Unearthing the Dynamics of Indonesia's Geothermal Energy Development

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Article

Unearthing the Dynamics of Indonesia's Geothermal Energy Development

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Abstract: Indonesia has one of the world's biggest geothermal energy reserves, accounting for 28.61 Gigawatts of electric energy (GWe). However, as of 2022, the installed geothermal capacity in Indonesia was only around 2.175 GWe, just 7.6% of its estimated potential. Geothermal energy development is required for Indonesia to empower sustainable energy systems and achieve its target of reaching 7.2 GW of geothermal energy by 2025. The geothermal energy sector is viewed as a complex dynamic system, with complicated challenges, including technical, financial, infrastructure, and many other issues. The purpose of this paper is to understand the complex nature of geothermal systems in Indonesia. To that end, this paper examines the geothermal development from a systematic and holistic standpoint, employing the interview technique to enable the conceptualization of the geothermal systems using the system dynamics (SD) approach. The SD model exhibits several underlying and important factors influencing the development of geothermal energy in Indonesia, such as capital investment, the collection of upstream data to reduce risk, infrastructure construction, pricing, incentives, permit procedures, environmental concerns, and public acceptance.

Keywords: geothermal; Indonesia; interview; system dynamics

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1. Introduction

Geothermal energy is one of the types of renewable energy sources produced from the Earth's subsurface, which can be conveyed as hot water, hot steam, or a combination of both. Geothermal energy has become one of the most vital sources of energy, with a substantial growth potential in recent years [1,2]. Not only does it supply an alternative energy to help replace the demand for conventional fossil energy, geothermal energy also contributes to reducing the reliance on fossil fuels. As one of the clean energy sources, geothermal energy serves to mitigate the effects of global warming and the health hazards associated with air pollution, such as respiratory-related diseases [3], caused by the usage of fossil energy sources. Depending on its qualities, geothermal energy can be utilized for district heating, or harnessed to provide sustainable electricity [4]. Lower enthalpy geothermal energy is frequently useful for direct usage (for example, room heating, tourism, agriculture, agroindustry, and fisheries) [4–7]. Meanwhile, geothermal energy with medium to high enthalpy can be utilized to generate electricity [8], which is common in active tectonics locations [9].

Indonesia has a wide-range of geothermal energy, from low to high enthalpy, that can be utilized for both district heating and generating electricity [10]. Located along the "ring of fire," which traverses around the Pacific Ocean's margins [11], and home to the world's most active volcanoes and earthquakes [11,12], Indonesia has one of the world's largest geothermal energy reserves that can potentially be used to generate 28.61 Gigawatts of electric energy (GWe) [13,14]. Despite the potential, Indonesia's utilization of geothermal energy, particularly for electricity generation, is not yet up to par [15]. As of 2021, geothermal energy used to generate electricity in Indonesia is at a capacity of 2.175 GWe, or only 7.6% of its potential [16]. In addition to that, according to Indonesia's National Energy Plan (RUEN), Indonesia pledges to achieve 7.2 Gigawatts (GW) of geothermal energy utilization by 2025, which will increase its contribution to the energy transition goal of net-zero emission by 2060 [17]. However, the geothermal energy development in Indonesia is currently hampered by numerous hindrances, such as technical and regulatory issues, which have significantly slowed the progress of the geothermal sector [18,19].

The development of geothermal energy is a very dynamic and complicated process that involves stakeholders, policies or regulations, institutions, technologies, and other interconnected and changing elements [20,21]. Such complexity increases the challenge for the government to achieve the goal. In order to understand the complex nature of geothermal energy development, systematic and holistic approaches are required. Understanding the relationships between the elements involved in the development of the geothermal energy sector is becoming increasingly more important and necessary for developing long-term strategies to boost the development of the geothermal energy sector.

In order to gain a more holistic, dynamic, and comprehensive perspective, it is necessary to solicit and analyze some critical information directly from the stakeholders in the geothermal sectors in Indonesia. Therefore, the aim of this paper is to analyze Indonesia's complex geothermal development structure. In so doing, the following research questions were subsequently proposed to ensure the achievement of transparent, repeatable, and credible research outcomes.

RQ1. How can the barriers associated with geothermal energy development in Indonesia be understood from the perspective of the geothermal stakeholders?

RQ2. What are the key elements within the dynamics of geothermal energy development in Indonesia, and how are they interrelated?

Such information gathering was primarily accomplished through literary work and interviews with the primary stakeholders of the geothermal energy sector in Indonesia, with the ultimate goal of identifying the key elements of the geothermal system. These key elements (and their interrelationships) were then modeled into a conceptual framework using the system dynamics (SD) modeling approach.

This paper offers key contributions to the body of knowledge by providing an integrated and holistic view of Indonesia's geothermal system and by taking into account some disparate elements (e.g., infrastructure, permits, incentives, and public acceptance) that to date have not been well discussed in the extant literature, yet are vitally important to geothermal system development. As this research incorporates information from all major geothermal projects operated by major actors or commercially operating companies in Indonesia to date, the SD model that is developed may act as a reference model that represents the geothermal system in Indonesia.

This paper is structured as follows: Section 1 provides the background and research questions for the research. Section 2 lays out the theoretical foundation for this research by elaborating on the various studies pertinent to this research, so the gaps in the existing literature can be clearly identified. Section 3 describes how the research was carried out, including data collection and analysis methods. Sections 4 and 5 discuss the findings and the analysis of their implications for understanding the problem. Section 6 concludes this research paper by outlining a set of proposals for Indonesia's geothermal sector development.

2. Related Work

Geothermal development is complex, as it is surrounded by a plethora of external factors that frequently create uncertainty and hinder its development. The project scale, interrelationship, regulation, context, permits, and project stages are some of the factors that contribute to the complex nature of geothermal development [22]. Due to the dynamic interactions of various elements within the energy system, including the geothermal energy sector, many researchers have attempted to identify and understand the complex elements of the energy sector. One of the many popular methods used by researchers to untangle this complexity is by using the SD modeling technique.

