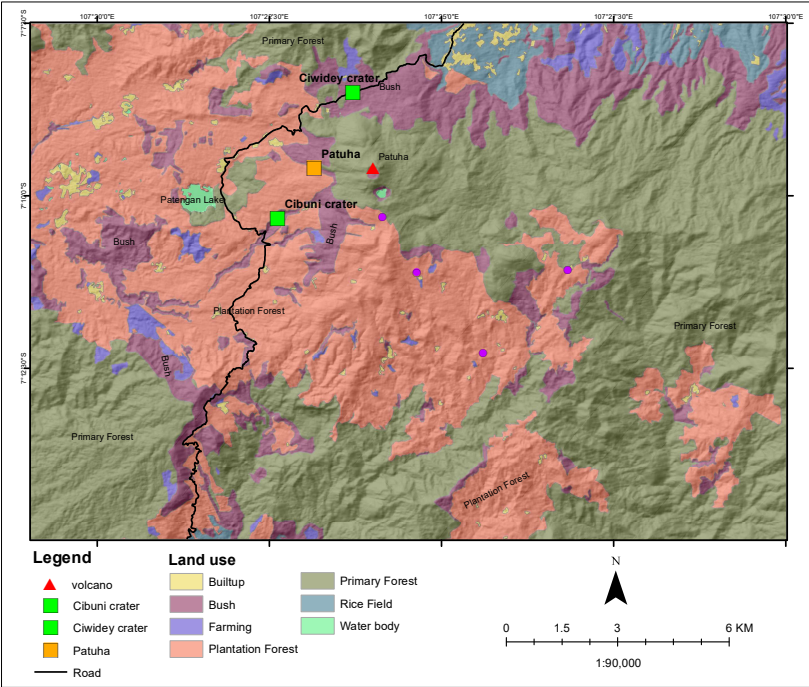


Figure 5 Existing land use of Ciwidey area

Table 3 Estimated area and land degradation

No	Land Use Land Cover Types	Area (m ²)	Estimated Area (%)
1	Primary forest	131252207.096	0.469
2	Forest plantation (Tea Plantation)	95031584.218	0.340
3	Farming	5793668.841	0.021
4	Rice field	6985176.996	0.025
5	Bush	36725983.719	0.131
6	Built up	3257654.262	0.012
7	Water bodies	649870.768	0.002
Total		279696145.9	100

Table 4 Characterization of land use system

No.	Picture	Explanation
1.		A primary forest is an entire natural forest with a large number of mature trees that has not been impacted by human activity like logging for several hundred years. There are multiple dense, well-developed canopy layers in this kind of forest. High biodiversity, which includes indigenous plants and trees as well as creatures like tigers, monkeys, snakes, and deer, is a result of favourable environmental conditions. The government owns the protected primary forest.

2.	Forest Plantation 	Tea plantations are methodically planted in every area. Both young and established plantations that have been set up for the commercial production of non-timber are included in this land use category. The plantations are monocultures that produce crops for both domestic and foreign markets. A huge landowner owns the majority of these plantations, and a number of tea pickers are employed to do the labour.
3.	Farming 	Lowland farming refers to a land use strategy in a plain or valley with sufficient stream flow or humidity for irrigation. Depending on the crop variety and its humidity requirements, the plots are either rainfed or irrigated. Generally speaking, monoculture systems are used to grow annual species like cabbage, strawberries, tomatoes, carrots, potatoes, and onion leaves. Market-oriented farmers range in size from small to large.
4.	Rice field 	Irrigated rice fields can be found in the plain, divided by soil bunds, or on hillsides as bench terraces. The water is directed into the paddies via drainage channels. The purpose of waterlogging is to establish ideal conditions for rice cultivation. Rice can be harvested twice a year or more because of the annual irrigation scheme. Depending on when they are planted and when they expand, irrigated rice fields can be in various states.
5.	Bush 	Bush with farming refers to any unstructured, improperly managed lands that are located on hills or ridges. Fruit trees like bananas and papayas are among the many types of crops, including tomatoes, chillies, beans, maize, cabbage, potatoes, and cassava. There is a spatial mix of endemic trees and shrubs with crops and fruit trees.
6.	Built-up 	All officially constructed regions where people live permanently or mostly permanently are called settlements. Their high residential density and related infrastructure make them easily recognisable. Cities, towns, and villages are examples of settlements, as is the infrastructure, which includes public buildings, hotels, restaurants, mosques, and schools. Some towns have residential fishponds, small cattle, or home gardens.

7.	Water Bodies 	Permanently open water regions are known as waterbodies. Both man-made and natural waterbodies, whether flowing or stagnant, fall under this category. Items in this category include lakes, fish ponds, reservoirs, rivers, and irrigation channels. Patengan Lake is one of the well-known lakes.
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- DPSIR Analysis

In the land use evaluation, the model of DPSIR can measure the correlation between industrial activities and the environment protection, and reflect the positive feedback of human society to manage environmental (Fu et al., 2012; Qu et al., 2020). The operational mechanism of the DPSIR model can be summarized as follows: as the long-term driving force (D) affecting geothermal development, growth rate population, and growth rate tourism caused various pressures (P) on the natural resources and land resources. These pressures (P) are directly reflected in the land state (S) such as land use change on residential land area and tourist land area. Moreover, there is a series of impacts (I) on especially the farmland loss and ecological degradation. Then, the condition led to human to take a series of positive response (R) how to achieve the goal of sustainable development. To form a circular or closed loop at the same time, these response from human (R) measures not only act on the system composed of human economy and society (D), but also directly have a positive impact (I) on pressure (P) and state (S), (Chen et al., 2022).

Table 5 DPSIR model of land use and land cover type

First level Indicator	Second Level Indicator
Driving	Geothermal development Growth rate population Growth rate tourism
Pressure	Natural resources Land resources
State	Residential land area Tourist land area
Impact	Farmland loss Ecological degradation
Response	Land use policy Energy policy

CONCLUSION

In land use planning context, land use alternative-based plan is a method to compare and to choose one of the multiple land uses for specific objective use of land. Alternative plan and scenario plan sometimes is used interchangeably. There are five elements of alternative plan, including alternatives, consequences, causations, frameworks and geography footprints.

Geothermal and tourism industries are related to a number of sustainable development challenges such as environmental, social, economy etc. Land evaluation is widely used for many purposes ranging from economic appraisal, business planning and land use planning. Land evaluation is to find the suitability of land based on specific land use requirements. Generally, qualitative and quantitative land evaluation methods are used to evaluate suitability of the land. Recently, the combination of GIS and MCE is one of prominent land evaluation. This method is based on multi criteria analysis in geography information system platform. Land evaluation is a complex process and there are multiple criteria and alternatives should be taken into consideration to accommodate also one reason behind SMCE.

To conclude, the correlation between industrial activities and the environment in Ciwidey geothermal area using base data analysis and DPSIR model. The long-term driving force of geothermal development, growth rate population, and growth rate tourism caused various pressures on the natural resources and land resources. The pressures are directly reflected in the land changes such as residential area and tourism area. The impacts of farmland loss and ecological degradation encouraging policy maker to take a series of measures to achieve the goal of sustainable development.

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