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Research article

Investment decisions under uncertainties in geothermal power generation

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Abstract: Geothermal energy is one of the strategies employed by the Indonesian government to meet rising electricity demand. Developing geothermal energy is often characterized by uncertainties and requires sequential decision-making which is divided into four development phases: 1) identification, 2) exploration, 3) exploitation, and 4) engineering, procurement, construction, and commissioning (EPPC) before it can be commercialized. Traditional valuation techniques often produce a negative net present value (NPV), suggesting decision to reject the project's investment plan. This paper investigates the economic viability of a geothermal power generation project using both NPV and real options analysis (ROA). Costs and uncertainties associated with the various development phases as well as the investment structure of geothermal projects are studied. We develop a framework for assessing the impact of four uncertainties using a binomial lattice: capacity factor, electricity price, make-up well-drilling costs, and operation and maintenance (O&M) costs. Secondary data from an Indonesian context geothermal power plant was used. Positive option values were found for the lattice approach compared to negative values found for the common NPV calculation. The result of this study showed the successful outcome of the exploration stage is very critical to determining the continuation of the project. The framework supports decision-makers in evaluating the impact of geothermal power generation projects in the face of uncertainty by providing a rigorous analysis. The movement of the underlying asset's value in the whole project's lifetime will assist the management in deciding on whether to exit or continue.

Keywords: uncertainty; real options analysis; geothermal project investments; geothermal power plant; NPV

Abbreviations: ASEAN: Association of Southeast Asian Nations; ASEAN: Association of Southeast Asian Nations; DCF: Discounted Cash Flow; NDC: Nationally Determined Contribution; NPV: Net present value; O&M: Operation and maintenance; ROA: Real options analysis; PMK: Peraturan Menteri Keuangan or Minister of Finance Regulation

1. Introduction

Stimulated economic development, increasing urbanization, and population growth account for 40% of Indonesia's total energy use in the Association of Southeast Asian Nations (ASEAN). As a result, Indonesia is the ASEAN member state with the most significant energy use [1]. Indonesia's power consumption is also anticipated to increase at a 6.86% annual pace until 2028 due to economic growth and demographic drivers [2].

Indonesia has been producing its energy needs mostly with fossil fuels; in 2018, oil, coal, and gas contributed 38.81%, 32.97%, and 19.67% of the country's energy, respectively [3]. Indonesia has committed to reducing greenhouse gas emissions by 29% in 2030 [4] and renewable energy is one of the country's strategies to meet that commitment. Indonesia aims to generate at least 31% of its primary energy needs from renewable energy by 2050 [5].

According to the 2019–2028 Electricity Supply Business Plan (Rencana Umum Penyediaan Tenaga Listrik, or RUPTL), geothermal energy accounts for the largest percentage of Indonesia's electricity production, at 9.63%. However, developing geothermal energy in the country is tricky, as proven by its underutilization despite having the biggest reserve in the world at 28.91 Gigawatt (GW) [6]. Indonesia's geothermal development also faces many challenges: technical, financial, and political challenges [7]. Technical issues are exacerbated by a dearth of high-quality, accessible, and country-wide data.

The investment cost of geothermal power plants is divided into the cost of surface equipment and activities and the cost of subsurface investment [8]. The high cost of geothermal development during the exploration and construction stage and the risk caused by the high possibility of unsuccessful drilling are the financial challenges for geothermal development in Indonesia. These risks make geothermal projects a less attractive investment.

The Power Purchase Agreement between geothermal energy developers and the State Electricity Company (PLN) sets an agreement on pricing and capacity before the exploration activity is performed. However, in reality, the resources available may be fewer than those expected during the tender phase due to the inherent uncertainty and risk of its undertaking. Many times, it contributes to the projects getting stalled or delayed. Such a situation adds more risks for investors financing the project. Current options available for developers are either the ad-hoc negotiation with PLN, or drilling more wells, both of which are high in costs and may delay the project [9].

However, little attention is still given to the approach to uncertainty analysis in most of the existing geothermal projects in Indonesia, especially in production well drilling. Unfortunately, such activity is surrounded by many uncertain factors. Therefore, paying more attention to the techniques to treat uncertainty in the geothermal production well drilling is essential to prevent the adverse effect on the continuity of geothermal project investment.

