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Evaluating feed-in tariff policies on enhancing geothermal development in Indonesia

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ABSTRACT

Geothermal is vital for sustainably meeting Indonesia's energy demand, given its estimated massive reserves potential equivalent to 24 GW of electricity. The Indonesian government has set geothermal contributions to the national energy mix at 7,241.5 MW by 2025 and 17,546 MW by 2050, despite harnessing such vast potential needing significant investment. To that goal, the government established a feed-in tariff (FIT) mechanism to encourage private sector investment in geothermal development. However, FIT has undergone significant alterations in a short period. Moreover, various complicating factors—bureaucracy, social, and technical—exist alongside FIT implementation. Therefore, the extent that FIT can effectively enhance geothermal development in Indonesia should be challenged with further investigation. This study explores the efficacy of FIT policies for geothermal electricity by comparing the performance of several FIT schemes in terms of their impact on the government's target achievement. This study combines the policy analysis framework with system dynamics modeling to understand the dynamic interaction of FIT policy and other important components in geothermal development. The findings show that modest bureaucracy and public support are required. Furthermore, to enhance geothermal development more effectively, FIT should be at least 11 cents US$/kWh and accompanied by technical breakthroughs and government-funded exploration activities.

1. Introduction

Geothermal is vital for sustainably meeting Indonesia's energy demand, given its estimated massive reserves potential equivalent to 24 Gigawatts (GW) of power generation—the world's second-largest. Moreover, the rise in energy consumption made the country experiencing significant electricity demand growth—from 910 kW-hours (kWh) per capita in 2015 to 1,084 kWh per capita in 2019 Katadata, 2019, leading to the need for more power generation development. To meet rising electricity demand through renewable and low-carbon energy sources, the Indonesian government has set a target of 7,241.5 Megawatts (MW) from 23 percent renewable energy share in the national energy mix by 2025. The renewable energy share is likewise expected to reach 31% by 2050, with geothermal contributing up to 17, 546 MW. Although extracting such vast geothermal reserves appears promising for providing sustainable power generation, the government's ability to meet the aim appears difficult. One complicating issue that makes the aim difficult is the budgetary imbalance (ESDM, 2020; Fan and Nam, 2018). While geothermal power generation provides large-scale energy production comparable to that of a coal-fired power plant, establishing and operating a geothermal power generation involves a significant investment from both government funding and private sector investment. Another issue is related to the selling price of geothermal electricity, which, from the off-taker perspective, is still

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Abbreviations: BAU, Business-as-usual; CLD, Causal loop diagram; COD, Commercial Operation Date; EPCC, Engineering procurement construction and commissioning; FGD, Focus group discussion; FIT, Feed-in tariff; GFF, Geothermal Fund Facility; IFGS, Infrastructure Financing for Geothermal Sector; IPP, Independent power producer; LCOE, Levelized cost of electricity; MEMR, Minister of Energy and Mineral Resources; O&M, Operation and maintenance; PPA, Power Purchase Agreement; SD, System dynamics; SFD, Stock and flow diagram.

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considered more expensive compared to that from fossil generators (e.g., coal, petroleum gas, and diesel).

To that end, the Indonesian government has set various regulations related to the selling price of electricity to encourage renewable energy development, starting with the Minister of Energy and Mineral Resources (MEMR) Regulation 31/2009 in 2009. It regulates the purchasing price of electricity by the State Electricity Company (PLN) from renewable energy power plants. Following this rule, the government has implemented a feed-in tariff (FIT) mechanism for geothermal electricity since 2011 to encourage private sector investment in enhancing geothermal development (ESDM, 2020). The FIT permits an independent power producer (IPP) to sell geothermal electricity to the state grid operator at a fixed rate for a set period (often 20–30 years). In general, FIT is intended to provide financial security to IPPs supplying electricity. However, the government seems to have difficulty formulating an optimally attractive FIT since it often changes unexpectedly, undergoing several changes within a short implementation period. From 2011 to 2017, the government released four different FIT schemes (ESDM, 2020). While these changes are part of government policy and strategy improvement efforts, they also reflect inconsistent FIT policies implementation. Such discrepancy calls into doubt the efficiency of FIT in boosting geothermal development in Indonesia, given that the total installed capacity of geothermal power generation accounted for 2,133 MW in 2020 (Richter, 2020), considerably below the 2025 objective of 7,241.5 MW. Furthermore, additional problematic problems impeding geothermal growth, in addition to the FIT implementation, have received inadequate attention. These factors include governance and regulatory barriers (e.g., a lengthy bureaucratic process in releasing geothermal exploration permits, a lack of coordination among institutions) (Fan and Nam, 2018; WWF, 2012), social acceptance (e.g., resistance from local people) (Fan and Nam, 2018; Wahjosoedibjo and Hasan, 2018), and technical aspects (e.g., technical difficulties during the exploration process) (Witter et al., 2019).

The elucidation above suggests that research is needed to evaluate the effectiveness of FIT in boosting geothermal development and provide insights for better geothermal development policy and strategy. As such, FIT has been an essential discussion topic in renewable energy policy literature. The literature suggests that successful renewable energy development will depend on effective policy implementation, particularly FIT (Dijkgraaf et al., 2018). FIT as a policy tool to accommodate tariffs is very important to attract developers and investors. Many studies mentioned that FIT is a powerful tool for inducing growth in the renewable energy sector and effective policy to increase renewable energy production (Jenner et al., 2013; Ming et al., 2013; Tongsopit and Greacen, 2013). Van Campen et al. (2017) specifically concluded that lower tariff makes geothermal development become less attractive. Literature also suggests that tariff is a significant determinant affecting IPPs' business operations and bottom-line profits (Dijkgraaf et al., 2018; Jenner et al., 2013). However, as noted by Aguirre and Gbenga Ibikunle (2014), poorly designed FIT schemes can impede growth, and FIT policy when applied in a less developed country or developing country such as Indonesia must work in tandem with other efforts (Dewi, 2016). The interplay between policy design and market dynamics is a more important determinant of success than policy enactment alone (Jenner et al., 2013). Therefore, studying how FIT policy can be effectively implemented is not only essential, but should also consider influential factors when designing it.

Several studies have been conducted to study and evaluate FIT policies to promote renewable energy development. They addressed topics such as the optimal design of the FIT scheme (Górnowicz and Castro, 2020; Kim and Lee, 2012; Ritzenhofen and Spinler, 2016; Zhang et al., 2016), the FIT contract schemes uncertainty (Barbosa et al., 2020), the technical expertise needed for FIT implementation (Ndiritu and Engola, 2020), and the risk implications of FIT on renewable energy development (Kitzing, 2014). Ndiritu and Engola (2020) evaluated the effectiveness of FIT policy in Kenya, underlining the effect of unavailable technical expertise on the low deployment of renewable energy development. Milad Mousavian et al. (2020) analyzed FIT policy design in Iran, measuring the impact of potential investors' trust and social acceptance on renewable energy growth. Meanwhile, Kim and Lee (2012) evaluated four types of feed-in policies—the fixed price, the fixed premium, the minimum price guarantee, and the sliding premium, focusing on optimizing FIT for maximizing the number of users.

Further, assessments on FIT policies have also been conducted not only in developed regions (e.g., Dijkgraaf et al., 2018; García-Alvarez et al., 2012; Górnowicz and Castro, 2020; Kitzing, 2014), but also in developing regions (e.g., Hidayatno et al., 2020; Milad Mousavian et al., 2020; Ndiritu and Engola, 2020; Zhang et al., 2016). Literature also indicates that most previous studies focused on the FIT scheme designed for intermittent renewable power generation such as solar photovoltaic, wind, and biomass (Dijkgraaf et al., 2018; García-Alvarez et al., 2012; Górnowicz and Castro, 2020; Hidayatno et al., 2020; Kim and Lee, 2012). A few studies assessed the FIT application without discriminating between different types of renewable energy sources (Milad Mousavian et al., 2020; Ndiritu and Engola, 2020). Furthermore, most studies on FIT evaluation used economic, financial, and risk analysis methods such as net present values (NPV) (Górnowicz and Castro, 2020; Rigter and Vidican, 2010), real options (Kim and Lee, 2012; Ritzenhofen and Spinler, 2016; Zhang et al., 2016), cost-benefit analysis (Krajačić et al., 2011), and mean-variance approach (Kitzing, 2014). To examine the dynamics of FIT policies, some research used simulation modeling methodologies such as system dynamics (Baur and Mauricio Uriona, 2018; Hsu, 2012; Yu-zhuo et al., 2017). Nonetheless, research on FIT for non-intermittent renewable energy sources, such as geothermal, remains restricted in the literature despite its advancement. Although a few studies have touched on taxation policies and fiscal incentives such as FIT to accelerate geothermal development in China by Jiang et al. (2016) and Indonesia by Kaneko et al. (2010), they are only conceptual. More specifically, there is insufficient research studying the effectiveness of FIT for geothermal electricity that explicitly considers various complicating factors in geothermal development. Therefore, the extent to which FIT can effectively enhance geothermal development with various complicating factors is at play still needs empirical investigation. Especially in Indonesia, this issue remains a subject of further investigation.

With this study, we aim to address the gap above by investigating the effectiveness of FIT policies on enhancing geothermal development in Indonesia. The analysis focuses on assessing the effectiveness of various FIT programs regarding their impact on the government's aim achievement. In that regard, this study offers a novel analysis of FIT policy design by addressing some complicated elements in geothermal development, such as bureaucratic complexity, social acceptance, and technical problems in exploration and exploitation activities. This study considers geothermal development a complex dynamic process involving exploration, exploitation, development, utilization (Jiang et al., 2016), and interrelated elements—such as actors, regulations, and technological elements that play decisive roles in achieving the goal (Dewi et al., 2020; Setiawan et al., 2020). Therefore, it is essential to understand geothermal development with a holistic perspective, such as through a systems approach (Forrester, 1968; Meadows, 2008) that provides insights into underlying causal relationships between elements that determine and influence geothermal development and its potential outcomes. Further, this would give better insights for policymakers when monitoring and evaluating the FIT policy's implementation for meeting the target.

For that purpose, this study incorporates the policy analysis framework (Walker et al., 2013) with system dynamics modeling (Forrester, 1994; Sterman, 2000) to elucidate the dynamic interaction of FIT policy and other elements that play significant roles in geothermal development. The underlying structure and causal relationships between geothermal development elements are examined using a critical indicator—the total installed capacity of geothermal power generation, reflecting the FIT policy's effectiveness in achieving the government's target under various plausible scenarios. The rest of this paper is structured as follows. Section 2 reviews the literature on the evolution of the geothermal electricity tariff policy in Indonesia. Section 3 describes the technique used to assess FIT policies. Section 4 explains dan discusses the study's results. Section 5 provides conclusion and policy implications of the study.

2. Evolution of geothermal electricity tariff policies in Indonesia

The need for significant capital investment has been one major challenge in geothermal development in Indonesia. The Indonesian government has taken some policy measures to attract private sector involvement in boosting geothermal development in technical, legal, and business aspects. Nonetheless, significant yet subtle competition between fossil fuel-based and geothermal electricity pricing has hindered policy implementation. As the sole purchaser of electricity generated by IPPs, PLN frequently prefers low-cost coal over renewables. Coal is a considerably more economically appealing energy source for PLN than renewables (Hasan et al., 2012). Apart from having a monopoly on electricity transmission and distribution, PLN operates most of the country's power plants, which generate the majority of the country's electricity. It forces PLN to pay IPPs to generate electricity from renewable sources while competing for total market share. The difference between generation costs and end-user prices would justify PLN regulating its capacity factor sufficiently to meet its contractual obligations. PLN is taking this effort to mitigate potential damages. Subsequently, this would jeopardize the government's objective of achieving the national energy mix target. This condition gives another complication to the electricity selling price produced by IPPs.

Geothermal electricity price is still one big policy issue that discourages private investors from investing in geothermal projects (Pambudi, 2018), pushing the government to take extra measures to regulate tariffs on geothermal electricity. Therefore, the tariff policies for geothermal electricity in Indonesia have been evolving with several revisions. The tariffs have been adjusted almost yearly and according to a changeable set of criteria pegged at various times to the power voltage, geographical regions, or cost of production benchmark (Bakhtyar et al., 2013). The evolution of Indonesia's geothermal electricity tariff policies can be divided into three phases (Fig. 1): before and after Law 27/2003 on geothermal enacted in 2003 (Ginting, 2014); and after Law 21/2014 on geothermal (as the revision of Law 27/2003) enacted in 2014.

Before enacting Law 27/2003, geothermal licensing was regulated under Presidential Decree 22/1981, issued in 1981. This presidential decree mandates the National Oil Company (Perusahaan Minyak Nasional or Pertamina) to explore and exploit designated geothermal working areas (Wilayah Kerja Panas Bumi or WKP) to sell geothermal electricity to PLN. At that time, geothermal electricity pricing was based on strategic consideration—not solely for economic consideration—through cross-subsidies between the state-owned companies (Ginting, 2014). However, this tariff policy led the purchase price of geothermal electricity from PLN to Pertamina below the economical price. In the subsequent development, the government released Presidential Decree 76/2000 in 2000 to revoke the mandated WKP from Pertamina, except for existing and ongoing WKP contracts. Following this policy change, the Ministry of Energy and Mineral Resources was mandated to regulate, foster, and supervise geothermal development and power generation.