Leaver and Unsworth [23], Lowry et al. [24], and Axelsson [25] have used SD to map the technical aspects of the geothermal system, using the datasets from a few specific geothermal fields. However, despite the detailed technical aspects offered, their work lacked several important non-technical aspects, deeming them as insufficient to fully elucidate the complexity of geothermal systems. Subsequently, Alfrink [26], Jiang et al. [27], and Splitter et al. [28] used SD to elaborate other elements of geothermal systems beyond the technical aspects, including the financial and economic aspects. Aslani et al. [29], Saavedra et al. [30], and Splitter et al. [31] also used SD to improve the deficiencies of the previous work by complementing the aspects of the geothermal systems to include a more holistic view of renewable energy use in different countries. While the aspects of geothermal systems have been incorporated in the abovementioned models, unfortunately, the models become too broad, leaving out too many details and aspects that determine the geothermal system's complexity.

In the context of Indonesia, SD has been used in the geothermal energy sector by Aditya [32], who developed a framework that integrates the technical and economic aspects of the geothermal system using the Mataloko Geothermal Power Plant in Kupang, East Nusa Tenggara. Akin to this work is a study by Setiawan et al. [33] that complements Aditya's work with a more holistic approach by covering more than just the economic and technical aspects.

Previous work, therefore, clearly demonstrates the paucity of research on renewable energy system dynamics, including geothermal energy. First of all, the extant work in geothermal dynamics is currently focused predominantly on the technical and economic aspects. In particular, the elaboration of the dynamic relationship of the key elements beyond the technical and economical viewpoints is lacking, and even if it exists, it is poorly discussed. Secondly, although there are a number of researchers who have also attempted to develop a more holistic coverage of more aspects of the geothermal system dynamics, there are gaps between the methodological pathway and the geothermal SD model itself. For instance, much of the previous work was based on the data originated from a single case of geothermal energy in a single area as a base model, which may not be representative of the overall picture, hence decreasing the robustness of the SD model being developed.

Therefore, in this research, the methodological framework of the research will be provided to bridge the gaps in discussing how the geothermal SD can be developed. This research will also use vast sources of data from geothermal plants in Indonesia, which improves the robustness, reliability, and accuracy of the SD models of the Indonesian geothermal system.

3. Research Design

This research focuses on developing a conceptual framework of the Indonesia's geothermal energy system. The overall research design comprises two main stages. In Stage 1, the semi-structured, in-depth interview method is carried out, involving a large number of key stakeholders in geothermal energy in Indonesia, to identify the key elements that play critical roles in the geothermal energy sector. In Stage 2, using SD modeling, these key elements and their structural interrelationships are mapped and modeled to provide a holistic understanding of geothermal development complexity in Indonesia, incorporating technical, economic, political, and social aspects.

3.1. Stage 1—In-Depth Interview

This research employs a qualitative approach based on face-to-face in-depth interviews as the primary data collection method. This method was chosen due to its ability to allow the interviewers to probe the stakeholders of the Indonesian geothermal energy sector in a systematic manner [34] using open-ended questions, while allowing the interviewers to follow up with other questions that may not necessarily be pre-determined. The qualitative method was deemed suitable, as it allowed for data collection flexibility and for the ability to obtain direct feedback to explain the complex phenomena, while requiring in-depth analysis [34]. The in-depth interview, while based on the semi-structured interviews [35,36], provided data generated in a descriptive and explanatory form [37,38].

3.1.1. Profiles of the Case Companies and Interviewees

The face-to-face, in-depth interviews incorporated the researchers as the interviewers and several geothermal stakeholders as the interviewees. Each of these stakeholders represents one of the seven biggest geothermal industry companies that are currently operating commercially in Indonesia. In addition to the companies, representing the industrial sector, interviews are also conducted with representatives of a state-owned electricity company, National Research and Innovation Agency, and the Indonesia Geothermal Association. These respondents were selected to gain information from the non-industrial perspective. In order to keep the confidentiality of each interviewee, the name of the companies will be stated as "Company-X," and the interviewees' will be identified by their codes.

Company-1 is a subsidiary of a state-owned oil and gas company in Indonesia. This company has been engaged in the utilization of geothermal energy since 2007. Company-1 has been one of the biggest contributors to national geothermal growth. As of 2020, the company has 672 MW of existing assets and 220 MW of existing projects. Currently, the company manages 15 geothermal working areas, with a total installed capacity of 1877 MW, which consists of 672 MW from its own operations, and 1205 MW from a JOC (joint operation contract). The geothermal working areas from its own operations are located in North Sumatra, South Sumatra, Lampung, West Java, and North Sulawesi.

Company-2 is a geothermal company in Indonesia that has been operating since 2007. The company has three subsidiaries that operate in three different areas of Indonesia. Subsidiary-1 is located in the South Solok Regency, West Sumatera Province, with initial synchronization of the 80 MW (nett) geothermal power plant and the 150 kV electricity network owned by a state-owned national electricity company. Subsidiary-2 is located in the South Lampung Regency, Lampung Province. This subsidiary is principally located at the southern end of the Sumatera Island, specifically on the eastern coast of Lampung Bay on the volcanic cone of Mount Rajabas, with the capacity of a 2 × 110 MW geothermal project. Subsidiary-3 is located in the Muara Enim, Lahat Regencies, and Pagar Alam City, South Sumatera Province, with a capacity of 92.1 MW as of 2022.

Company-3 is developing the 110 MW Blawan Ijen Geothermal Power Plant in Blawan Ijen, East Java, Indonesia (Ijen Project). The company has signed PPA (power purchase agreement) with a state-owned power company for a 30 years contract. The commercial operation date starts in 2021, with the capacity of 2 × 55 MW power generation and an approximately 28 km transmission line to the nearest substation.

Company-4 is an Indonesian state-owned enterprise engaged in geothermal exploration and exploitation since 2002. Initially, the company was established in the form of a joint venture between a state-owned oil and gas company and a state-owned electricity company to manage WKP Dieng and Patuha, according to the assignment from the government. Currently, Company-4 operates the Dieng and Patuha geothermal working areas (WKP) with a capacity of 55 MW each. In addition, this company also received an assignment from the government to manage WKP Umbul Telomoyo and WKP Arjuno Welirang.