Regarding the concern above, this paper aims to analyze the uncertainty in geothermal project investments using ROA with specific emphasis on four different sources of uncertainty. That is, to value the option that may be taken by the company, whether or not the project is economically feasible from the uncertain output of the production well drilling.

2. Literature review

2.1. Uncertainty and risk in geothermal project

Geothermal development is a high-risk business, involving capital-intensive physical assets as well as long cycle times [10–12]. There are many complex uncertainties related to the development of geothermal energy, such as subsurface uncertainties [13], policy and regulatory instability as well as market uncertainties [7,14,15]. These uncertainties have led geothermal investment to the riskiest end of the investment spectrum [16].

Table 1. Summary of typical project aspects, uncertainties, and risks.

Stage	Example of activities	Example of uncertainties	Example of risks
Exploration	Reconnaissance survey Access road and drill pad Construction Drilling and testing exploratory wells Appraising the result	The existence of a heat source Existence of a hydrological system Its characteristics (i.e., Flow direction) geological structures (fracture and fault) Area extent of the prospect Permitting period: Social acceptance	Reconnaissance Survey cost Drilling cost Probability of success
Exploitation	Additional civil work Drilling production and reinjection wells Construction and commissioning Power plant	Temperature Pressure Producible area Porosity Permeability Size of plant Dissolved solids	Production cost Drilling costs Facilities costs

Source: Authors' compilation from [18] and [11].

In general, the execution of a typical geothermal development project is divided into two major parts: (a) exploration and (b) exploitation, which involve the construction of power plants prior to the project entering the commercialization stage [17,18]. Through two primary activities: resource exploration and resource assessment, the exploration stage is designed to confirm resource discoveries in terms of well sizing, well productivity characteristics, and reservoir fluid characteristics [12]. Although this stage involves relatively low-cost investments of approximately 15 to 20% of the total cost of the project [17,18], it is considered to have the highest level of uncertainty due to the lack of direct information from the subsurface [19,20]. Most importantly, it also serves as a decision gate for whether or not to proceed with future development based on viability verification at this stage [11]. Once the resource is classified as unfeasible, the associated costs might ultimately be unrecoverable [21].

After confirmation of a favorable result, development proceeds to the exploitation stage. Drilling at this stage is intended to provide sufficient steam to run the plant as well as additional wells for reinjection purposes [12]. The project costs increase during the well drilling stage of field development as well as during the plant's construction; nevertheless, the uncertainties decrease noticeably [18]. Although the level of uncertainty has decreased, the project remains inherently uncertain [22], which may result in a lower probability of successful drilling. These uncertainties may cause project delays and/or over budget, resulting in a loss of revenue or opportunity for the company. The potential threat of loss or option in investment is defined as risk.

2.2. Investment valuation

To appraise an investment value, the Discounted Cash Flow (DCF) method, as a traditional quantitative valuation tool, is the most widely used. If the NPV of its future cash flows is positive, an investment should be funded as it will create more value than it will cost [23]. However, this method is prone to assumptions on capital expenditure projections, operating expenditure projections, growth rate, and discount rate. It assumes at the outset that all future outcomes are fixed. Thus, companies tend to underestimate the value of their projects and exercise extreme caution when investing in uncertain but highly promising opportunities. In the real-world, changes in the business environment, as well as the limitation of accurate information, can be the source of uncertainty for any project [24,25]. As a result, investors need flexibility which allows them to immediately invest or delay the decision until a less risky and more profitable period of investing is available [26].

However, the ROA method has already captured those uncertainties [27] through probability and volatility metrics. ROA is based on the premise that investments under uncertainty should be decided with option pricing than the DCF method [28]. Management flexibility and volatility of project returns are considered in contrast to the traditional DCF, which involves deterministic assumptions of returns [29].

Kogut and Kulatilaka [30]defined real options as “an investment decision characterized by uncertainty, the provision of future managerial discretion to exercise at the appropriate time, and irreversibility”. In [31], a real option was defined as “the right, but not the obligation, to execute an action (e.g., deferring, expanding, contracting, or abandoning) at a predetermined cost, known as the exercise price, for a predetermined period of time—the option's life”. According to the definition, company has the opportunity to take action through investment, with the time option to spend the money. It could be now or in the future, in exchange for a valuable asset. The company would invest if the option has a positive net payoff. Otherwise, the firm would not invest if the option has a negative net payoff. The true value of options arises from technical flexibilities and market opportunities. The greater the uncertainty, the higher the value of project flexibility. The traditional NPV is then used as the underlying asset value in an option valuation model.