In 2003, Law 27/2003 on geothermal was enacted. About this law, Government Regulation 59/2007 was released in 2007, allowing private sectors or IPPs to acquire geothermal licensing through WKP tender. As a result, the pricing of geothermal electricity began to consider the economic factors of geothermal development (ESDM, 2020; Ginting, 2014). Furthermore, following the 2008 MEMR Regulation 14/2008, many tariff restrictions on geothermal electricity regulate the purchase price from PLN to IPPs. MEMR Regulation 14/2008 establishes the ceiling price of geothermal electricity based on the cost of local generation (Biaya Pokok Penyediaan Pembangkitan or BPP) and the capacity of power generation. The ceiling prices are 85% of BPP for 10–55 MW generation capacity and 80% of BPP for generation capacity more than 55 MW. However, the scheme was not economically viable for geothermal projects in Sumatra and Java. Therefore, in 2009, the government released MEMR Regulation 05/2009 to revise MEMR Regulation 14/2008.

MEMR Regulation 05/2009 stipulates PLN to determine the owner's estimate price, calculated based on power generation's type, location, capacity size, and capacity factor. The anticipated price for geothermal power generation, in particular, includes the reference costs for exploration and development. However, due to the lack of prior research and feasibility studies, PLN had trouble determining the owner's anticipated price for geothermal electricity during its installation. As a result, later that year, the government implemented a revision under MEMR Regulation 32/2009, which established the cap price at 9.7 cents US$/kWh. Nevertheless, this regulation has no clause that PLN must use the geothermal electricity price from the WKP tender as the base price for purchasing electricity from IPP.

In 2011, the government revised MEMR Regulation 32/2009 by formulating FIT for geothermal electricity under MEMR Regulation 02/2011 with a ceiling price of 9.7 cents US$/kWh. Based on this regulation, the purchase price of geothermal electricity from the WKP tender is final, non-negotiable, and used as the reference price in the Power Purchase Agreement (PPA) between PLN and IPPs. However, the ceiling price was uneconomically viable for Eastern Indonesia regions or small-scale geothermal projects. As a result, the regulation lasted only one year.

The government then released a revision on FIT for geothermal electricity through MEMR Regulation 22/2012 in 2012. This regulation represents a significant change from the previous one, which formulates the FIT scheme based on regions classified into high and medium transmission voltages. The prices are 10–17 cents US$/kWh for high

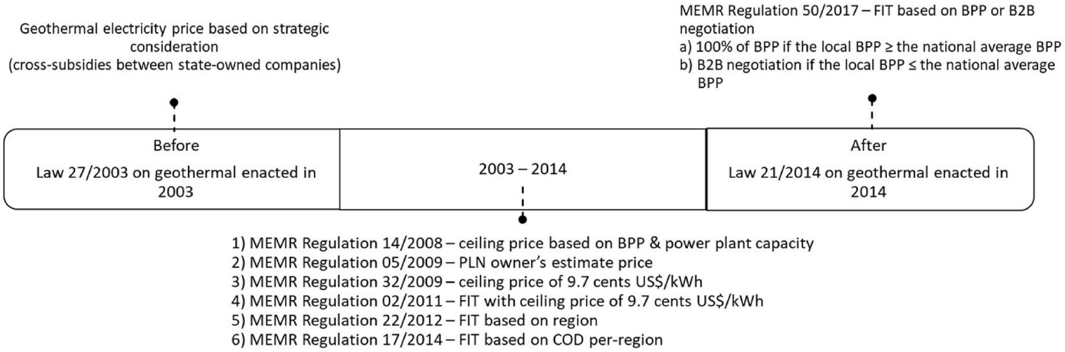


Fig. 1. Evolution of geothermal electricity tariff policies in Indonesia.

transmission voltage regions and 11.5–18.5 cents US$/kWh for regions with medium transmission voltage. However, after almost two years of issuance, this regulation was incompatible with the WKP tender mechanism that applies the floor price according to Government Regulation 59/2007. Consequently, the government revoked the MEMR Regulation 22/2012 by revising FIT for geothermal electricity under MEMR Regulation 14/2014 in 2014. This regulation sets the FIT scheme with ceiling price based on the Commercial Operation Date (COD) per region, which varies from 11.8 to 29.6 cents US$/kWh (see Table 1). PLN and IPPs can renegotiate the electricity price after completing feasibility studies to accommodate geothermal projects under PPA before issuing this regulation.

Not long after the issuance of MEMR Regulation 14/2014 in 2014, Law 21/2014 on geothermal was enacted in the same year. Following this new law, there have been two mechanisms for geothermal licensing under Government Regulation 7/2017, issued in February 2017. The first mechanism is WKP tender (open for private sectors or IPP), and the second one is government assignment (given to state-owned companies and public service agencies). Further, in March 2017, the government released Presidential Regulation 22/2017, which authorized the General Planning for National Energy (Rencana Umum Energi Nasional or RUEN). RUEN stipulates renewable energy targets in the national energy mix of 23% by 2025 and 31% by 2050. RUEN also demonstrates the government's determination to accelerate new and renewable energy development, particularly power production. Geothermal power is expected to reach 7,241.5 MW by 2025 and 17,546 MW by 2050, according to RUEN. Later that year, the government announced another change to the FIT for geothermal electricity under MEMR Regulation 50/2017. This legislation establishes the BPP regime's FIT scheme, which sets the geothermal energy price at 100% of BPP if the local BPP is more than or equal to the national average BPP. If the local BPP is less than or equal to the national average BPP, the price is negotiated between PLN and IPP on a business-to-business (B2B) basis.

The elucidation above shows that the tariff setting for geothermal electricity in Indonesia is undeniably very dynamic. Especially after Law 27/2003 was enacted in 2003, geothermal electricity price varies according to the applicable regulation used when PLN and IPP sign the PPA. Following the phases of tariff policies evolution, as explained above, there have been three different tariff schemes generally applied to geothermal electricity in Indonesia:

1. The first scheme uses the tariff based on strategic consideration, ranging from 6.6 cents US$/kWh to 11.4 cents US$/kWh. Most geothermal power generations built and operating before the enactment of Law 27/2003 applied this tariff scheme at 7.53 cents US$/kWh on average.
2. The second scheme is somewhat problematic to define due to different regulations issued in a not distance period, leading to a variation of tariff applied by PLN and IPPs in their PPA. Most geothermal projects that started operating during 2003–2014 were at least aiming to apply FIT at the ceiling price of 9.7 cents US$/kWh. However, in the general practice of negotiation, PLN seeks to purchase electricity based on its owner's estimate price. Therefore, the price has fallen below the ceiling price to an average of 8.86 cents US$/kWh, although two geothermal power plants operated under this scheme have exceptionally reached the deal prices at 12 and 13 cents US$/kWh.
3. The third scheme follows MEMR Regulation 50/2017. This scheme is based on BPP, applied to geothermal projects with PPA signed after the regulation was issued in 2017. The electricity prices ranging from 7.66 cents US$/kWh to 20.27 cents US$/kWh. However, since PLN generally seeks to impose a tariff based on its owner's estimate price (Draps and Modjo, 2020), the scheme will likely fall into the B2B negotiation.

Table 1
The FIT scheme for geothermal electricity under MEMR Regulation 14/2014.

Year of COD	Ceiling Price (cents US$/kWh)		
	Region I	Region II	Region III
2015	11.8	17.0	25.4
2016	12.2	17.6	25.8
2017	12.6	18.2	26.2
2018	13.0	18.8	26.6
2019	13.8	19.4	27.0
2020	13.8	20.0	27.4
2021	14.2	20.6	27.8
2022	14.6	21.3	28.3
2023	15.0	21.9	28.7
2024	15.5	22.6	29.2
2025	15.9	23.3	29.6

Further on the third tariff scheme, what is also problematic is that PLN purchase intention is based on the lowest BPP. The cost of acquiring power to PLN is a combination of generating power through its power plants and the cost of purchasing power from third-party suppliers such as IPPs and power rental businesses. For geothermal, it is often only 85% of the local BPP or even lower (ESDM, 2020).

Such a low intention to buy from PLN can make the tariff unattractive for IPPs to enter the geothermal business—since most IPPs see the tariff will be uneconomically viable for running geothermal projects in the long run.

3. Methodology

3.1. System dynamics modeling for energy policy analysis

Geothermal energy development is a complex system that involves multiple dynamically interacting variables. To quantitatively evaluate the impacts of FIT, this study uses the system dynamics (SD) simulation modeling approach (Forrester, 1994; Sterman, 2000). The SD approach explicitly captures and quantifies causal relationships between system variables as well as feedback loops among them, to simulate the system's behavior over time (Forrester, 1994). This approach consists of two elements. The first element is a causal loop diagram (CLD), which explicitly portrays the conceptual causal relationships and/or connections between the variables using words and arrows (Richardson, 2011). CLD is mainly used in the model conceptualization phase.

The qualitative and conceptual CLD can be further translated into a quantitative model in the form of stock and flow diagram (SFD), which is the second element of the SD modeling methodology. SFD is built on differential equations reflecting the system's structure. Solving these equations numerically through computer simulation generates the model behavior over time, which is used to evaluate the impacts of possible interventions under different plausible scenarios. SFD is therefore the quantitative part of the SD modeling methodology.

SD modeling has been used to investigate and understand complex issues in energy policy domains (Dyner, 2000; Hsu, 2012; Naill and Roger, 1992), energy systems in general (Davidsen et al., 1990), renewable energy systems (Jeon and Shin, 2014; Rendon-Sagardi et al., 2014), and the adoption of renewable energy technology and its policy (Eker and van Daalen, 2015; Hidayatno et al., 2020; Mutingi, 2013). Some studies used SD modeling to assess the implementation of FIT policies for intermittent renewables (Baur and Mauricio Uriona, 2018; Hidayatno et al., 2020; Hsu, 2012). Hence, SD is helpful to study complex energy policy problems such as geothermal development, as demonstrated in the literature (Jiang et al., 2016).

In accordance with the SD modeling methodology, this study begins with model conceptualization to identify and capture the variables within the geothermal development system as well as the interactions between them. This includes an analysis of the problem owner's objectives and how they translate into the system's outcome indicators, policy instruments used by the problem owner to achieve the goals, and external factors that influence the problem owner's objectives. The created conceptual system model, which is in the form of a CLD, is then translated into a quantitative SD model (i.e., the SFD). Next, the model is used to test and evaluate the policy's effects on the system's outcome indicators. For this purpose, several plausible scenarios are developed based on the identified external factors.

In building the model, this study extends the conceptual CLD model of geothermal development in Indonesia of Setiawan et al. (2020), which was then refined and validated through a focus group discussion (FGD). The FGD was held virtually (most participants joining virtual were in Jakarta) in December 2020 to verify the system model's logic and ensure its validity with the actual best practice and condition. The FGD participants were government officials, geothermal industry practitioners, academia, and geothermal association members.

3.2. Model conceptualization

Model conceptualization starts with identifying and mapping variables that build geothermal development in Indonesia as the system under study. It is visualized in a system diagram that is used to analyze and understand the problem. The system diagram is based on the stakeholder's mental model discussed during the FGD.

The system diagram depicted in Fig. 2 portrays five essential elements, described as follows:

1. The objective of the problem owner, which is enhancing geothermal development to achieve the RUEN target on the geothermal contribution by 2025 and 2050. The Ministry of Energy and Mineral Resources is specifically recognized as the problem owner in this case. Meanwhile, IPP, PLN, funding institutions, and other government agencies like the Ministry of Finance and the Ministry of Environment are stakeholders. These stakeholders are also involved in geothermal development, share common interests with the problem owner, and impact the problem owner's policy action.
2. The outcome indicator derived from the problem owner's objective: the total installed capacity of geothermal power generations (PLTP) (in MW). It serves as the criterion of target achievement and a crucial indicator to measure the effectiveness of FIT as the policy instrument.
3. The problem owner's policy alternatives to achieve the objective, which effects will be quantitatively simulated through the SFD. In this case, the policy alternative is FIT, which is enacted with an aim to enhance geothermal development.
4. The external uncertainty variables that influence the problem owner's objectives: geological variables, social acceptance, bureaucratic complexity, and private funding. Geological factors (such as temperature and enthalpy) correspond to technical uncertainty in geothermal drilling activities. Uncertainty or delay in acceptance or resistance from local population about geothermal project execution refers to social acceptance. Meanwhile, bureaucratic complexity exists due to misalignment between regulation and actors' coordination, further complicated with conflicting interests between actors; and private funding corresponds to private sector investment in a geothermal project.
5. The conceptual system model, consisting of system variables and their causal relationships and/or connections. The system model is visualized in more detail in CLD (Fig. 3).

One key feature of a CLD is the identification of conceptual feedback loops that shape the system's outcome indicators in the long run. The CLD depicted in Fig. 3 has five reinforcing feedback loops (R1, R2, R3, R4, R5) and five balancing feedback loops (B1, B2, B3, B4, B5). These loops represent feedback mechanisms associated with geothermal development activities. Loop R1 represents the main loop of geothermal development. Loops B1, B2, B3, and B4 explicate the creation of cost and total investment needed in geothermal development. Meanwhile loops R2, R3, R4, R5, and B5 further explain the investment and financing of geothermal projects. Details of the description of these loops are provided in Appendix A (Part I. Description of Causal Loop Diagram).

3.3. Quantitative model development

Model development consists of two steps: transforming the CLD into an SFD and testing the model. The CLD depicted in Fig. 3 is transformed into three SFD modules: main geothermal development, detailed costing of geothermal development, and investment and financing of geothermal projects. This study used Powersim Studio software to develop and simulate the constructed SFD. Details of the description, formula and data for each module are presented in Appendix A (Part II. Model Formulation).