Company-5 is a geothermal company that has been commercially operated over the past few years. The company has built one of the biggest geothermal power plant projects using a single contract, with a capacity of 3 × 110 MW. The geothermal project is located in the Pahae Julu and Pahae Jae Districts, North Tapanuli Regency, North Sumatra Province. The first unit was commissioned commercially in March 2017. The second unit started operating in October 2017. In May 2018, the third unit was established and also started operating. The geothermal power plants of Company-5 are fueled by brine and steam from production and injection facilities at the Silangkitang and Namora-I-Langit reservoirs.

Company-6 is one of Indonesia's largest geothermal energy producers. Company-6 partners up with two state-owned companies to convert geothermal energy into electricity in West Java Province. In Pangalengan, Company-6′s Geothermal Wayang Windu Limited operates a geothermal facility with a gross installed generation capacity of 227 MW. In Sukabumi, Company-6 manages one of the largest geothermal fields in the world, with a gross installed generation capacity of 197 MW and steam sales capacity of 180 MW. In Garut, Company-6 Limited has a gross installed generation capacity of 216 MW and a steam sales capacity of 55 MW.

Company-7 is one of the biggest geothermal project development companies in Indonesia. The company's project is situated in Mandailing Natal Regency, North Sumatra Province. Company-7 obtained the majority shares of the company in mid-2016. Since then, the geothermal project has completed drilling operations for 18 wells, and it has confirmed at least 55 MW of proven resources. The project is targeted to connect 45 MW of electricity produced to the grid of a state-owned electricity company by the end of September 2019, and this target has been exceeded as of 2022.

Company-8 is a state-owned electricity company or enterprise that deals with all aspects of electricity in Indonesia. The company has a subsidiary that specifically deals with geothermal energy. This subsidiary was established on 28 January 2009 to carry out the development of a geothermal system in Indonesia with a function of providing the security of supply and cost-efficiency. Since its establishment, the company subsidiary managed to develop several geothermal-related projects and programs in Indonesia to support the government in increasing the availability of electricity for all Indonesian people, such as the geothermal working areas of the Tulehu, Lahendong Power Plant, and the Mataloko Power Plant. In addition, the company has eight geothermal work area projects that have been developed.

Company-9 is the National Research and Innovation Agency, a non-ministerial government agency that is under the direction of and responsible to the president of Indonesia through the minister in charge of government affairs in the field of research and technology. This institution, which was first formed in 2019, is attached to the Ministry of Research and Technology (MRT). As of 2021, the agency separated from the MRT and became independent, becoming directly responsible to the president. Currently, the institution is working on the development of equipment and technology required for geothermal projects. The objective is to develop and produce geothermal equipment so that it can be produced on an industrial scale.

Company-10 is the Indonesia Geothermal Association, a non-profit organization, which acts as a forum or medium of communication, consultation, and coordination in order to enhance the members' understanding, cooperation, capabilities, and responsibility of the role of geothermal energy development in Indonesia. The organization represents the geothermal sector and is a forum for professionals, developers, and implementers of the geothermal sector; it is non-political and has no political affiliation.

Table 1 provides information on the initials of the interviewees, their positions within their organizations, and their responsibilities to their respective organizations.

Table 1. List of the case companies and interviewees.

Case	Code	Type of Company; Position of the Interviewee: Job Description
Company-1	Interviewee-1A	Geothermal company; Director: Making major corporate decisions and managing the company's overall resources and geothermal operations.
	Interviewee-1B	Geothermal company; Director of Exploration and Development: Overseeing the company's geothermal operations and maximizing the company's geothermal operating performance.
	Interviewee-1C	Geothermal company; Corporate Secretary: Planning and implementing corporate governance within the company.

Table 1. *Cont.*

Case	Code	Type of Company; Position of the Interviewee: Job Description
Company-2	Interviewee-2	Geothermal company; Director: Making major corporate decisions and managing the company's overall resources and geothermal operations.
Company-3	Interviewee-3A	Geothermal company; Senior Vice President—Geothermal: Overseeing geothermal operations and maximizing the company's geothermal operating performance.
	Interviewee-3B	Geothermal company; Senior Geologist: Overseeing geological operations and site investigations of the geothermal project area.
Company-4	Interviewee-4	Geothermal company; Director: Making major corporate decisions and managing the company's overall resources and geothermal operations.
Company-5	Interviewee-5A	Geothermal company; Stakeholder Manager: Managing geothermal stakeholder mapping and coordinating with other geothermal stakeholders.
	Interviewee-5B	Geothermal company; Chief Administrator: Providing input for geothermal business and strategic planning for the company.
	Interviewee-5C	Geothermal company; External Relations Manager: Liaising the company with other geothermal stakeholders.
Company-6	Interviewee-6A	Geothermal Company; Deputy Director of Operations: Overseeing geothermal operations in the project area.
	Interviewee-6B	Geothermal company; Director of Strategy and Planning: Overseeing the company's operations and processes to identify strategic initiatives that will drive the company in its long-term growth and development.
	Interviewee-6C	Geothermal company; General Asset Manager: Managing and monitoring the company's geothermal energy assets.
Company-7	Interviewee-7	Geothermal/Renewable Energy Company; Head of Environmental Operations: Managing stakeholder relations, sustainability, and business development.
Company-8	Interviewee-8	State-owned electricity company; Executive Vice President of Strategic Planning: Assisting in overseeing the company's operations and processes to identify strategic initiatives that will drive the company in its long-term growth and development.
Company-9	Interviewee-9	A national research institution; Deputy of Research and Innovation Utilization: Overseeing, managing, and evaluating research activities, products, and future developments.
Company-10	Interviewee-10	Non-profit organization; President: Overseeing policy setting and the strategic direction for the organization, both for the short-term and the foreseeable future.

3.1.2. Guiding Questions

The semi-structured interviews were carefully designed, so that the interviewer prepared several questions prior to the interviews to help guide the conversation between the interviewer and the interviewees in regards to geothermal development in Indonesia. The semi-structured interview method was chosen, as it allowed the interviewer to probe the interviewees for more in-depth information. In this way, the interviewer can follow up with questions regarding the reasons behind the answers, allowing the interviewees to open up about sensitive issues. This format may also provide qualitative data as a basis for comparison with previous and predicted data [39]. The guided questions were formulated based on the most common issues found in the geothermal industries in Indonesia, and the interviewer then took a deep dive into the issues based on, but not limited to, the prepared questions (see Table 2).