2.3. Valuation of renewable energy investment

The real options method has been widely applied to various aspects to account for uncertainty and irreversibility, such as natural resources, competition, business strategy, production, real estate, research and development, public good, mergers and acquisitions, corporate governance, interest rates, inventory, labor, venture capital, advertising, legal, hysteretic effect, and corporate behavior, as well as environmental development and protection [32]. ROA has recently been more frequently applied in renewable energy investment decisions [33–38], hydropower [39], wind energy [34,40], and solar energy have all employed it [41–43]. The application of real options to geothermal energy investment value is still limited to date.

Sakakibara & Kanamura [44] studied the uncertain impact of temperature differences between production and injection wells on the maintenance cost of geothermal power generation techniques using real options valuation. Their findings showed that the uncertainty of the maintenance cost and the uncertainty of the selling price of the electricity generated must be taken into consideration to properly value the project. Siyuan et al. [45] studied investment strategies for shallow geothermal resources using uncertainty in marginal revenues that are linked to prices. Yu et al. [46] considered carbon trading prices and resource taxes as uncertainties and applied two real options: deferral and abandonment, simultaneously. They concluded that delaying the project would result in a higher project value, that different subsidy methods would affect the project value and investment time, that using carbon trading would enhance the project value, and that adopting a resource tax would decrease the project value. Bilqist & Dachyar [47] investigated the project value using an NPV and real options valuation approach with uncertainties in the discount rate, production volume, and O&M costs. Knaut et al. [48] compared the project value from NPV to that from the evaluation of the real options with temperature uncertainty based on the data collected in The Hague, the Netherlands. Their results show that negative project values are obtained from the NPV, whereas positive project values are obtained from the real options analysis.

In addition to providing more insight into investment decisions in geothermal projects, an additional uncertain factor resulting from the volatility of make-up well drilling costs was investigated. Allen as cited on Nugraha et al [49] assumes that the success ratio of make-up well drilling is 100%. It will correlate to the cost of it since we have learned during development drilling that the cost of it will certainly be controlled. However, make-up well is sometimes found in a new cluster, which may result in a different response. It has a significant influence on the financial model and the power bill [50–52]. Therefore, this should be taken into consideration when evaluating geothermal energy projects in terms of the major risks associated with these projects.

3. Methodology

The development of geothermal energy is characterized by uncertainties influenced by costs during the development stages, either the exploration or exploitation phase. Sanyal [52] stated that geothermal power costs consist of three components: capital cost, O&M cost, and make-up drilling cost. Those factors which may have a significant influence on the project's economic feasibility have to be considered. Before making a major decision, all factors need to be carefully evaluated. A framework, as shown in Figure 1, is used to assist in the valuation process. It has three steps, as described in detail in the following sections.

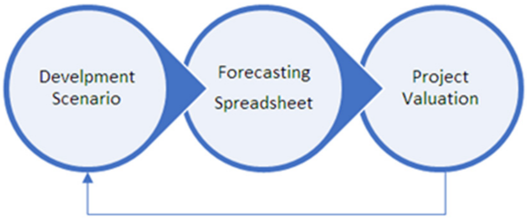


Figure 1. Framework for project valuation.

3.1. Scenario development

Here, a common approach to breaking down the investment process is to divide it into identification, exploration, exploitation, EPCC, and production. Cost estimates and duration to complete each phase can be divided as follow (see Table 2).

Table 2. Geothermal development phase.

	Identification	Exploration	Exploitation	EPCC
Activities	Geoscientific survey, Geotechnical study, environmental study, temperature gradient well, conceptual model, resource estimation, pre-feasibility study	Exploration infrastructure construction, 2–3 wells drilling, well logging, well testing, refining conceptual model, determination of well productivity for production, design for development well, forecast of reservoir performance, project budget and revenue projection, ESIA Assessment,	Infrastructure construction, development drilling, well logging, well testing, update conceptual model, update reservoir model	Engineering, Procurement, Construction, and Commissioning
Duration Estimation	1 year	1–2 years	2–3 years	2–3 years
Cost Estimation (US$/MW)	30.000–90.000	1.5–2 million	1.1–2.7 million	1.4–3 million
	20.000–80.000	0.32–0.8 million	0.9–2 million	1.5–2.5 million

Source: Author's Compilation from [11,18,53].