Fig. 4 presents the SFD of the main geothermal development module. In this module, the outcome indicator of the system, which is the total

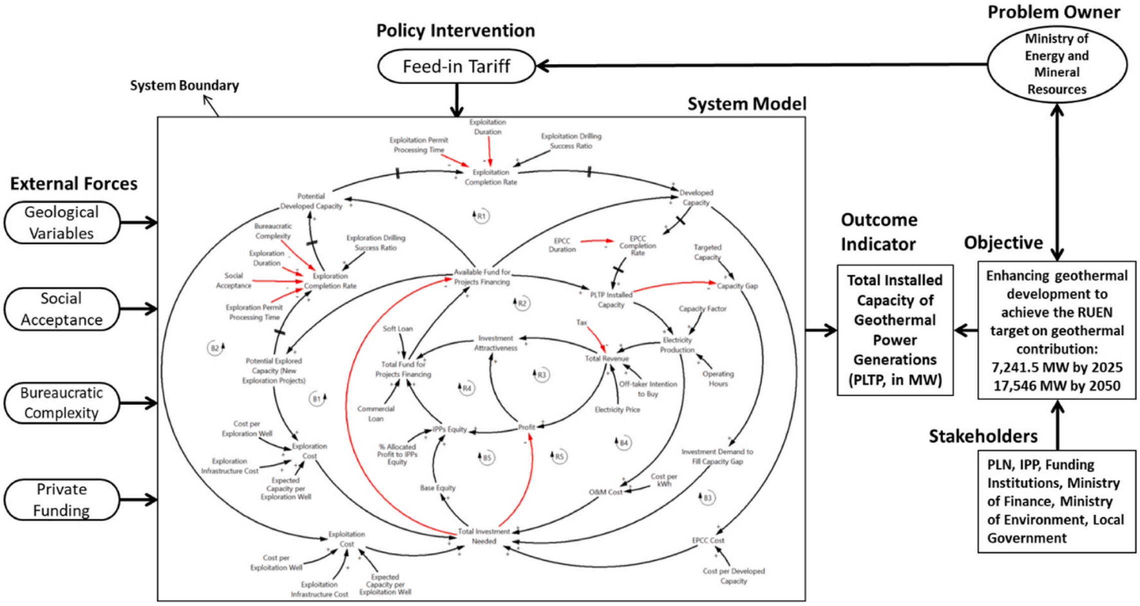


Fig. 2. System diagram of geothermal development in Indonesia (Note: the enlarged visualization of the system model or causal loop diagram is displayed in Fig. 3).

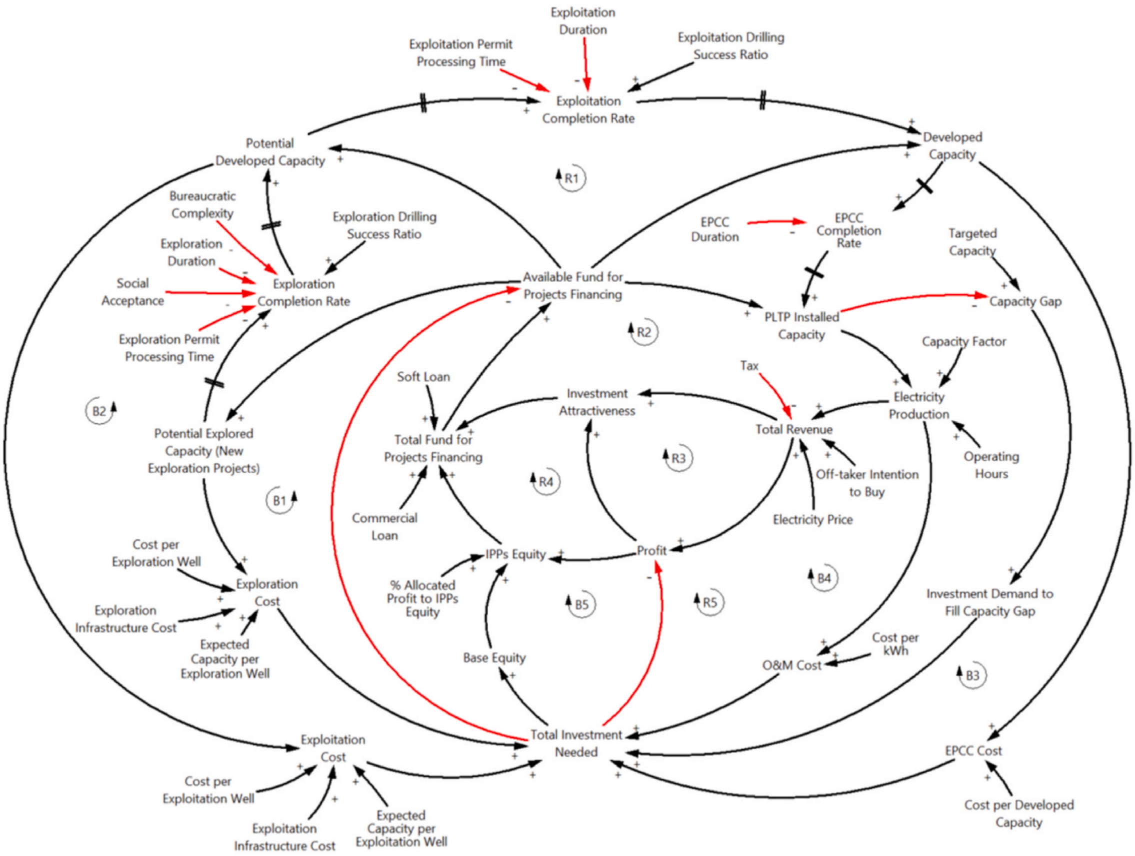


Fig. 3. Causal loop diagram of geothermal development in Indonesia. Positive link from variable 'A' to variable 'B' indicates that an increase in variable 'A' would lead to an increase in variable 'B', vice versa. Negative link indicates that an increase in variable 'A' would lead to a decrease in variable 'B', vice versa.

installed capacity of geothermal power generations, is simulated. Following the division of three tariff schemes as explained in Section 2, the total installed capacity comes from the summation of three categories of geothermal projects. The first category is the old arrangement development, consisting of geothermal projects contracted before Law 27/2003 enacted in 2003. The *Initial Installed Capacity* falls to the first category, representing the existing capacity of geothermal power generations—for this purpose, this study used data of the total installed capacity in 2019, which accounted for 1,948.5 MW (ESDM, 2020). The second category is the semi-old arrangement development, consisting of geothermal projects possessing the contract after Law 27/2003 enacted, which mostly took place between 2003 and 2014. The outputs of this category in the module are *Installed Capacity 1* and *Installed Capacity 2.* The third category is the new arrangement development, which consists of geothermal projects that follow MEMR Regulation 50/2017 issued in 2017. In the module, this category results in *Installed Capacity 3*.

Fig. 4 depicts the main activities in geothermal development, showing the variables that determine the resulting total installed capacity from installed capacity in each geothermal project category. *Installed Capacity* is the result of *Developed Capacity*, which is determined by *EPCC Completion Rate* and influenced by *EPCC Duration*. The shorter the EPCC duration, the faster the developed capacity can be realized into installed capacity. *Developed Capacity* is a factor of *Potential Developed Capacity* and *Exploitation Completion Rate*. Several variables influence *Exploitation Completion Rate*: *Exploration Duration*, *Exploitation Duration*, *Exploitation Drilling Success Ratio*, *Delay due to Social Acceptance*, *Delay due to Bureaucracy* as well as *Exploration Permit Processing Time*. Meanwhile, *Potential Developed Capacity* is the result of *Potential Explored Capacity* and determined by *Exploration Completion Rate.* Similar to *Exploitation Completion Rate*, *Exploration Completion Rate* is influenced by *Exploration Duration* and some delaying variables. In addition to these variables, *Exploration Completion Rate* is also affected by *Exploration Drilling Success Ratio* and *Fund Adequacy for Financing Project.* The latter variable connects the investment and financing of geothermal projects module with the geothermal development module. Finally, the sum of *Initial Installed Capacity* and *Installed Capacity* results in the *Total Installed Capacity*.

Fig. 5 displays the SFD of geothermal development cost module, translated from loops B1, B2, B3, and B4 of CLD in Fig. 3. This module explicates the cost incurred in each phase of geothermal projects. The SFD of investment and financing of geothermal projects module is visualized in Fig. 6, highlighting three revenue streams coming from the electricity production of each geothermal projects category.

Fig. 7 shows the connections between the SFD modules, depicting the links between variables of each connected module. Link 1A represents the influence of variables in the investment and financing of geothermal projects module on variables in the geothermal development module, while Link 1B represents the reverse relationships. The connection of variables in the geothermal development module to variables in the geothermal development cost module is described by Link 2. Meanwhile, Link 3A depicts the connection of variables in the geothermal development cost module to variables in the investment and financing of geothermal projects module, and Link 3B represents the vice versa connection.

3.4. Quantitative model validation and scenario development

Before the quantitative SFD can be used for evaluating policy alternatives, its validity needs to first be assessed. This study employs four standard validation and verification tests for SD modeling: dimension analysis, integration error test, extreme condition test, and behavior analysis (Sterman, 2000). A business-as-usual (BAU) scenario was used

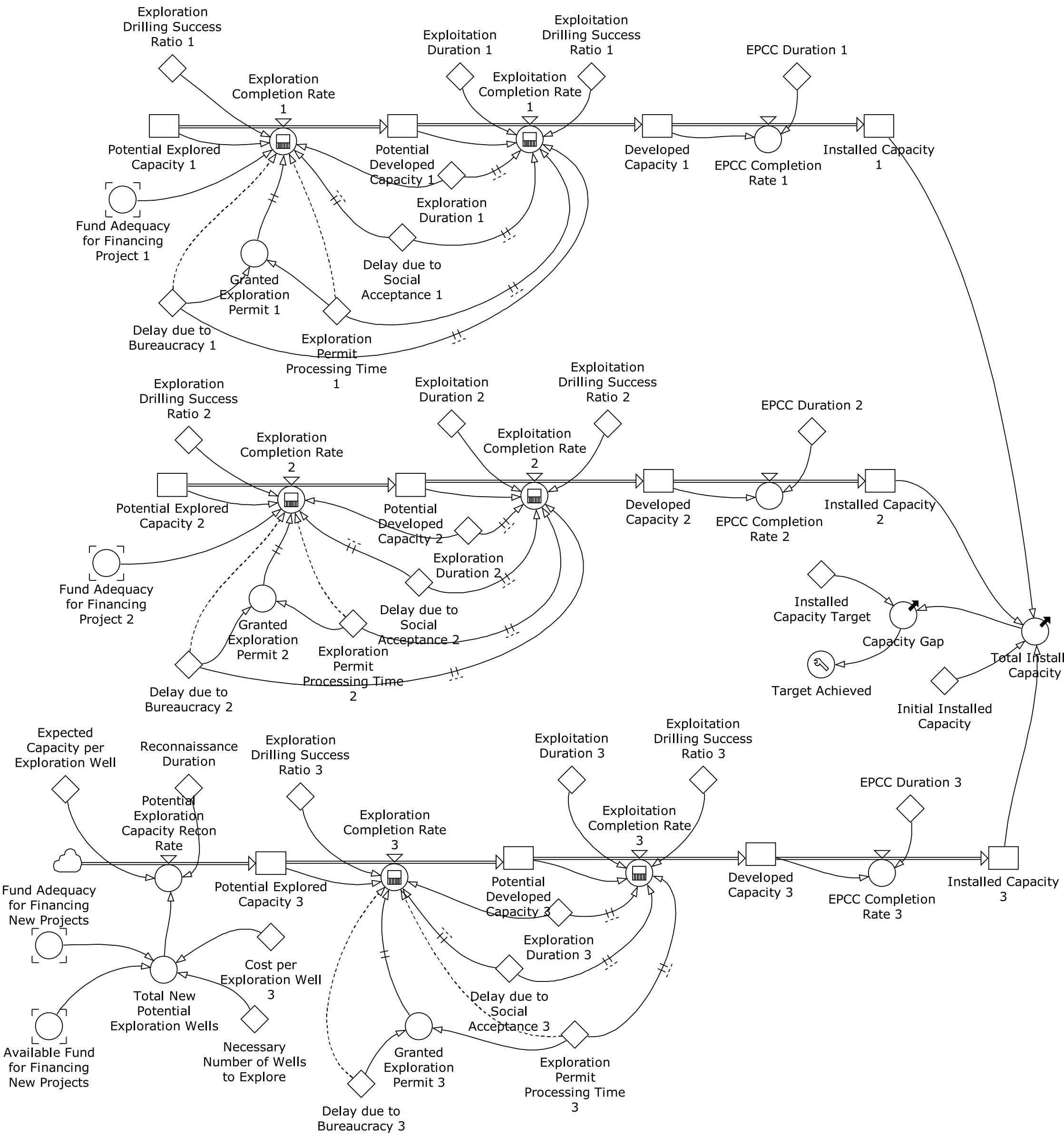


Fig. 4. The geothermal development module.

to experiment (see Appendix A for the data and details of variable values). The period was set to year, with a temporal span ranging from 2019 to 2050. In the simulation scenario, the time step unit is one year. As mentioned in Section 2, the current FIT comprises three separate electricity prices applied differently to geothermal power generation in each geothermal project category. Tariffs for geothermal power generation in the first, second, and third categories are 7.53 cents US$/kWh, 8.86 cents US$/kWh, and 7.66 cents US$/kWh, respectively. Permit processing can take up to a year on average, and negotiations with communities and non-governmental organizations can take up to a year before projects can begin. Duration of exploration, exploitation, and EPCC, can take two years on average for each. Meanwhile, the exploration and exploitation drilling success ratios often reach 50% and 80%, respectively. The model passed the standard tests, concluding its validity corresponds to reality. Details of the model testing and their results are presented in Appendix A (Part III. Model Testing Results).

In addition to the BAU scenario, three scenarios were developed to investigate the effectiveness of FIT policies. They were developed to assume that certain conditions should be improved from the BAU to implement FIT policies, resulting in better target achievement. In each scenario, three FIT schemes (FIT-1, FIT-2, FIT-3) with different electricity prices were applied equally to geothermal power generations in each geothermal project category (see Table 2). Each type of FIT scheme was set to its average and maximum prices.