Table 2. Guiding questions for the interviews.

Questions
Risk is one of the most important keys in decision making for developing a project. What are your views on the risks associated with geothermal projects?
The geothermal energy development would depend on locations. How has the location of geothermal prospects affected the geothermal development?
The economic value of geothermal projects, particularly in revenue generation, seems to depend on how the geothermal is valued in the pricing mechanism. How is the geothermal pricing mechanism in Indonesia?
Infrastructure is one of the most important aspects of the geothermal energy development. What are your views on the state of geothermal infrastructure in Indonesia?
What are the other aspects of geothermal energy that need to be considered to enhance its development?

3.2. Stage 2—System Dynamics Modeling

Following the interview stage, SD modeling was chosen as the theoretical lens through which the data were analyzed. This systems-level method was chosen because it is capable of providing a befitting theoretical perspective for constructing informative decision insights for renewable energy development [40]. SD modeling is a technique to identify, comprehend, and analyze many different complex systems. The behavior of a system's complexity normally requires a holistic understanding, for which the complex nature of the smallest unit, element, or constituent can be sufficiently understood, so better policy recommendations can be designed and ultimately proposed to improve the system [41,42].

In system dynamics (SD), conceptualization is a primary step needed to provide an understanding of the system that is being observed or analyzed. The causal loop diagram (CLD) is a conspicuously useful tool for developing a conceptual SD model. CLD contributes to the development of the systems' dynamic hypothesis. CLD enables the comprehensive depictions of causal relationships between the elements that were included within the system's boundary. CLD depicts the interaction of system elements with their neighboring environments, for example, the problem owner, stakeholders, system goals, and criteria, and policy instruments used to improve the system. In this research, the information from the stakeholders' interviews is analyzed using this approach, which is very useful in understanding and mapping the important cause and effect interrelationships among the geothermal system's elements [43].

4. Findings

Indonesia's geothermal resources, accounting for over 40% of the global potential (or 28,617 MW) can be used in a power plant where geothermal fluid produced through production wells will go through a separation and cleaning process before entering the turbine and being converted into electric power. Despite its huge potential, there are still many obstacles that hinder the optimal utilization of geothermal energy, from both the technical and non-technical aspects. In this section, these obstacles will be analyzed based on the interviews with the geothermal stakeholders.

4.1. High Risk of Geothermal Exploration

One of the biggest obstacles in developing geothermal energy lies in the early stage of the geothermal upstream project, which is the exploration stage. At this stage, geothermal potential and economics are highly dependent on the interpretation of geophysical, geochemical, and geological (3G) survey results. The results of this 3G survey can provide a glimpse into the geothermal system of interest, which includes the reservoir, temperature, and pressure values of the geothermal location. However, these 3G surveys are not sufficient, and they must be supported by more data. The only way to prove this interpretation is by performing test drilling. The 3G surveys and test drilling can be very expensive, as confirmed by Interviewee 1A:

> *" . . . it is very expensive to start a geothermal project. I will give you an example, the cost estimate to carry out the exploration stage including drilling with only a total of 3 wells, which was around USD 34.1 million, that included the Geological, Geophysical, and Geochemical surveys, but it is necessary for the making sure the geothermal area that we are assessing is promising or not."*—Interviewee 1A

While Interviewees 2 through 7 did not provide the cost estimate of this exploration, all of the interviewees who represent the geothermal companies agreed that this exploration phase required hefty costs.

A greater risk of a geothermal project will potentially increase the capital cost due to project loss, as stated by Interviewee 4:

> *" . . . the significant upfront cost of these exploration activities does not guarantee a significant return because if it turns out that after drilling there is no reservoir as interpreted in the initial 3G survey, then the large costs paid by the geothermal developer, which is certainly very detrimental to the company, would fall through."*—Interviewee 4

Interviewees 1 through 7, and interviewee 10, stated that the high risks of geothermal exploration, as well as the expensive initial costs that must be faced by geothermal developers to carry out the exploration stage, have made the development of geothermal energy becomes sluggish. Therefore, according to Interviewee 5A, government intervention in the upstream data strategy is needed:

> *" . . . upstream data strategy, including data integration from all state-owned companies, or government-funded drilling would be one of the scenarios that not only can make sure the potential of a geothermal area and increase the certainty during the exploration, but also increase the geothermal attractiveness."*—Interviewee 5A

Interviewees 1 through 7 concurred that a clear risk of geothermal exploration enables the bankability of a geothermal project and could ease the geothermal investment. Interviewee 3A, for instance, argued that:

> *" . . . a crystal-clear image of geothermal exploration risk is necessary for the bank to determine whether our project is bankable or not. Lower risk for them would make the process easier and more attractive."*—Interviewee 3A

4.2. Geothermal Locations within National Parks or Protected Forests

Most potential geothermal drilling sites in Indonesia are located within protected forest areas, which has caused various problems for decades, as Interviewee 4 expressed:

> *" . . . around 80% of the potential sites are in protected forest areas where open-pit mining is prohibited by Forestry Law No.39/2004. This law is believed to have become a major barrier to the development of geothermal exploration in Indonesia, particularly during the permit approval."*—Interviewee 4

For decades, geothermal activities had been classified as mining activities, which has created further problems because, in conservation forest areas, it is completely forbidden to carry out geothermal activities, so efforts are needed to determine the types of geothermal activities that should be allowed. Since geothermal activities are aimed at thermal, and not materials, extraction, they can be distinguished from mining activities, such as coal or mineral resource extraction.

The Indonesian government has issued Law No. 14 of 2014, which no longer includes geothermal activities as mining activities, to allow for geothermal exploration and production activities in protected forest areas. However, the regulation still has some loopholes that have not made it possible to fully carry out exploration and exploitation of geothermal resources within a national park. In addition to that, land disputes are often complicated by public resistance towards geothermal projects. Interviewees 1A, 3A, 4, 5A, and 6A agreed that carrying out drilling activities, building infrastructure, and building geothermal power plant units, requires the easement of land permits; otherwise, a geothermal developer will not be able to develop a geothermal working area. As Interviewee 3A mentioned:

> *" . . . if we want to increase the pace, make the permit process easier, because otherwise, many geothermal working areas in Indonesia, especially those currently undergoing the exploration stage, the geothermal utilization target of 7.2 GW in 2025 set by the government would be very difficult to achieve."*—Interviewee 3A.