Table 3 presents the variables set for each scenario, reflecting the conditions under which the FIT policies are applied. The affected variables are *Total Revenue, Investment Attractiveness, Total Available* Fund *for Financing Projects, Exploration Completion Rate, Exploitation Completion Rate, Potential Developed Capacity, Developed Capacity, EPCC Completion Rate, Installed Capacity, and Total Installed Capacity*.

Table 3 furthermore shows that all scenarios are dominantly influenced by similar external variables. They influence the affected variables through the following mechanisms:

1. *Off-taker Intention to Buy*

It is a critical factor in this regard. The power industry in Indonesia is monopsony, and the power market adopts a levelized cost of electricity (LCOE). Geothermal electricity, like other electricity from renewable energies, has a higher LCOE compared to electricity from fossil fuels. If

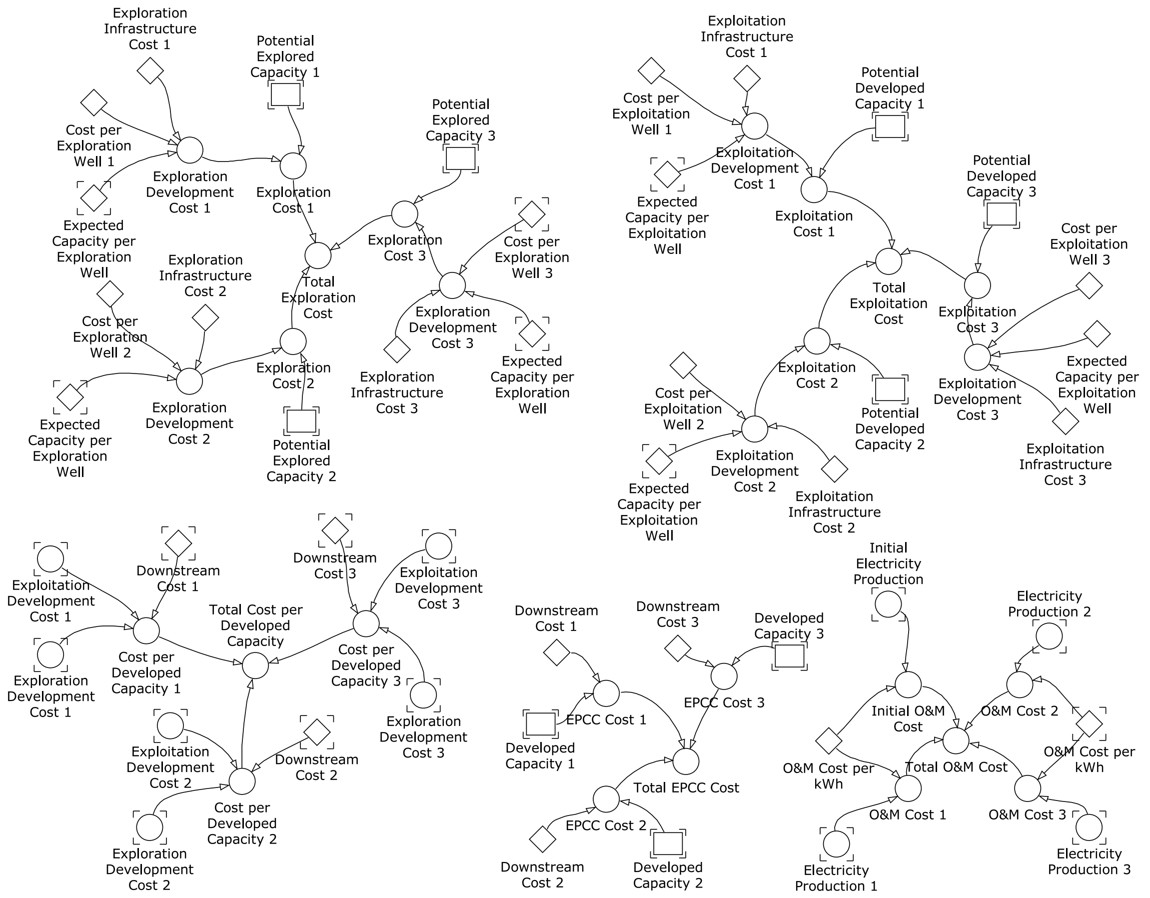


Fig. 5. The geothermal development cost module.

the off-taker does not intend to buy the electricity generated by geothermal, there will be no further contributions from geothermal. In this sense, the off-taker intention to buy will affect developers' revenue, investment attractiveness, and the available fund for financing projects and thus determine the achievement of total installed capacity in the subsequent process.

2. *Delay due to Bureaucracy* and *Delay due to Social Acceptance*

Refers to Fig. 4, the bureaucratic complexity and social acceptance will affect the exploration completion rate. Any delay in the bureaucratic process (i.e., permit processing time) and social acceptance will impede the exploration stage, which subsequently will have an impact on the commercial operation date (COD) of the power plants. The success of completing exploration at the earliest possible time will affect the subsequent process, which is the completion of the exploitation stage. Once both stages can be completed on time, the EPCC stage will be completed as per plan and COD can be achieved. Once COD is achieved, developers can start monetizing their investment by generating electricity from the installed capacity.

3. *Exploration Duration, Exploitation Duration,* and *EPCC Duration*

Refers to Fig. 4, the total installed capacity will be achieved after completing the exploration stage, exploitation stage, and the EPCC stage successfully. Any delay during each of these stages will have an impact on COD and eventually affect the total installed capacity.

4. *Exploration Drilling Success Ratio* and *Exploitation Drilling Success Ratio*

Both variables will determine how many development wells are required to fulfil the targeted capacity, thus affecting to the total investment needed for exploration and exploitation activities. More investment needed will decrease the potential profit for the developers. Consequently, it will lower the investment attractiveness. Once the investment attractiveness is less, developers' appetite to invest further will also decrease. Thus, potentially no further growth in geothermal development.

In Indonesia's power sector landscape, the electricity base price will remain the same over the period of the contract as well as the agreed minimum capacity factor. Therefore, the volume of electricity produced will remain constant at ±5% over the contract period. Meanwhile, the revenue is the function of electricity base price and electricity volume produced. While both factors can be forecasted over the contract period, so does the revenue. In the case of any increment to the investment needed, it will affect the profit since the revenue will not change too much over time. Investment attractiveness, defined as the ratio of profit over revenue in this model, is regarded as the acceptance criterion for developers to invest in geothermal projects. Whenever the investment attractiveness is above the threshold (in the model, the threshold is set at 10%), it is expected that developers would like to invest more to increase the total installed capacity. The investment attractiveness will also increase when the incentive–in terms of electricity price or FIT–is sufficient to attract investors to develop further. Therefore, the incentive must give a substantial margin for investors.

Following the setting of variables, the narratives for scenarios 1, 2, and 3 are described below:

1. Modest Bureaucracy

Due to bureaucratic complexity, permit processing time and price negotiation between IPPs and PLN can consume considerable time,

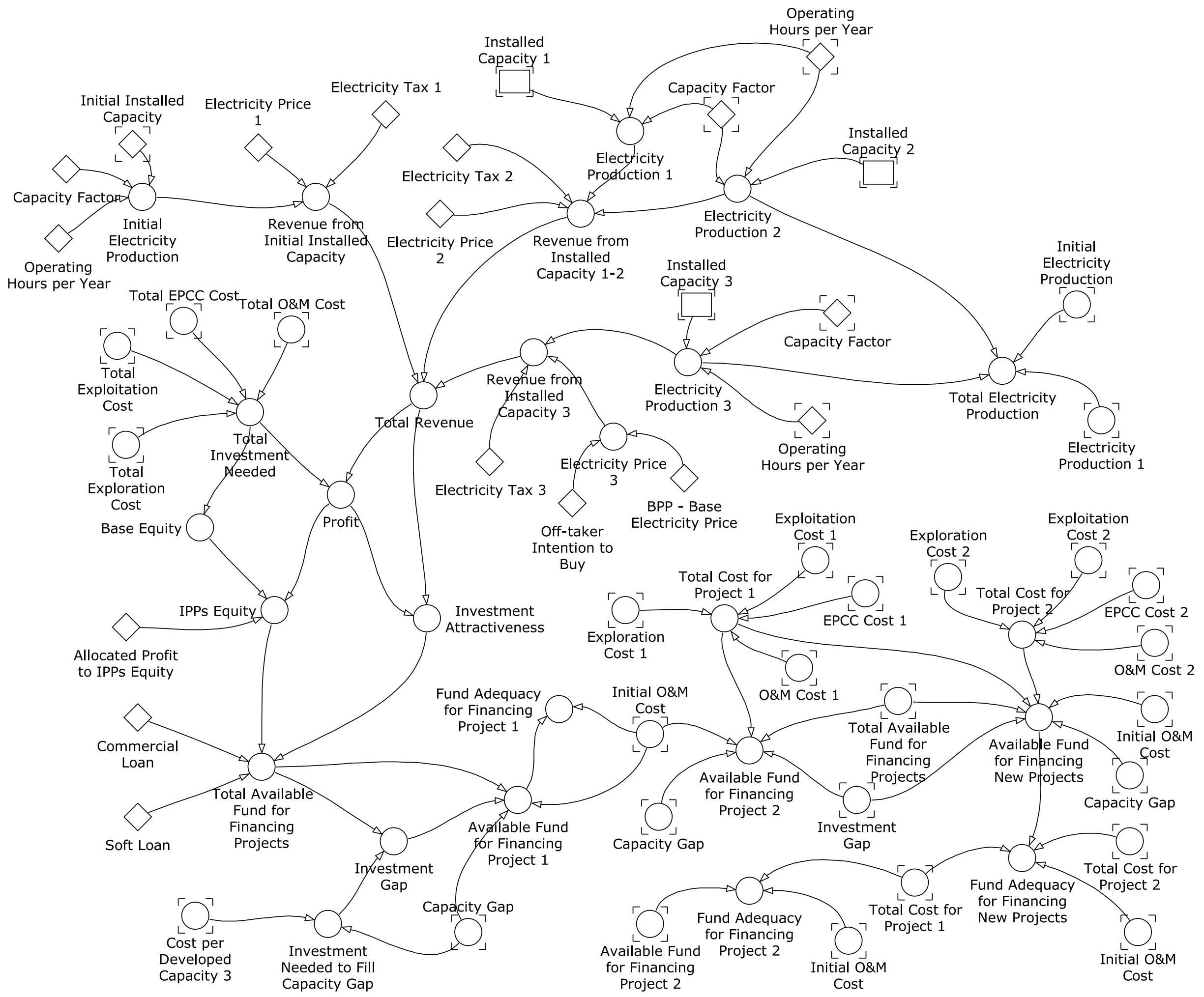
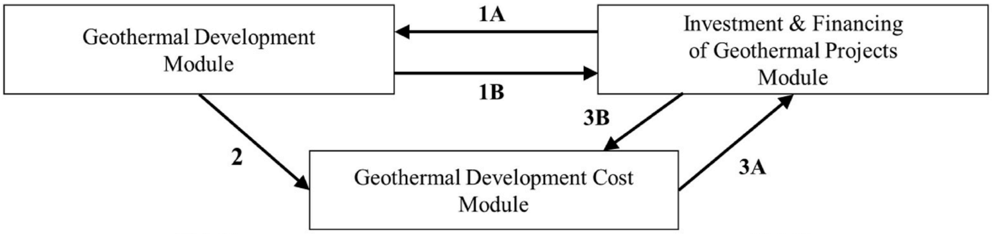


Fig. 6. The investment and financing of geothermal projects module.



Link 1A

1) *Fund Adequacy for Financing Project* linked to *Exploration Completion Rate.*
2) *Fund Adequacy for Financing New Projects* and *Available Fund for Financing New Projects* linked each to *Total New Potential Exploration Wells.*

Link 1B

1) *Capacity Gap* linked to *Investment Needed to Fill Capacity Gap, Available Fund for Financing Project* and *Available Fund for Financing New Projects.*
2) *Initial Electricity Production* linked to *Initial Electricity Production.*
3) *Installed Capacity* linked to *Electricity Production.*

Link 2

1) *Expected Capacity per Exploration Well* linked to *Exploration Development Cost* and *Exploitation Development Cost.*
2) *Potential Explored Capacity* linked to *Exploration Cost.*
3) *Potential Developed Capacity* linked o *Exploitation Development Cost.*
4) *Developed Capacity* linked to *EPCC Cost.*

Link 3A

1) *Exploration Cost, Exploitation Cost, EPCC Cost,* and *O&M Cost* linked each to *Total Cost for Project.* (applicable in geothermal projects category 2: the semi-old arrangement development)
2) *Cost per Developed Capacity* linked to *Investment Needed to Fill Capacity Gap.* (applicable in geothermal projects category 3: the new arrangement development)
3) *Initial O&M Cost* linked to *Fund Adequacy For Financing Project, Fund Adequacy for Financing New Projects, Available Fund for Financing Project* and *Available Fund for Financing New Projects.*
4) *Total Exploration Cost, Total Exploitation Cost, Total EPCC Cost,* and *Total O&M Cost* linked each to *Total Investment Needed.*

Link 3B

1) *Initial Electricity Production* linked to *Initial O&M Cost*
2) *Electricity Production* linked to *O&M Cost.*

Fig. 7. The connections between the SFD modules.

Table 2
Tariff settings for scenario testing.

Geothermal projects category	Applied FIT (cents US$/kWh)	FIT-1		FIT-2		FIT-3	
		Average	Maximum	Average	Maximum	Average	Maximum
		(cents US$/kWh)		(cents US$/kWh)		(cents US$/kWh)	
1	7.53	7.53	11.4	8.86	13.00	7.66	20.27
2	8.86	7.53	11.4	8.86	13.00	7.66	20.27
3	7.66	7.53	11.4	8.86	13.00	7.66	20.27

Table 3
The setting of variables for each scenario.

Variables	Unit	Business-as-Usual	Scenario 1 (Modest Bureaucracy)	Scenario 2 (Public Support)	Scenario 3 (Technical Breakthrough)
Off-taker Intention to Buy	Unitless	1	1	1	1
Delay due to Bureaucracy	year	1	0.75	1–2	1–2
Delay due to Social Acceptance	year	1	1	0.5	1
Exploration Duration	year	2	2	2	1.75
Exploitation Duration	year	2	2	2	1.75
EPCC Duration	year	2	2	2	1.75
Exploration Drilling Success Ratio	%	50	50	50	65
Exploitation Drilling Success Ratio	%	80	80	80	85

delaying projects execution. This circumstance involves the government taking steps such as reducing some procedures and limiting price negotiations to a realistic time frame. Such initiatives cut permit processing time by up to a quarter year, allowing IPPs and PLN to sign the PPA sooner than typical. Regardless of these efforts, most project developers should set aside at least one year to get social acceptance from the local community. Although it is still likely that social approval will be difficult to attain, rare occurrences have been discovered on geothermal projects in Indonesia. There is no technical breakthrough in exploration and exploitation, and each phase takes two years to complete, with the drilling success ratios at 50% and 80% on average, respectively.

2. Public Support

The raising concern about a sustainable and environmentally friendly power supply to support economic growth leads to more significant public support for geothermal development. Although stakeholder deliberation is necessary for achieving social acceptance, the process can be smoother when the projects agree with the concern of local people regarding the benefits of geothermal for them. This situation can ease geothermal projects executed half a year earlier than usual after the government permits are granted. However, unfortunately, bureaucratic complexity exists, delaying the permit processing time of 1–2 years. Also, with no technical improvement in the exploration and exploitation, each activity can take two years on average to achieve the drilling success ratios at the maximum of 50% and 80%, respectively.

3. Technical Breakthrough

Technical breakthrough—advanced reservoir modeling and drilling method—can reduce uncertainty in exploration and exploitation (Wang et al., 2021; Witter et al., 2019). With the technical breakthrough, project developers can increase exploration and exploitation drilling success ratios to up to 65 percent and 85 percent, respectively, in less than two years. Furthermore, the government gives financial incentives to encourage the development of new geothermal plants. Despite the technological advancements, the bureaucratic procedure has improved slightly. It takes 1–2 years for the permit to be obtained. Meanwhile, negotiation with local people can take one year until a project starting to execute.

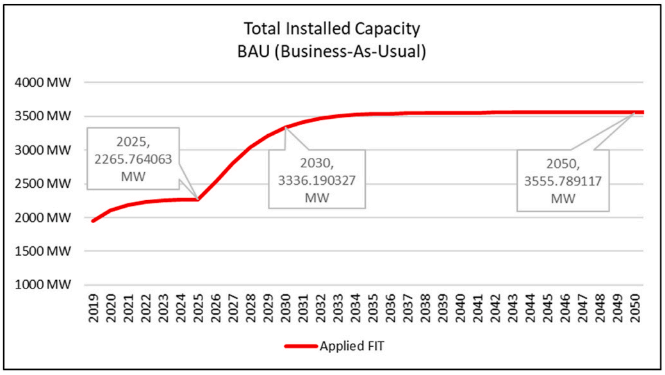


Fig. 8. Total installed capacity under the BAU scenario with applied tariff setting.

4. Results and discussion

Fig. 8 shows the total installed capacity achievement under the BAU scenario with the Applied FIT setting. The total installed capacity reaches 2,265.76 MW in 2025, with the total addition of 317.26 MW since 2019. Afterward, the total installed capacity starts climbing to 3,336.19 MW by 2030 and begins to steady with a slight increase, reaching 3,555.79 MW in 2050. These achievements, however, are far below the RUEN targets, which are 7,241.5 MW and 17,546 MW in 2025 and 2050,

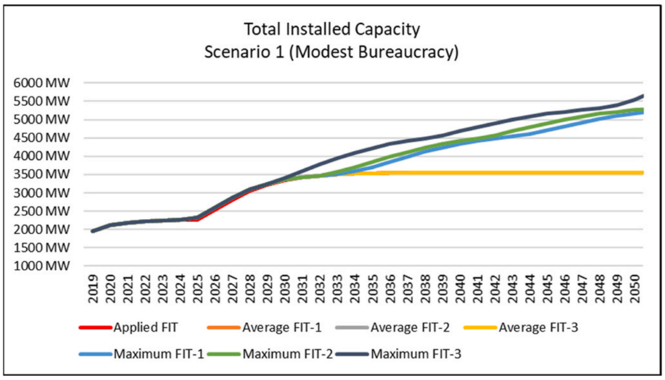


Fig. 9. Total installed capacity under scenario 1 (Modest Bureaucracy).

Table 4
Total installed capacity (MW) in 2025, 2030, and 2050 under scenario 1 (Modest Bureaucracy).

Year	Applied FIT	Average FIT-1	Average FIT-2	Average FIT-3	Maximum FIT-1	Maximum FIT-2	Maximum FIT-3
2025	2,525.28	2,595.96	2,595.96	2,595.96	2,595.96	2,595.96	2,595.96
2030	3,428.96	3,428.96	3,428.96	3,428.96	3,428.96	3,428.96	3,594.26
2050	3,555.79	3.555,79	3,555.79	3,555.79	5,222.55	5,299.28	5,744.85

respectively.

Fig. 9 and Table 4 show the total installed capacity under the Modest Bureaucracy scenario. The total installed capacity will reach 2,595.96 MW in 2025 under all average and maximum FIT settings. Under the Maximum FIT-3, the total installed capacity will reach 3,594.29 MW by the end of 2030. Meanwhile, comparable findings will be obtained under alternative FIT scenarios, where the total installed capacity will only be 3,428.98 MW. Under all average FIT options, a somewhat different result is obtained in 2050, with a total installed capacity of 3,555.79 MW. On the other hand, all maximum FIT settings will yield in better results than all average FIT settings, increasing total installed capacity by roughly 40% on average. With less complex bureaucracy, the total installed capacity will reach 5,744.85 MW under the Maximum FIT-3 by 2050.

Fig. 10 and Table 5 show the total installed capacity under the Public Support scenario. In 2025, the total installed capacity under all average and maximum FIT settings will reach 2,595.96 MW. And, under all FIT settings except the Maximum FIT-3, total installed capacity will expand by 833 MW on average by 2030, reaching 3,428.96 MW. Under the Maximum FIT-3, the total installed capacity will be 3,594.26 MW in 2030 and 5,744.85 MW in 2050, respectively. Although the highest total installed capacity under the Public Support and Modest Bureaucracy scenarios shows similar results by the end of 2050, the incremental installed capacity under all maximum FIT settings shows better achievement under the Public Support scenario. Furthermore, the total installed capacity shows better achievement in 2030 under the Public Support scenario than under the Modest Bureaucracy scenario.

Fig. 11 and Table 6 reveal the total installed capacity under the Technical Breakthrough scenario. The total installed capacity will reach 2,710.66 MW in 2025, increased by 762.16 MW since 2019 under all FIT settings. By the end of 2030, the total installed capacity starts flying to 3,798.06 MW under the Maximum FIT-3. However, it will only reach 3,500.74 MW under other FIT settings. Significant results are projected in 2050 where the growth of total installed capacity is more notable, getting its maximum achievement of 8,774.28 MW under the Maximum FIT-3. These results furthermore show that all maximum FIT settings lead to better achievements in all scenarios than other FIT settings.

Discovering and exploiting geothermal energy while mitigating its impact constitutes a significant technical and sociopolitical challenge (Gehringer and Loksha, 2012). The simulation results support the statement. Overcoming the technical challenge improves the total installed capacity more significantly than shortening the bureaucratic process and gaining public support. However, shortening the bureaucratic process and enhancing the societal acceptance of the community will surely help increase the total installed capacity.

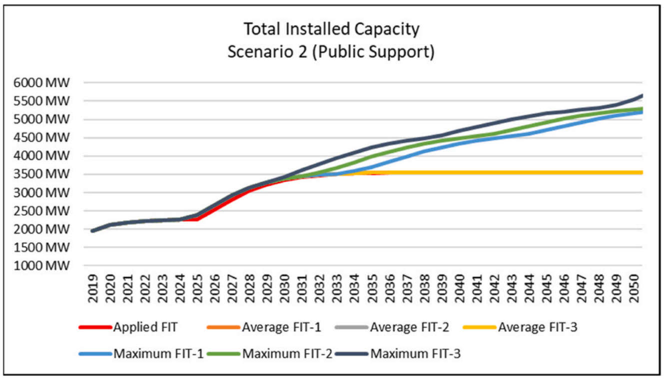


Fig. 10. Total installed capacity under scenario 2 (Public Support).

Under the Modest Bureaucracy and the Public Support scenarios, the total installed capacity achievements by 2050 are almost similar. The results differ significantly in 2025 and 2030, where the total installed capacity is larger under the Public Support scenario than under the Modest Bureaucracy scenario. However, in the Modest Bureaucracy scenario with all maximum FIT options, the total installed capacity progressively increases beginning in 2030. It reaches a parallel position toward that of the Public Support scenario in 2037 at 3,986.97 MW. Although the increment of yearly installed capacity is slightly higher under the Modest Bureaucracy scenario from 2019 to 2037, the overall increment of yearly installed capacity is at par in both scenarios.

The findings above explicate that public support is a prerequisite factor for the industrial players to start geothermal projects. In democratic countries, the demands and opinions of the public are significant factors in the policy-making process; in particular, public approval is a critical restricting factor of technology development and diffusion (Bronfman et al., 2012; Devine-Wright, 2007; Foxon and Pearson, 2007). As noted by Assefa and Frostell (2007), neglecting public acceptance might result in a large lag between proposal talks and project implementation. Therefore, solid public support can provide more opportunities to utilize renewable technologies (Devine-Wright, 2007; E. Moula et al., 2013), including geothermal.

While getting public acceptance is desirable, the level of reception from local people to a geothermal project is not always easy to anticipate, and thus social resistance might still occur. Lack of understanding about geothermal energy as they have not received any socialization and education from the government and the developer may create a negative perception toward geothermal projects. Therefore, it is imperative to have appropriate knowledge and capacity to manage social issues in developing geothermal power plants. Engaging the public on a big scale through social mapping ahead of time could be an effective method to avoid social resistance. One of the essential techniques to improving awareness and acceptance of geothermal projects in Indonesia is to provide enough information and develop transparent communication with local people and stakeholders. It is also advised to build a beneficial partnership with the media as public information agents to disseminate official news about the geothermal project. Such an approach could help to lessen social tension by avoiding the circulation of false information—if any.

The implication of heightening public acceptance surely helps increase the total installed capacity, although it will not sustain for a long period as indicated in the simulation results. It will only help projects that are already in the exploration and operating stages. The acceptability of project expansion will be greater because it will shorten the period between discussion and project execution. However, greenfield projects may still face social opposition from local residents concerned about the potential negative consequences of geothermal projects on their way of life. As such, geothermal reserves are point-source because there is one area in which they can be exploited, and they cannot be easily reproduced elsewhere (Winters and Matthew, 2015).

Besides the levitation of public acceptance, the bureaucratic process must be improved. In Indonesia, geothermal industry players are often discouraged from investing in the sector due to excessive red tape in the country and the fact that the geothermal industry's policy sphere is often

Table 5
Total installed capacity (MW) in 2025, 2030, and 2050 under scenario 2 (Public Support).

Year	Applied FIT	Average FIT-1	Average FIT-2	Average FIT-3	Maximum FIT-1	Maximum FIT-2	Maximum FIT-3
2025	2,525.28	2,666.63	2,666.63	2,666.63	2,666.63	2,666.63	2,666.63
2030	3,441.95	3,441.95	3,441.95	3,441.95	3,441.95	3,441.95	3,607.25
2050	3,555.79	3,555.79	3,555.79	3,555.79	5,222.55	5,302.88	5,744.85

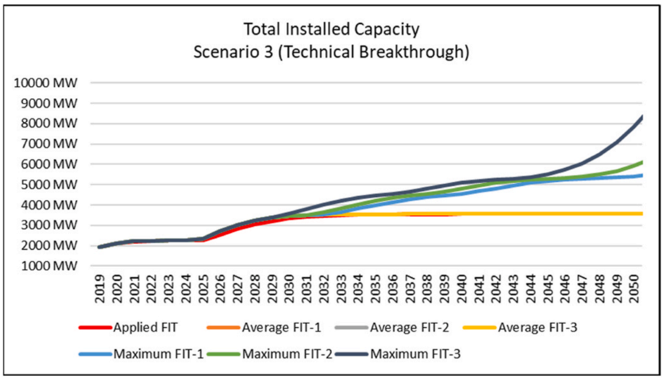


Fig. 11. Total installed capacity under scenario 3 (Technical Breakthrough).

uncertain. There is also a lack of mutual understanding between industrial and political entities. Unsynchronized rules between central and regional governments, normally enacted at the macro-level, are not or are only partially implemented at the micro-level. Furthermore, there are many overlapping regulations, and the rest is a difficult and time-consuming bureaucracy. It has generated multi-layered bureaucratic difficulties for investors interested in generating geothermal energy, which has resulted in less favorable investor attitudes toward investing further in Indonesia's geothermal business. Investors and lenders view the uncertain legislation and lengthy bureaucratic process as a danger for developers and investors, preventing them from investing resources. Harmonization and synchronization of the regulations, particularly across ministries and agencies, should be carried out by the government to accelerate geothermal development in Indonesia (Fan and Nam, 2018; Poernomo et al., 2015).