4.3. Pricing Mechanism

Geothermal resource development projects in Indonesia can be categorized as public-private partnerships (PPP), where the business relationship formed between private sector companies and government institutions aims to carry out projects to provide electricity. In Indonesia, geothermal developers can only sell the electricity produced to the State Electricity Company (PLN) as a single buyer or off-taker. As a result, the existence of a market mechanism does not work, and the government must periodically create tariffs to anticipate the dynamics of operating costs where the regulated tariff will be difficult to satisfy both the seller and buyer.

Interviewees 1 through 7, and interviewee 10, mentioned that there are several problems in the electricity buying and selling scheme for geothermal energy development projects in Indonesia. The State Electricity Company (PLN), as the only electricity company in Indonesia, does not directly approve the tender price. As Interviewee 1A stated:

> *" . . . we, as developers, have to negotiate with PLN to determine the price of the Power Purchase Agreement (PPA) after winning the tender where in most cases, the PPA price, roughly around 7 cents per kWh, is lower than the tender price."*—Interviewee 1A

Interviewee 4 stated that this certainly has the potential to hamper the pace of investment in geothermal projects because investors find it difficult to determine the economics of the project, one element of which is determined by the sale and purchase price of electricity.

As a result of this pricing mechanism, another set of problems also occurs during the bidding system. Interviewees 5A and 7 stated that the geothermal developers have difficulty determining a reasonable bid price, while the government also has difficulty finding serious developers. Using the bidding system, the lowest bidder is the winner of the geothermal prospect area license offered, so some developers try to propose very low, and often unreasonable, prices. Problems arise when the developer, after winning the license, does not kickstart the geothermal development project which has been obtained because it feels that the price offered is not economically attractive.

Interviewee 6A stated that pricing and incentive regulation is needed to increase geothermal attractiveness:

> *" . . . in business, the more revenue we gained, the more attractive the business is, that's why we need the pricing mechanism that can attract the appetite for geothermal. Apart from that, incentives can be an appealing approach to attract the geothermal investors."*—Interviewee 6A

4.4. Underdeveloped Infrastructure Affecting Geothermal Development

The problem of geothermal development in Indonesia is also strongly influenced by infrastructure conditions, such as road access, transportation modes, and high-voltage electricity transmission that will be used to the supply electricity produced by geothermal power plants. Interviewee 2 stated that one of the main problems faced by Indonesia as an archipelagic country is inter-island connectivity, which directly affects domestic shipping costs. Interviewee 2 also mentioned that Indonesia's low level of investment in physical infrastructures, such as roads and bridges, has contributed significantly to Indonesia's connectivity problems. Transportation problems, congestion, and poor road quality are among the worst business constraints.

Interviewee 1A stated that in geothermal development, Indonesia's geothermal prospect locations are generally located in mountainous forest areas, which are far from main access roads, provincial roads, and district roads, making it difficult to mobilize drilling equipment. Interviewee 5A explained that the higher the logistics and equipment mobilization costs, the higher the cost of geothermal development projects, which in turn can make the investment in this sector less attractive. Quoting from Interviewee 5A:

> *" ... when we first started the geothermal project, we needed to build the infrastructure such as road access, for example, and that cost a lot and it was one of the main factors to consider that could make the project less attractive."*—Interviewee 5A

As a part of the infrastructure, the facility is also an important factor. Effective and efficient technology is needed to reduce costs, especially during exploration. Interviewee 9 stated that Indonesia is capable of producing equipment for geothermal projects in the country; currently, an equipment test project is being carried out by National Research and Innovation Agency, at the Kamojang geothermal site.

4.5. Power Wheeling

Geothermal companies in Indonesia still have limited options to electrify their facilities and supply chains using geothermal energy sources. Therefore, it is necessary to consider a mechanism that can facilitate the transfer of electricity from geothermal energy sources to the company's operating facilities directly, or what is known as "power wheeling," or shared utilization of the electricity network. According to Interviewee 8, in Indonesia, the basic rules regarding power wheeling have been established through the Minister of Energy and Mineral Resources (MEMR) Regulation No. 1 of 2015, concerning cooperation in the provision of electricity and joint utilization of the electric power network.

First, the business model for this scheme is the transfer of electricity from the holders of the operating permit for distribution to the company itself. This makes it possible for companies to build their own power plants, even though they are far from company facilities. Another business model is the buying and selling of electricity between private power plants and holders of business permits for the provision of electric power (IUPTL) in different business areas. However, it is difficult for the private sector to obtain a business area because most of the business area is owned by PLN (in one location, only one business area is allowed).

Interviewee 10 stated that the limitations of this business model can have an impact on the less massive transfer of geothermal energy to electrify private facilities, whereas the flexibility for the private sector to conduct direct transactions in this scheme can increase the development of geothermal energy on a large scale, when the private sector can help ensure electricity supply from geothermal energy sources and maintain electricity supply and tariffs. As mentioned by Interviewee 4:

> *" ... to overcome this challenge, PLN needs to change the business paradigm so that the power wheeling scheme can be widely applied, starting from plant development planning, system operation, to target customers."*—Interviewee 4

Interviewee 10 mentioned that many details of this scheme have not been regulated in the Energy and Mineral Resources Ministerial Regulation, including the portion of involvement of each party and technical instructions regarding network rental prices. As a first step to optimizing the available business model, PLN can start issuing technical instructions related to the formulation of transmission and distribution network rental prices, as well as technical standard procedures for implementing joint utilization of the electricity network. On the other hand, the Ministry of Energy must also actively participate in ensuring transparency and fairness regarding network rental prices to provide certainty for both the PLN and the customers.