One notion about the implication from the Modest Bureaucracy scenario is how the total installed capacity will catch up with the similar achievement under the Public Support scenario by 2037. Such an idea is sensible because reducing the bureaucratic process will take time. The favorable influence will be felt gradually by the involved agencies over time. This research confirms that reducing the bureaucracy and changing the interaction between the central and regional governments is necessary to enhance the investment climate in Indonesia, particularly in the geothermal business. The presence of a well-functioning public sector is a key to foster economic growth and social transformation through the geothermal sector.

Further, the Technical Breakthrough scenario results also indicate that although shortening the bureaucratic process and ensuring social acceptance can help to improve the total installed capacity, overcoming the technical challenges seems the determining factor in reaching the RUEN targets more effectively. The exploration stage—before production—accounts for up to 50% of the risk for developing the geothermal resources further. Drilling is the riskiest and most expensive component of exploration activity to confirm geothermal resources due to sub-surface uncertainties (Gehringer and Loksha, 2012; Witter et al., 2019). Even though it is considered relatively modest as a proportion of total project costs, the owner's equity to finance this stage that had been spent will not be covered if the resource is not economically viable for the projects to continue to the next stage.

Many countries have already developed schemes to address geothermal resource risks by mobilizing capital for exploration drilling and resource confirmation. Another option is to split the drilling costs. In 2011, the Indonesian government established the Geothermal Fund Facility (GFF), which is managed by the Indonesia Investment Agency and provides data on geothermal resources and financing for exploratory efforts. Nonetheless, the money has never been disbursed because the agency is not permitted to incur losses on investments. Therefore, the agency usually lends to local governments purposively where repayment is relatively sure. So far, it is still deemed ineffective. In 2017, the Ministry of Finance released Ministerial Decree 62/2017 to regulate the transfer of geothermal funds, replacing the GFF with the Infrastructure Financing for Geothermal Sector (IFGS). IFGS provides a risk mitigation facility for geothermal exploration by delivering data and information through government or public exploration drilling. However, it has not yet begun to do so.

Another approach to address the technical challenges could be by implementing unconventional power plant technology. As a producer, the faster it can tap geothermal resources, the sooner it will generate income. The revenue will only be generated once the power plant is commissioned and operated commercially. The technology enforces the producer to implement the appropriate strategy to utilize its resources. There are three basic technologies to utilize geothermal energy indirectly: dry steam, flash steam, and binary cycle. The choice of technology to utilize geothermal energy depends on the prevailing characteristics of the geothermal resource (Matek, 2016). In Indonesia, most geothermal power plants are the flash steam type.

Besides the well-known technology, Kenya has implemented a technology that allows geothermal power generation directly from wellheads (Rojas, 2015). Using wellhead plants will reduce the time it takes to generate power following the successful drilling of a geothermal producing well. It can also power field development activities, lower drilling costs, and generate early cash streams if connected to the grid. When sufficient wells and steam have been created, wellheads are removed to join the steam from separate wells to establish a traditional geothermal power plant. The wellhead approach has the potential to be a game-changer in geothermal energy. However, further investigation should be performed to assess the legal framework with the off-taker. PLN—as the sole off-taker of electricity in Indonesia—has defined certain characters of steam or electricity to be supplied on its PPA with the producer, which can be used as a reference for assessing the legal framework on geothermal technology.

Table 6
Total installed capacity (MW) in 2025, 2030, and 2050 under scenario 3 (Technical Breakthrough).

Year	Applied FIT	Average FIT-1	Average FIT-2	Average FIT-3	Maximum FIT-1	Maximum FIT-2	Maximum FIT-3
2025	2,525.28	2,710.66	2,710.66	2,710.66	2,710.66	2,710.66	2,710.66
2030	3,416.02	3,500.74	3,500.74	3,500.74	3,500.74	3,500.74	3,798.06
2050	3,555.79	3.555,79	3,555.79	3,555.79	5.514.14	6,273.15	8,774.28

5. Conclusion and policy implications

The Indonesian government has issued several tariff regulations on geothermal electricity to enhance geothermal development. Although several formulas are used, the geothermal power purchase price generally follows the same policy: the ceiling price or the highest benchmark price. According to the findings of this study, all FIT situations require a reasonable price to stimulate geothermal development. A minimum tariff of 11 cents US$/kWh is unquestionably required to achieve significant gains in total installed capacity in the future years. The electricity tariff is currently regulated by MEMR, which uses the regional BPP as a reference for pricing IPPs. If the regional BPP is lower than the national BPP, the tariff is negotiable between the renewable energy developers and PLN; otherwise, if the local BPP is higher than the national BPP, then the tariff is pegged to 85 percent of regional BPP at maximum.

However, the problem with BPP is that the value is composed of all power plant technologies operating in the region, in which coal-fired power plants are still dominant. Therefore, geothermal developers see the current tariff setting as a disincentive due to an unfair calculation mechanism. Similarly, coal-fired power stations have been promoted by the Ministerial Decree of MEMR 261/2019, mandating continuous and affordable supply in the domestic market (DMO). Most coal-fired power plants are developed on a large scale, producing electricity at a lower cost than alternative technologies such as geothermal, resulting in a low BPP tariff. Meanwhile, geothermal electricity has yet to benefit from current FIT laws. This circumstance raises the initial and operating expenses of geothermal power plants. To make it even, the generation cost from coal-fired power plants shall add the external cost into the cost structure.

Another factor that hinders the progress of geothermal development in Indonesia is the escalation treatment of the applied tariff. As this study found, the current applied FIT seems hardly effective in achieving the RUEN targets. Escalation clauses seem normally allowed from commercial operation onwards, but no mechanism to accommodate any escalation during the project lifetime could mean a 3–5 year inflationary erosion of the negotiated tariff. Furthermore, given substantial uncertainties surrounding the pricing and regulatory structure, bureaucratic complexity will inhibit investment unless the expected gains are significant. However, it does not seem to be the case, given the observable evidence of delayed investment (Kompas.com, 2012; Sahide Muhammad Alif et al., 2018). This situation can disincentivize investors and developers to take part in Indonesia's geothermal industry.

Energy plays a vital role in achieving social, economic, and environmental goals for sustainable development. If Indonesia wants to meet its energy mix target, investments in renewable energy, especially geothermal, will need a rapid acceleration. However, the unfinished business is figuring out how to do geothermal projects appealing to investors and developers. Currently, Indonesia's geothermal policies are modest yet effective. Developers and investors are unlikely to calculate the anticipated return on investment. The uncertainties that arise during the exploration stage sometimes disincentivize private investment. The lack of investment capital might easily stymie geothermal growth in Indonesia. In this regard, an acceptable policy strategy will generally be defined by available geothermal resources, current impediments to, the potential for, and existing renewable energy priorities and goals. Ultimately, policymakers should design a unified policy to address the geothermal development barriers that are most prominent in Indonesia's jurisdiction.

The findings of this study indicated that without giving any positive stimulation toward the existing conditions, the total installed capacity did not reach the RUEN targets under all scenarios. They also claimed that FIT deployment alone would not result in considerable progress. And, while the technological advancement may help to accomplish the RUEN targets more successfully, the manufacturers must still incur the risk of large investment with equivalent government incentives. As a result, additional relevant policies outside of FIT are required to assist geothermal development in Indonesia. In this regard, the government should attempt to consistently implement the combination of incentives such as FIT and government-funded facilities for the risky exploratory phases of geothermal projects.

A notable addition has been made by this study to research on tariff policy, especially for non-intermittent renewable power generation development such as geothermal (i.e., Jiang et al., 2016; Kaneko et al., 2010). It also enriches the literature on renewable energy development (e.g., Fan and Nam, 2018; Lesser and Su, 2008), renewable energy technologies adoption (e.g., Baur and Mauricio Uriona, 2018; Dijkgraaf et al., 2018), and policy on renewable energy (e.g., Ayoub and Yuji, 2012; Jiang et al., 2016) in which tariff policy plays a vital role. Although the scope of this study is limited to Indonesia, which has a vast geothermal reserves potential, the conclusions of this study can still provide significant insights for other countries striving to fulfill their geothermal reserves potential through FIT regulations.

This study has shed light on the influence of key complicating variables—bureaucracy, social, and technical—on the realization of geothermal reserve potential, even though these elements can vary by country. Further, this paper has made a notable contribution to the literature on the use of SD modeling to appraise FIT policies in geothermal, which is still lacking previously. More specifically, by considering the key complicating factors rigorously in the analysis, the study has provided insight into opportunities for a better formulation of FIT policy design. For example, in our case study, we found that FIT policy design should consider a short bureaucratic process in permit issuance and tariff negotiation, tamed local issues, government-funded exploration activities, and technical breakthroughs. Though the key complicating factors on the FIT policy are highly contextual, the approach used in this study can be followed and is applicable to other countries. Such knowledge can assist policymakers and renewable energy providers in developing a solid strategy to overcome such challenges.

This study's model-based policy analysis has proved beneficial in elucidating geothermal development's dynamic complexity and FIT policies in Indonesia. However, future research can improve the current investigation by profoundly exploring the effects of uncertainties in geothermal exploration. Witter et al. (2019) noted that the exploration stage is crucial in determining the continuation of geothermal projects. Thus, addressing uncertainties in this stage is of paramount importance. Methods such as exploratory modeling and analysis (Eker and van Daalen, 2015; Kwakkel and Erik, 2013) can be used to explore the plausible effects of uncertainties in geothermal exploration and seek robust policies and strategies to deal with them.

Regarding investment and financing of geothermal projects, this study used the best practice value of the soft loan and the commercial loan without assuming any interest rate as the input value for the system dynamics model (as presented in Table A3 of Appendix A). Although the data has been validated by interviewing experts through the FGD, future research could consider uncertain changes in interest rates of the soft loan and the commercial loan in the analysis. Also, based on the best practice in geothermal projects, the debt-to-equity ratio ranges from 50% to 75% (Antonaria et al., 2014; Gehringer and Loksha, 2012; Wall et al., 2017). Therefore, in cases where a loan is necessary for project financing, the ratio in that range can be applied in the model. However, since such a ratio was not covered in the recent study, we propose future research on this matter, using the combination of financial modeling and exploratory modeling for further examination.

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CRediT authorship contribution statement

Andri D. Setiawan: Conceptualization, Methodology, Software, Validation, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Marmelia P. Dewi:** Conceptualization, Data curation, Software, Validation, Investigation, Formal analysis, Resources, Writing – review & editing. **Bramka Arga Jafino:** Data curation, Software, Formal analysis. **Akhmad Hidayatno:** Methodology, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data has been included in the appendix.

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Appendix A. Model Description and Model Testing Results

Part I. Description of Causal Loop Diagram

1. Geothermal development (Loop R1)

R1 is the main loop, highlighting the main processual activities or stages in geothermal development before commercialization: exploration activities, exploitation activities (exclude EPCC—engineering, procurement, construction, and commissioning). The loop is initiated by the requirement to fill the capacity gap in order to attain the desired capacity. The greater the capacity gap, the greater the investment required to support geothermal projects, and vice versa. The projects begin with exploratory activities to evaluate how much potential capacity can be tapped before progressing to installed capacity (in MW) for power generation. Overall, loop R1 depicts a reinforcing cycle in which increased exploration activities lead to increased exploitation operations and, eventually, increased installed capacity as the government's principal goal in geothermal development. The mechanism includes factors that influence the completion of each development stage, such as the processing time for exploration and exploitation permits. In particular, three complicating factors in the exploration stage can bring uncertainty to project outcomes: bureaucratic complexity, social acceptance, and success ratio to find the resource (determined by geological variables, i.e., enthalpy and temperature).

2. Geothermal development cost (Loops B1, B2, B3, and B4)

Loops B1, B2, B3, and B4 explain how each development stage and the operation and maintenance (O&M) of power generations create cost and determine the total investment needed. Three loops, B1, B2, and B3, clarify a balancing mechanism in which increased exploration, exploitation, and EPCC operations lead to larger investment requirements but eventually reduce available funds. Several factors influence this process, including the cost per exploration and exploitation well, the cost per developed, and the estimated capacity per exploration and exploitation well. Meanwhile, loop B4 demonstrates a balancing mechanism. Increased installed capacity led to increased power output and increased O&M costs, which raises the total investment required but eventually reduces the available fund. Several factors affect this mechanism, such as the capacity factor, power plants' operating duration, and the cost of electricity produced per hour.

3. Investment and financing of geothermal projects (Loops R2, R3, R4, R5, and B5)

Geothermal development requires considerable upfront investment in which the projects need to be attractive for the private sector to invest. Loops R2 and R3 explain how investment attractiveness affects the available fund for projects financing. The attractiveness of geothermal projects is determined by the revenue and profit generated from the sale of power. Such desirability may facilitate access to additional funding sources, such as soft and commercial loans. Loop R4 describes the IPP's equity as another cash source for project financing that is profit-driven. At the same time, loop R5 shows how the total investment required influences the revenue profit. Overall, these four loops depict a self-reinforcing cycle in which increased installed capacity generates more revenue and potentially higher profit. Higher yield leads to increased investor attractiveness, more equity, and, finally, more funds available for project finance. The mechanism involves factors affecting revenue from selling electricity, such as tax, electricity price, and off-taker buying intention.

Meanwhile, loop B5 reflects a balancing mechanism where the higher the total investment needed, the more IPP's equity is required to fund the projects. As a result, more funds will be available for financing the projects to increase installed capacity. Thus, it will eventually narrow the capacity gap and lessen the total investment needed to fill the capacity gap.

Part II. Model Formulation

1. Geothermal Development Module

Geothermal projects start once adequate funds are available, and exploration permits have been granted. However, various complicated circumstances, particularly during the exploration and exploitation phases, might cause project delays. These are external issues that the problem owner has little control over, resulting from bureaucratic complexity in the exploration and exploitation permit processing and societal acceptance, particularly from local neighbors. Another complicating aspect is geological factors, which are reflected in drilling success percentages for exploration and extraction. The drilling success ratio of an exploration well is difficult to estimate. However, based on IPP's best practice, the success ratio of exploration and exploitation drilling should be at least 50% and 80%, respectively, before proceeding further to the next phase.

Following the division of three tariff schemes as explained in Section 2, the module reflects three categories of geothermal projects. The first category is the old arrangement development, consisting of geothermal projects contracted before Law 27/2003 enacted in 2003. The *Initial Installed Capacity* falls to the first category, representing the existing capacity of geothermal power generations—for this purpose, this study used data of the total installed capacity in 2019, which accounted for 1,948.5 MW (ESDM, 2020). The second category is the semi-old arrangement development, consisting of geothermal projects possessing the contract after Law 27/2003 enacted, which mostly took place between 2003 and 2014. The outputs of this category in the module are *Installed Capacity 1* and *Installed Capacity 2*. The third category is the new arrangement development, which consists of geothermal projects that follow MEMR Regulation 50/2017 issued in 2017. In the module, this category results in *Installed Capacity 3*.

Unlike geothermal projects in the first and the second category whose potential explored capacity has already been identified, projects in the new arrangement development should start with the reconnaissance phase to determine the potential explored capacity. The geothermal development module also possesses the main indicator of geothermal development target achievement. The total installed capacity is the sum of the installed capacity from geothermal power generations in each geothermal project category.

Table A1

Formula for the geothermal development module

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
Available Fund for Financing New Projects	US$	IF(‘Investment Gap’≥0<<USD>> OR ‘Capacity Gap’ = 0<<MW>>,0<<USD>>,(‘Total Available Fund for Financing Projects’-’Initial O&M Cost’-’Total Cost for Project 1’-’Total Cost for Project 2′))
Capacity Gap	MW	MAX(‘Installed Capacity Target’-’Total Installed Capacity’,0<<MW>>)
Cost per Exploration Well	US $/well	6000000
Delay due to Bureaucracy 1	yr	1
Delay due to Bureaucracy 2	yr	1
Delay due to Bureaucracy 3	yr	1
Delay due to Social Acceptance 1	yr	1
Delay due to Social Acceptance 2	yr	1
Delay due to Social Acceptance 3	yr	1
Developed Capacity 1	MW	322.3
Developed Capacity 2	MW	0
Developed Capacity 3	MW	0
EPCC Completion Rate 1	yr	‘Developed Capacity 1’/’EPCC Duration 1′
EPCC Completion Rate 2	yr	‘Developed Capacity 2’/’EPCC Duration 2′
EPCC Completion Rate 3	yr	‘Developed Capacity 3’/’EPCC Duration 3′
EPCC Duration 1	yr	2
EPCC Duration 2	yr	2
EPCC Duration 3	yr	2
Expected Capacity per Exploration Well	MW/well	10
Exploitation Completion Rate 1	MW/yr	DELAYPPL(IF((‘Exploration Permit Processing Time 1’+’Delay due to Bureaucracy 1’+’Delay due to Social Acceptance 1’+’Exploration Duration 1′)≤5,1,0),’Exploration Permit Processing Time 1’+’Delay due to Bureaucracy 1’+’Delay due to Social Acceptance 1’+’Exploration Duration 1′,0)*(‘Potential Developed Capacity 1’*’Exploitation Drilling Success Ratio 1’/’Exploitation Duration 1′)
Exploitation Completion Rate 2	MW/yr	DELAYPPL(IF((‘Exploration Permit Processing Time 2’+’Delay due to Bureaucracy 2’+’Delay due to Social Acceptance 2’+’Exploration Duration 2′)≤5,1,0),’Exploration Permit Processing Time 2’+’Delay due to Bureaucracy 2’+’Delay due to Social Acceptance 2’+’Exploration Duration 2′,0)*(‘Potential Developed Capacity 2’*’Exploitation Drilling Success Ratio 2’/’Exploitation Duration 2′)
Exploitation Completion Rate 3	MW/yr	DELAYPPL(IF((‘Exploration Permit Processing Time 3’+’Delay due to Bureaucracy 3’+’Delay due to Social Acceptance 3’+’Exploration Duration 3′)≤6,1,0),’Exploration Permit Processing Time 3’+’Delay due to Bureaucracy 3’+’Delay due to Social Acceptance 3’+’Exploration Duration 3′,0)*(‘Potential Developed Capacity 3’*’Exploitation Drilling Success Ratio 3’/’Exploitation Duration 3′)
Exploitation Drilling Success Ratio 1	%	80
Exploitation Drilling Success Ratio 2	%	80
Exploitation Drilling Success Ratio 3	%	80
Exploitation Duration 1	yr	2
Exploitation Duration 2	yr	2
Exploitation Duration 3	yr	2
Exploration Completion Rate 1	MW/yr	‘Fund Adequacy for Financing Project 1’*DELAYPPL(IF(‘Delay due to Social Acceptance 1’<5,’Granted Exploration Permit 1′,0),’Exploration Permit Processing Time 1’+’Delay due to Bureaucracy 1’+’Delay due to Social Acceptance 1′,0)*(‘Potential Explored Capacity 1’*’Exploration Drilling Success Ratio 1’/’Exploration Duration 1′)
Exploration Completion Rate 2	MW/yr	‘Fund Adequacy for Financing Project 2’*DELAYPPL(IF(‘Delay due to Social Acceptance 2’<5,’Granted Exploration Permit 2′,0),’Exploration Permit Processing Time 2’+’Delay due to Bureaucracy 2’+’Delay due to Social Acceptance 2′,0)*(‘Potential Explored Capacity 2’*’Exploration Drilling Success Ratio 2’/’Exploration Duration 2′)
Exploration Completion Rate 3	MW/yr	DELAYPPL(IF(‘Delay due to Social Acceptance 3’<6,’Granted Exploration Permit 3′,0),’Exploration Permit Processing Time 3’+’Delay due to Bureaucracy 3’+’Delay due to Social Acceptance 3′,0)*(‘Potential Explored Capacity 3’*’Exploration Drilling Success Ratio 3′)/’Exploration Duration 3′
Exploration Drilling Success Ratio 1	%	50
Exploration Drilling Success Ratio 2	%	50
Exploration Drilling Success Ratio 3	%	50
Exploration Duration 1	yr	2
Exploration Duration 2	yr	2
Exploration Duration 3	yr	2
Exploration Permit Processing Time 1	yr	1

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Table A1 (*continued*)

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
Exploration Permit Processing Time 2	yr	1
Exploration Permit Processing Time 3	yr	1
Fund Adequacy for Financing Project 1		IF(‘Available Fund for Financing Project 1’<’Initial O&M Cost’,0,1)
Fund Adequacy for Financing Project 2		IF(‘Available Fund for Financing Project 2’<(‘Initial O&M Cost’+’Total Cost for Project 1′),0,1)
Fund Adequacy for Financing New Projects		IF(‘Available Fund for Financing New Projects’<(‘Initial O&M Cost’+’Total Cost for Project 1’+’Total Cost for Project 2′),0,1)
Granted Exploration Permit 1		IF(‘Exploration Permit Processing Time 1’+’Delay due to Bureaucracy 1’≤3,1,0)
Granted Exploration Permit 2		IF(‘Exploration Permit Processing Time 2’+’Delay due to Bureaucracy 2’≤3,1,0)
Granted Exploration Permit 3		IF((‘Exploration Permit Processing Time 3’+’Delay due to Bureaucracy 3′)≤4,1,0)
Installed Capacity 1	MW	0
Installed Capacity 2	MW	0
Installed Capacity 3	MW	0
Installed Capacity Target	MW	17546
Initial Installed Capacity	MW	1948.5
Necessary Number of Wells to Explore		3
Potential Developed Capacity 1	MW	1285
Potential Developed Capacity 2	MW	0
Potential Developed Capacity 3	MW	0
Potential Exploration Capacity Recon Rate	MW/yr	(‘Total New Potential Exploration Wells’*’Expected Capacity per Exploration Well’)/’Reconnaissance Duration’
Potential Explored Capacity 1	MW	1160
Potential Explored Capacity 2	MW	705
Potential Explored Capacity 3	MW	0
Reconnaissance Duration	yr	1
Target Achieved	true/ false	STOPIF(‘Capacity Gap’<=0<<MW>>)
Total Installed Capacity	MW	‘Initial Installed Capacity’+’Installed Capacity 1’+’Installed Capacity 2’+’Installed Capacity 3′
Total New Potential Exploration Wells	well	IF(‘Fund Adequacy for Financing New Projects’ = 1,FLOOR(IF((‘Available Fund for Financing New Projects’/’Necessary Number of Wells to Explore’)<’Cost per Exploration Well 3’*1<<well>>,0,1)*’Available Fund for Financing New Projects’/(‘Cost per Exploration Well 3’*’Necessary Number of Wells to Explore’)))

2. Geothermal Development Cost Module

Each phase in geothermal projects incurs costs that determine the total investment needed. The exploration cost comes from the potential explored capacity multiplied by the exploration development cost. The cost of exploration development is determined using the cost of exploration infrastructure, the expected capacity per exploration well, and the cost per exploration well. The cost incurred during the exploitation phase results from the prospective created capacity and the exploitation development cost. The latter cost is calculated using the cost of exploitation infrastructure, the cost per exploitation well, and the projected capacity per exploitation well. Following that is the EPCC cost, which is decided by the created capacity and the downstream cost.

Meanwhile, the O&M cost is determined by the electricity production and cost per kWh of electricity. Especially for projects in the new arrangement development category, the cost per developed capacity determines the investment needed to fill the capacity gap. This cost type is usually used as an indicator to measure a geothermal project’s efficiency, calculated based on three components: exploration development cost, exploitation development cost, and downstream cost.

Table A2
Formula for the geothermal development cost module

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
Cost per Developed Capacity 1	US$/MW	‘Exploration Development Cost 1’+’Exploitation Development Cost 1’+’Downstream Cost 1′
Cost per Developed Capacity 2	US$/MW	‘Exploration Development Cost 2’+’Exploitation Development Cost 2’+’Downstream Cost 2′
Cost per Developed Capacity 3	US$/MW	‘Exploration Development Cost 3’+’Exploitation Development Cost 3’+’Downstream Cost 3′
Cost per Exploitation Well 1	US$/well	6000000
Cost per Exploitation Well 2	US$/well	6000000
Cost per Exploitation Well 3	US$/well	6000000
Cost per Exploration Well 1	US$/well	6000000
Cost per Exploration Well 2	US$/well	6000000
Cost per Exploration Well 3	US$/well	6000000
Developed Capacity 1	MW	322.3
Developed Capacity 2	MW	0
Developed Capacity 3	MW	0
Downstream Cost 1	US$/MW	1600000
Downstream Cost 2	US$/MW	1600000
Downstream Cost 3	US$/MW	1600000
Electricity Production 1	kWh	‘Installed Capacity 1’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Electricity Production 2	kWh	‘Installed Capacity 2’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Electricity Production 3	kWh	‘Installed Capacity 3’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
EPCC Cost 1	US$	‘Downstream Cost 1’*’Developed Capacity 1′

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Table A2 (*continued*)

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
EPCC Cost 2	US$	‘Downstream Cost 2’*’Developed Capacity 2′
EPCC Cost 3	US$	‘Downstream Cost 3’*’Developed Capacity 3′
Expected Capacity per Exploitation Well	MW/well	10
Expected Capacity per Exploration Well	MW/well	10
Exploitation Cost 1	US$	‘Exploitation Development Cost 1’*’Potential Developed Capacity 1′
Exploitation Cost 2	US$	‘Exploitation Development Cost 2’*’Potential Developed Capacity 2′
Exploitation Cost 3	US$	‘Exploitation Development Cost 3’*’Potential Developed Capacity 3′
Exploitation Development Cost 1	US$/MW	(‘Cost per Exploitation Well 1’/’Expected Capacity per Exploitation Well’)+’Exploitation Infrastructure Cost 1′
Exploitation Development Cost 2	US$/MW	(‘Cost per Exploitation Well 2’/’Expected Capacity per Exploitation Well’)+’Exploitation Infrastructure Cost 2′
Exploitation Development Cost 3	US$/MW	(‘Cost per Exploitation Well 3’/’Expected Capacity per Exploitation Well’)+’Exploitation Infrastructure Cost 3′
Exploration Cost 1	US$	‘Exploration Development Cost 1’*’Potential Explored Capacity 1′
Exploration Cost 2	US$	‘Exploration Development Cost 2’*’Potential Explored Capacity 2′
Exploration Cost 3	US$	‘Exploration Development Cost 3’*’Potential Explored Capacity 3′
Exploration Development Cost 1	US$/MW	(‘Cost per Exploration Well 1’/’Expected Capacity per Exploration Well’)+’Exploration Infrastructure Cost 1′
Exploration Development Cost 1	US$/MW	(‘Cost per Exploration Well 2’/’Expected Capacity per Exploration Well’)+’Exploration Infrastructure Cost 2′
Exploration Development Cost 1	US$/MW	(‘Cost per Exploration Well 3’/’Expected Capacity per Exploration Well’)+’Exploration Infrastructure Cost 3′
Exploitation Infrastructure Cost 1	US$/MW	500000
Exploitation Infrastructure Cost 2	US$/MW	500000
Exploitation Infrastructure Cost 3	US$/MW	500000
Exploration Infrastructure Cost 1	US$/MW	300000
Exploration Infrastructure Cost 2	US$/MW	300000
Exploration Infrastructure Cost 3	US$/MW	300000
Initial Electricity Production	kWh	‘Operating Hours per Year’*’Initial Installed Capacity’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Initial O&M Cost	US$	‘O&M Cost per kWh’*’Initial Electricity Production’
O&M Cost 1	US$	‘O&M Cost per kWh’*’Electricity Production 1′
O&M Cost 2	US$	‘O&M Cost per kWh’*’Electricity Production 2′
O&M Cost 3	US$	‘O&M Cost per kWh’*’Electricity Production 3′
O&M Cost per kWh	US$/kWh	0.005
Total Cost per Developed Capacity	US$/MW	‘Cost per Developed Capacity 1’+’Cost per Developed Capacity 2’+’Cost per Developed Capacity 3′
Total EPCC Cost	US$	‘EPCC Cost 1’+’EPCC Cost 2’+’EPCC Cost 3′
Total Exploitation Cost	US$	‘Exploitation Cost 1’+’Exploitation Cost 2’+’Exploitation Cost 3′
Total Exploration Cost	US$	‘Exploration Cost 1’+’Exploration Cost 2’+’Exploration Cost 3′
Total O&M Cost	US$	‘Initial O&M Cost’+’O&M Cost 1’+’O&M Cost 2’+’O&M Cost 3′

3. *Investment and Financing of Geothermal Projects Module*

Electricity production is computed using installed capacity, operational hours per year, and a capacity factor for geothermal power generation. Electricity output, electricity pricing, and electricity tax all contribute to revenue. The electricity price under the new arrangement development relates to the local cost of generation or BPP. However, the final tariff will be determined by the off-takers desire to purchase. The overall amount of money invested and the total amount earned define how much profit the project owners can make. At the same time, the ratio between profit and total investment defines investment attractiveness. As noted above, the total investment needed is the sum of costs incurred from exploration, exploitation, EPCC, and O&M. It is also used as the reference for calculating the base equity. Besides the base equity, IPPs equity also comes from allocated profit, of course, whenever profit is available. With the soft loan (if available) and commercial loan, IPPs equity becomes the source of funds for financing projects influenced by investment attractiveness. For each project, the available fund depends on the investment gap, the capacity gap, and the O&M cost.