4.6. Public Resistance

The factors that were least discussed, but certainly not least important, were related to the public acceptance of geothermal projects. Interviewee 6A stated that the lack of public understanding of the importance of geothermal projects often leads to resistance, which eventually ends in the delay of geothermal development projects. This situation especially occurs when the geothermal project is still in the exploration stage, when local governments, development companies, and local communities are still in the stage of recognizing each other, and trust has not yet been built between each party. As stated by Interviewee 6A:

> *" ... this is not news to geothermal developers, especially with the many reports in the mass media about the public's resistance to geothermal projects in Indonesia. However, in practice in the field often, companies have not carried out education or counselling sustainably and comprehensively."*—Interviewee 6A

5. Discussion

This section discusses the development of the SD model that describes the relationships between elements that play a crucial role in geothermal system development in Indonesia. The causal loop diagram (CLD) is employed to link up the critical elements of the geothermal system that make up the conceptual framework, as shown in Figure 1. The loops and their elements were obtained from the interviews with the geothermal stakeholders (see Table A1 in Appendix A).

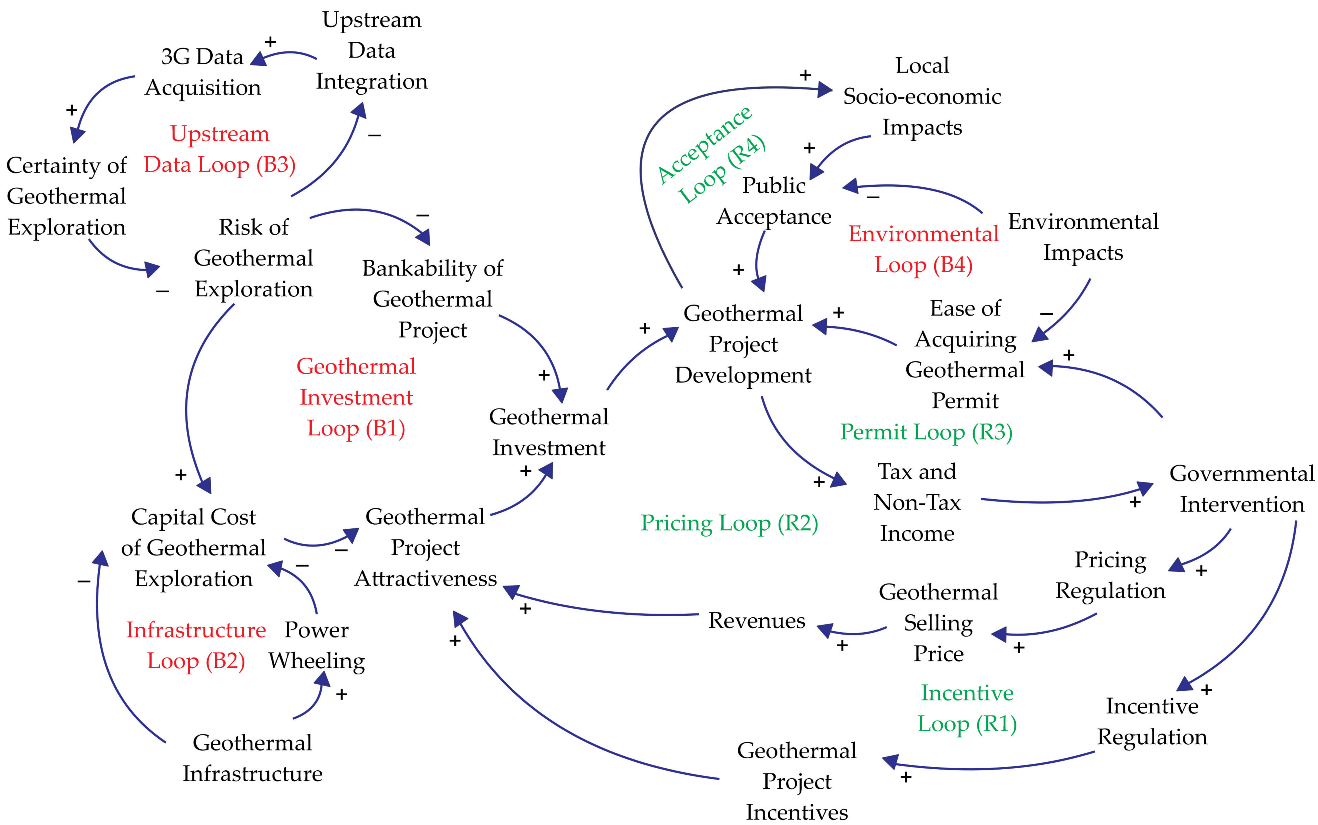

Figure 1. CLD of geothermal energy development in Indonesia.

Table 3 lists the structure of the feedback loops within the conceptual framework. The loops detail multiple factors that can potentially enable and inhibit the growth of geothermal energy in Indonesia. Understanding these loops subsequently allows further investigation into the factors that can stabilize (or else strengthen) the regime so as to better align it with the goals of the geothermal systems being developed.

Table 3. Structure of the feedback loops of the conceptual framework.

Loop	Type	Causal Effect Path
Geothermal Investment Loop (B1)	Balancing	Risk of Geothermal Exploration → Capital Cost of Geothermal Exploration → Geothermal Project Attractiveness → Geothermal Investment → Bankability of Geothermal Project → Risk of Geothermal Exploration
Infrastructure Loop (B2)	Balancing	Geothermal Infrastructure → Power Wheeling → Capital Cost of Geothermal Exploration → Geothermal Infrastructure
Upstream Data Loop (B3)	Balancing	Upstream Data Integration → 3G Data Acquisition → Certainty of Geothermal Exploration → Risk of Geothermal Exploration → Upstream Data Integration
Environmental Loop (B4)	Balancing	Environmental Impacts → Ease of Acquiring Geothermal Permit → Geothermal Project Development → Public Acceptance → Environmental Impacts
Incentive Loop (R1)	Reinforcing	Governmental Intervention → Incentive Regulation → Geothermal Project Incentives → Geothermal Project Attractiveness → Geothermal Investment → Geothermal Project Development → Tax and Non-Tax Income → Governmental Intervention
Pricing Loop (R2)	Reinforcing	Governmental Intervention → Pricing Regulation → Geothermal Selling Price → Revenue → Geothermal Project Attractiveness → Geothermal Investment → Geothermal Project Development → Tax and Non-Tax Income → Governmental Intervention
Permit Loop (R3)	Reinforcing	Governmental Intervention → Ease of Acquiring Geothermal Permit → Geothermal Project Development → Tax and Non-Tax Income → Governmental Intervention
Acceptance Loop (R4)	Reinforcing	Local Socioeconomic Impacts → Public Acceptance → Geothermal Project Development → Local Socioeconomic Impacts

5.1. Geothermal Investment Loop (B1)

Geothermal energy development is the primary focus of this research. The geothermal investment loop illustrates geothermal investment in Indonesia and how its elements are interconnected. This loop shows the balancing relationship between its dynamic elements. The lower risk of geothermal exploration will increase the bankability of geothermal projects, which will eventually lead to the increase in investment in geothermal projects. More investment directed towards geothermal projects will increase the development of geothermal projects.