Table A3
Formula for the investment and financing of geothermal projects module

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
Allocated Profit to IPPs Equity	%	10
Available Fund for Financing Project 1	US$	IF(‘Investment Gap’≥0<<USD>> OR ‘Capacity Gap’ = 0<<MW>>,0<<USD>>,IF((‘Total Available Fund for Financing Projects’<’Initial O&M Cost’),0<<USD>>,(‘Total Available Fund for Financing Projects’-’Initial O&M Cost’)))
Available Fund for Financing Project 2	US$	IF(‘Investment Gap’≥0<<USD>> OR ‘Capacity Gap’ = 0<<MW>>,0<<USD>>,(‘Total Available Fund for Financing Projects’-’Initial O&M Cost’-’Total Cost for Project 1′))
Available Fund for Financing New Projects	US$	IF(‘Investment Gap’≥0<<USD>> OR ‘Capacity Gap’ = 0<<MW>>,0<<USD>>,(‘Total Available Fund for Financing Projects’-’Initial O&M Cost’-’Total Cost for Project 1’-’Total Cost for Project 2′))
Base Equity	US$	0.5*’Total Investment Needed’
BPP – Base Electricity Price	US $/kWh	0.0766
Capacity Factor	%	90
Capacity Gap	MW	MAX(‘Installed Capacity Target’-’Total Installed Capacity’,0<<MW>>)
Commercial Loan	US$	300000000
Cot per Developed Capacity 3	US $/MW	‘Exploration Development Cost 3’+’Exploitation Development Cost 3’+’Downstream Cost 3′
Electricity Price 1	US $/kWh	0.0753
Electricity Price 2	US $/kWh	0.0886
Electricity Price 3	US $/kWh	IF(‘Off-taker Intention to Buy’ = 1,’BPP - Base Electricity Price’,85%*’BPP - Base Electricity Price’)
Electricity Production 1	kWh	‘Installed Capacity 1’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>

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Table A3 (*continued*)

Variable	Unit	Formula/Value (variable value “0” indicates an initial value)
Electricity Production 2	kWh	‘Installed Capacity 2’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Electricity Production 3	kWh	‘Installed Capacity 3’*’Operating Hours per Year’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Electricity Tax 1	%	34
Electricity Tax 2	%	34
Electricity Tax 3	%	2.5
EPCC Cost 1	US$	‘Downstream Cost 1’*’Developed Capacity 1′
EPCC Cost 2	US$	‘Downstream Cost 2’*’Developed Capacity 2′
EPCC Cost 3	US$	‘Downstream Cost 3’*’Developed Capacity 3′
Exploitation Cost 1	US$	‘Exploitation Development Cost 1’*’Potential Developed Capacity 1′
Exploitation Cost 2	US$	‘Exploitation Development Cost 2’*’Potential Developed Capacity 2′
Exploitation Cost 3	US$	‘Exploitation Development Cost 3’*’Potential Developed Capacity 3′
Exploration Cost 1	US$	‘Exploration Development Cost 1’*’Potential Explored Capacity 1′
Exploration Cost 2	US$	‘Exploration Development Cost 2’*’Potential Explored Capacity 2′
Exploration Cost 3	US$	‘Exploration Development Cost 3’*’Potential Explored Capacity 3′
Fund Adequacy for Financing Project 1		IF(‘Available Fund for Financing Project 1’<’Initial O&M Cost’,0,1)
Fund Adequacy for Financing Project 2		IF(‘Available Fund for Financing Project 2’<(‘Initial O&M Cost’+’Total Cost for Project 1′),0,1)
Fund Adequacy for Financing New Projects		IF(‘Available Fund for Financing New Projects’<(‘Initial O&M Cost’+’Total Cost for Project 1’+’Total Cost for Project 2′),0,1)
Initial Electricity Production	kWh	‘Operating Hours per Year’*’Initial Installed Capacity’*’Capacity Factor’*1000<<1/MW>>*1<<kWh>>
Initial Installed Capacity	MW	1948.5
Initial O&M Cost	US$	‘O&M Cost per kWh’*’Initial Electricity Production’
Installed Capacity 1	MW	0
Installed Capacity 2	MW	0
Installed Capacity 3	MW	0
Investment Attractiveness		Profit/’Total Revenue’
Investment Gap	US$	‘Total Available Fund for Financing Projects’-’Investment Needed to Fill Capacity Gap’
Investment Needed to Fill Capacity Gap	US$	‘Capacity Gap’*’Cost per Developed Capacity 3′
IPPs Equity	US$	IF(Profit>0<<USD>>,’Base Equity’+(‘Allocated Profit to IPPs Equity’*Profit))
O&M Cost 1	US$	‘O&M Cost per kWh’*’Electricity Production 1′
O&M Cost 2	US$	‘O&M Cost per kWh’*’Electricity Production 2′
O&M Cost 3	US$	‘O&M Cost per kWh’*’Electricity Production 3′
Off-taker Intention to Buy		1
Operating Hours per Year	1/yr	365*24
Profit	US$	‘Total Revenue’-’Total Investment Needed’
Revenue from Initial Installed Capacity	US$	(‘Initial Electricity Production’*’Electricity Price 1′)*(1-’Electricity Tax 1′)
Revenue from Installed Capacity 1–2	US$	(‘Electricity Price 2’*(‘Electricity Production 1’+’Electricity Production 2′))*(1-’Electricity Tax 2′)
Revenue from Installed Capacity 3	US$	(‘Electricity Price 3’*’Electricity Production 3′)*(1-’Electricity Tax 3′)
Soft Loan	US$	200000000
Total Available Fund for Financing Projects	US$	IF(‘Investment Attractiveness’≥0.10,((‘IPPs Equity’)+’Commercial Loan’+’Soft Loan’),’IPPs Equity’)
Total Cost for Project 1	US$	‘Exploration Cost 1’+’Exploitation Cost 1’+’EPCC Cost 1’+’O&M Cost 1′
Total Cost for Project 2	US$	‘Exploration Cost 2’+’Exploitation Cost 2’+’EPCC Cost 2’+’O&M Cost 2′
Total Electricity Production	US$	‘Initial Electricity Production’+’Electricity Production 1’+’Electricity Production 2’+’Electricity Production 3′
Total EPCC Cost	US$	‘EPCC Cost 1’+’EPCC Cost 2’+’EPCC Cost 3′
Total Exploitation Cost	US$	‘Exploitation Cost 1’+’Exploitation Cost 2’+’Exploitation Cost 3′
Total Exploration Cost	US$	‘Exploration Cost 1’+’Exploration Cost 2’+’Exploration Cost 3′
Total Investment Needed	US$	(‘Total Exploration Cost’+’Total Exploitation Cost’+’Total EPCC Cost’+’Total O&M Cost’)
Total O&M Cost	US$	‘Initial O&M Cost’+’O&M Cost 1’+’O&M Cost 2’+’O&M Cost 3′
Total Revenue	US$	‘Revenue from Initial Installed Capacity’+’Revenue from Installed Capacity 1–2’+’Revenue from Installed Capacity 3′

Part III. Model Testing Results

1. Dimension Analysis

The dimension analysis checks whether each variable in the model has a correct unit and all units correspond to reality (Sterman, 2000). It was done by checking any errors regarding units and the links between model variables through the Powersim Studio. As seen in Table A1, A2, and A3 of this appendix, the dimension analysis results show that all variables and their units had been coded correctly and consistently correspond to reality with no error notifications in the Powersim Studio.

2. Integration Error Test

The integration error test checks whether the simulation results are robust under different numerical solvers or time steps. As such, numerical errors may surface when a reduction of simulation time step significantly changes the model’s outputs behavior (Sterman, 2000). By changing the time step to half and one-fourth of its reference value one year, the simulation results showed no significant differences in the model’s outputs behavior with an average margin error detected at ±1.02%. This margin error is considered very low and acceptable in system dynamics standard tests (Sterman, 2000). Fig. A1. displays the results of the integration error test on *Total Installed Capacity* for different time steps: 1 year, 0.5 years, and 0.25 years.

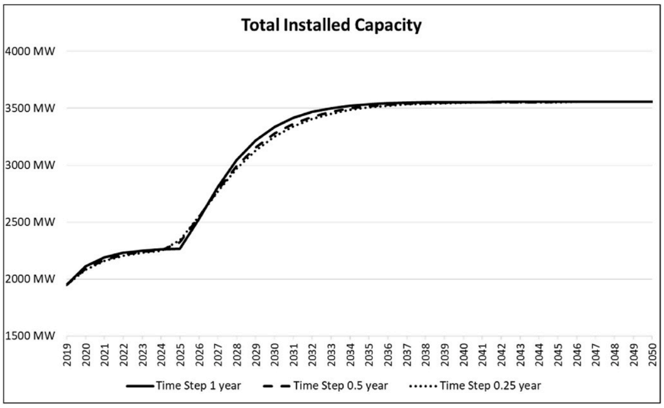

Fig. A1. The integration error test result

3. *Extreme Condition Test*

The extreme condition test was performed to ensure that the simulation results do not show irrational behavior (Sterman, 2000). A zero extreme test was conducted by setting some parameter values to zero (*Exploration Drilling Success Ratio* and *Exploitation Drilling Success Ratio*) and observed the effect to the related variables (*Total Installed Capacity* and *Capacity Gap*). If all variable relations are rational, then there will be no additional potential developed capacity to be exploited further into developed capacity. As a result, the installed capacity and capacity gap will stagnate and remain similar to their initial values. The simulation results from this test showed rational behaviors as displayed in Fig. A2; the *Total Installed Capacity* and *Capacity Gap* stay the same as their initial values; there is no additional installed capacity and the capacity gap remains unchanged.

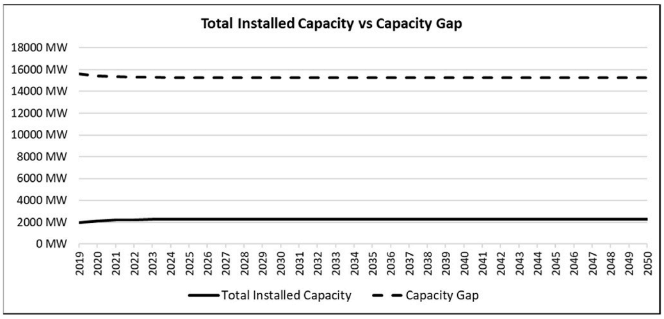

Fig. A2. The zero extreme test result

4. *Behavior Analysis*

The behavior analysis checks whether the simulation results confirm the dynamic hypothesis of the problem (Sterman, 2000). Two variables were observed for this purpose: *Total Installed Capacity* and *Capacity Gap*. The dynamic hypothesis was straightforward, that is, the more installed capacity, the less capacity gap. The simulation results on *Total Installed Capacity* and *Capacity Gap,* as shown in Fig. A3, confirmed the dynamic hypothesis. As the total installed capacity starts to increase in 2024, the capacity gap starts to decline. Further, another dynamic hypothesis was if the installed capacity target remains unchanged, then the stagnancy in the total installed capacity will lead to stagnancy in the capacity gap. As shown in Fig. A3, when the total installed capacity starts to stagnant in 2033, so does the capacity gap, confirming the latter hypothesis.

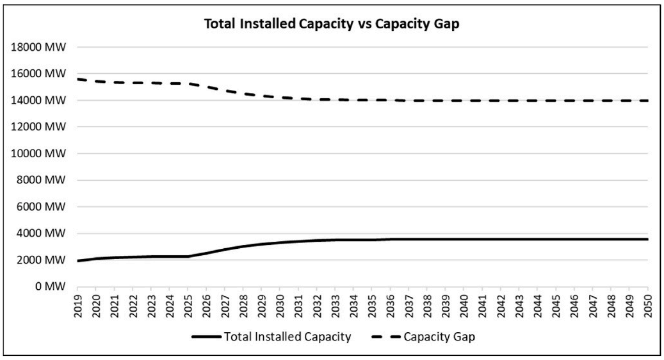

Fig. A3. Total installed capacity vs. capacity gap under business-as-usual

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