In addition to that, the lower risk of a geothermal project will reduce the capital cost of geothermal exploration, because when the geothermal risk is lower, its prospect is higher. Therefore, the risk of paying hefty costs for exploration is also reduced, thus decreasing the overall capital cost that a geothermal project would require. A lower capital cost for a geothermal project will increase the attractiveness of the project, inviting more geothermal investments.

5.2. Infrastructure Loop (B2)

The infrastructure loop shows how the infrastructure elements are involved within the geothermal project, and the loop shows the balancing relationship between its elements.

The majority of the geothermal prospect areas in Indonesia are located in fairly remote, mountainous areas, which are often far from the main access roads. Therefore, sometimes the developer has to build the road or other infrastructure once they decide to continue with geothermal project development. However, this also increases the capital cost of the geothermal project and subsequently reduces the attractiveness of the project. In addition to this, shared utilization of the electricity transmission, or power wheeling, can reduce the capital costs, which include building a transmission system. Lower capital costs could potentially increase the attractiveness of the geothermal project.

5.3. Upstream Data Loop (B3)

The upstream data loop shows the balancing relationship between its elements; it mainly plays a role during the exploration stage as a part of the upstream activity. Upstream data integration, which includes government drilling and existing data from the state-owned companies, can be combined and integrated as part of the keys to increasing the certainty of geothermal projects.

Following the data integration, to complete the missing information, geology, geophysics, and geochemistry (3G) surveys, including the drilling test, are required to obtain the information and prospect of geothermal potential in an area during the exploration stage. The greater the amount and the better of the quality of data, the more stability can be obtained, which can then be used during decision making for the continuity of geothermal projects. To lower the risk of the geothermal projects will require further data integration, with more detailed resolution and quality.

5.4. Environmental Loop (B4)

The environmental loop shows a balancing relationship that consists of several integral elements. Despite geothermal energy being one of the renewable and eco-friendly energy sources, environmental concerns still exist, such as minor earthquakes, air and water pollution, thermal pollution, and land subsidence. However, these possible risks are manageable with the right mitigation plan and standardized technology. The more manageable the risks regarding the impact that a geothermal project has on the local environments, complemented by the right counselling, education, and communication, the more likely the public will be to accept the development of the geothermal project.

In addition, environmental risk assessment is one of the crucial parts of gaining the operational permit for a geothermal project. A high-quality environmental risk assessment and mitigation plan will ease the process of obtaining the project permit.

5.5. Incentive Loop (R1)

Geothermal projects have a very high risk in terms of the cost for their projects, which can be discouraging for geothermal investors and developers. As part of the financing aspect, incentives can be an appealing factor for the geothermal developer. Formulating an incentive scheme, which could be a fiscal incentive (e.g., tax holiday, exploration reimbursement), will make the geothermal projects in Indonesia more attractive and could invite more geothermal investments. As a result, more geothermal investments would result in more geothermal project developments that could generate both tax and non-tax income (such as profit from electricity sales through the state-owned electricity company) for the government.

There are a few fiscal incentives that can be applied for the case geothermal development [44], which include:

1. Tax allowance: a reduced income tax for 6 years.
2. Import duty facilitation: a 2-year exemption from import duty for machinery and equipment, and also an additional 2-year exemption for the duty on raw materials for companies that use local machinery and equipment at a rate of at least 30%.
3. Tax holiday: tax easement provided for 5 to 20 years, with a maximum 100% reduction in income tax for a minimum investment of IDR 500 billion.
4. Mini tax holiday: 5 years tax relief, with a maximum income tax reduction of 50% for an investment of IDR 100–500 billion.

5.6. Pricing Loop (R2)

The pricing loop is one of the main keys in geothermal development. A suitable pricing mechanism, or regulations that take into account the geothermal developers' input, such as feed-in tariffs, could result in a better geothermal selling price. A better selling price results in a revenue increase for the geothermal developers, which would make a geothermal project more attractive. Similar to the incentive loop (R1), increasing geothermal attractiveness could invite more geothermal investments and thus, more geothermal project developments. Eventually, that could potentially generate both tax and non-tax income for the government.

The situation where the PLN is the sole buyer or off-taker of electrical energy in Indonesia must be balanced with government intervention to implement regulations that can produce tariff schemes that are attractive to investors, but still profitable for the PLN. Further and more detailed studies on the most suitable method to reduce exploration and production costs should be carried out by the government, practitioners, and academics so that the baseline cost of a geothermal energy development project in Indonesia can be determined.

5.7. Permit Loop (R3)

A geothermal system can vary depending on many aspects, such as geographical situation, politics, market, etc. The geothermal system in Indonesia is different from that in the Philippines [45], New Zealand [46], Iceland [47], the United States [48], and some other countries [49]. In Indonesia, geothermal projects are often located in forested areas that can sometimes result in disputes and complicate the process of obtaining an operational permit. Land-use permission procedures for infrastructure projects in Indonesia are still complex, and have significantly hampered geothermal development in Indonesia. Creating a reformed, less complicated mechanism for obtaining the operating permit could be one of the factors that will increase the development of geothermal projects. The more easily these geothermal projects could be executed, the more tax and non-tax income would be available for the Government.

Obtaining land issue permits is a problem that cannot be ignored in developing geothermal energy in Indonesia. Therefore, multi-sectoral coordination and communication between ministries, local governments, and companies must be improved regarding this particular issue.

5.8. Acceptance Loop (R4)

The acceptance loop depicts the importance of public acceptance from the local community for geothermal development. More resistance coming from the public would hinder advancement and result in a delay of geothermal development.

Various methods of community approach must be studied and implemented, including the use of the local community within the geothermal project environment during all phases, including exploration, construction, and geothermal production activities to minimize the risk of rejection by the community located near the project site. There have been many studies that offer various alternative approaches, one of which is the direct use of geothermal resources for tourism, drying of agricultural products, etc. which are expected to help develop the economy around the geothermal project area and involve the local community on an ongoing basis. In addition to this, incorporating the socioeconomic factor that could benefit the local community could also increase the public acceptance of the geothermal development project.

6. Conclusions

This paper illustrates the complex nature of geothermal development in Indonesia through model conceptualization by employing the SD modeling technique. The research employed semi-structured qualitative interviews of several important stakeholders of the geothermal energy sector in Indonesia. The information obtained was used as a basis for building the SD model.

The interviews highlight several aspects in the geothermal energy sector in Indonesia, including the high risk of geothermal exploration, restrictions for geothermal locations within national parks or protected forests, pricing mechanisms, underdeveloped infrastructure, power wheeling, and public resistance towards geothermal projects.

The SD diagram visualized the entire process, the elements, and the stakeholders incorporated within the geothermal system. The relationship between these elements is illustrated in the causal loop diagram forming four balancing loops, namely the geothermal investment loop, infrastructure loop, upstream data loop, and environmental loop, as well as four reinforcing loops, which include the incentive loop, pricing loop, permit loop, and acceptance loop. These loops highlighted the behavior and the dynamics of the systems that influence the output of the system.

6.1. Theoretical Contributions

This paper provides theoretical implications in several ways. Firstly, the geothermal business is a complex system with complex elements. There are a number of researchers that have identified the barriers to geothermal energy development, but most of the research has been focused on two major aspects, namely the technical and economic aspects. This paper provides a more holistic view and takes into account some other aspects or elements that are still poorly discussed, but which are vital to geothermal development, such as infrastructure, permits, incentives, and public acceptance.

Secondly, this research complemented the work of Aditya [32] and Setiawan et al. [33], who identified the key elements of the geothermal SD models. This research addressed the shortcoming in their work, in particular the lack of robustness of the models' references in representing geothermal development in Indonesia. This research incorporates information from all major geothermal projects that exist in Indonesia to date, either operated by major actors or commercially operating companies. Therefore, the framework may serve as a reference model that represents the comprehensive geothermal system in Indonesia.

Finally, this paper provides a novel way of identifying the complex elements of geothermal energy businesses by employing qualitative, semi-structured interviews involving major stakeholders with diverse cases regarding a geothermal system. The information obtained from the interviews was used to develop the framework.

6.2. Practical Implications

In terms of practical implications, the proposed framework can explain the causal structure and interconnections of every aspect of the geothermal energy sector, which is vital in enabling geothermal energy development. The proposed framework could be used to guide policy-level scenario planning by facilitating dynamic analyses of geothermal energy sectors.

A geothermal system can vary depending on many aspects, such as geographical situation, politics, market, etc. The proposed framework could be adopted by the governmental institutions and organizations to advance decision making in the countries where geothermal energy can be developed. This is done by taking into account several key factors, such as geothermal potential and settings, current policies, market conditions, and stakeholders.

6.3. Limitations and Future Work

The future work will focus on formulating a quantitative SD model for geothermal development in Indonesia. Thus, it is envisaged to employ the model to explore several scenarios when proposing and implementing policies to accelerate and boost geothermal energy development.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of quotes from the interviewees and their associated loops

Statements	Source (Interviewee)	Loop
More certainty of geothermal exploration will reduce the risk of geothermal exploration	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 10	B1, B3
To obtain more detailed information and data resolution, a geothermal area with lower risk would require further study and data integration.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 10	B3
The more risk of a geothermal project will potentially increase the capital cost due to project loss.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 10	B1, B3
Clear risk of geothermal exploration enables the bankability of a geothermal project.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C	B1, B3
The capital cost of geothermal exploration determines the attractiveness.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 10	B1
Geothermal investment depends on the geothermal attractiveness and its bankability.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 10	B1
Geological, geophysical, and geochemical (3G) surveys are important for determining certainty in exploration	1A, 1B, 1C, 2, 3A, 1B, 4, 5A, 5B, 5C, 6A, 6B, 6C	B3
Government-funded exploration can reduce the capital cost and increase the attractiveness.	2, 3A, 3B, 5A, 5B, 5C, 6A, 6B, 6C, 7	B1
Upstream data integration is needed to solve the issues about the certainty of geothermal exploration.	1A, 1B, 1C, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C	B3
Geothermal investment depends on the bankability and attractiveness of geothermal projects.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 10	B1
Building geothermal infrastructures costs a lot.	1A, 1B, 1C, 2, 3A, 3B, 5A, 5B, 5C, 6A, 6B, 6C, 10	B2
Power wheeling is one of the key points in reducing the capital cost of geothermal energy.	1A, 1B, 1C, 3A, 3B, 5A, 5B, 5C, 8	B2
Government regulations and interventions are needed in terms of solving the geothermal issues.	1A, 1B, 1C, 2, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7, 8, 9, 10	R1, R2, R3
Easier permit regulation will lead to increasing geothermal development.	1A, 1B, 1C, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C	R3
More developed geothermal projects could potentially generate income as tax and non-tax income that would be beneficial for supporting the government.	1A, 1B, 1C, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7	R1, R2, R3
Pricing regulation is needed to increase geothermal attractiveness.	1A, 1B, 1C, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7	R2
Incentives will increase geothermal attractiveness.	1A, 1B, 1C, 2, 3A, 3B, 3C, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7	R1
Better environmental risk assessment and mitigation plans will ease the permit processing.	1A, 1B, 1C, 3A, 3B, 4, 5A, 5B, 5C, 6A, 6B, 6C, 7	B4, R3
Incorporating socioeconomic factors with the right communication, education, and counseling could increase public acceptance of the geothermal projects.	4, 6A, 6B, 6C	B4, R4
Public acceptance of geothermal projects can ease development.	4, 6A, 6B, 6C	B4, R4

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