Based on information in Table 1, the sequential of investment is depicted in Figure 2.

The result of the identification phase affected the decision to continue to the exploration phase and determined whether the next step would be taken or the project abandoned. Likewise, the result of the exploration phase affected the decision to invest some funds in the exploitation phase. A similar process also applies to EPCC and the operation phase.

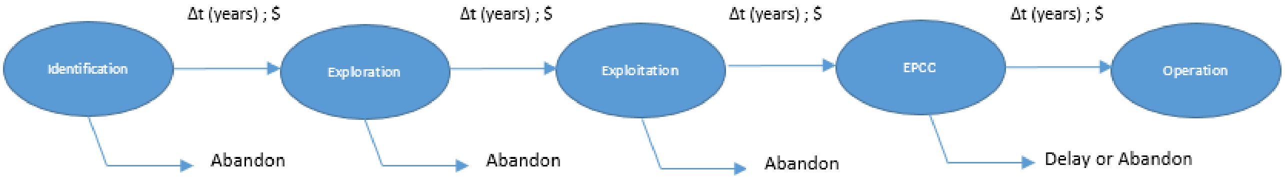


Figure 2. Investment sequential.

3.2. Forecasting spreadsheet

To determine the volatility of the projects, the uncertainties that affect the valuation of projects (capacity factor, electricity price, make-up well drilling cost, O&M cost) are defined in three scenarios, namely: worst, moderate and best. The tariff and the capacity factor are specified by the power purchasing agreements. However, under the current PMK, the tariff will be based on B-to-B negotiation with the sole off-taker. Meanwhile, the capacity factor fluctuates since the off-taker most of the time absorbs the production as much as the minimum allowable threshold. O&M cost is affected by the inflation as well by the maintenance programs which are implemented to sustain the operation. Drilling cost is a function of rig rate and drilling time. To better control the risk associated with the drilling cost, it is also selected as a key variable. The values of the four variables for each of the three scenarios are shown in Table 3: moderate, best, and worst.

Table 3. Three scenarios for project valuation.

Variables	Worst	Moderate	Best
Capacity factor	90%	95%	100%
Decline rate	6%	4%	3%
Electricity price	0.0753	0.118	0.2027
Make up well drilling	8,000,000	7,000,000	5,000,000
O&M cost	70,0000	60,0000	50,0000

Source: Author's compilation from [18,53].

To estimate the current value of the underlying asset of a 55 MW geothermal power generation project with parameters attached in Attachment 1, the cash flow generated under a moderate scenario is used as the basis. The value of a project can be defined as an NPV of a net cash flow over a project's life. It is calculated using the DCF method based on cash flow expectations formula Eq (1) using the below formula:

$$\mathrm{NPV} = \frac{\mathrm{Rt}}{(1+\mathrm{i})^{\mathrm{t}}} \tag{1}$$

where:

- NPV is the net present value
- Rt is net cash flow at time t
- i is the discount rate
- t is the time of the cash flow

3.3. Real options valuation

A three-point estimation technique of values for each of the variables in each of best, worst, and most-likely) is adopted to estimate the volatility of a project's value with the assumption that the project follows a lognormal distribution. Kim & Lee (2012) have defined the formula to estimate the volatility as follows:

$$\sigma = \frac{ln\left(\frac{S_{best}}{S_{worst}}\right)}{4\sqrt{t}} \tag{2}$$

The binomial lattice forecasts the evolution of the project value. Up (u) and down (d) factors are functions of the time increment and project value volatility can be estimated by:

$$u = e\sigma\sqrt{\Delta t} \tag{3}$$

$$d = {}^{1}/_{u} \tag{4}$$

risk-neutral probability (q), and option value (C) are estimated using the following equations:

$$q = \frac{e^{rt} - d}{u - d} \tag{5}$$

$$C = e^{rt} [\, q\, C_u + (1 - q)\, C_d] \tag{6}$$

where:

- S_{best} is the underlying asset value under the best scenario;
- S_{worst} is the underlying asset value under the worst scenario;
- t is the project period;
- r is the risk free interest rate;
- C_u and C_d are the option values associated with up and down respectively.

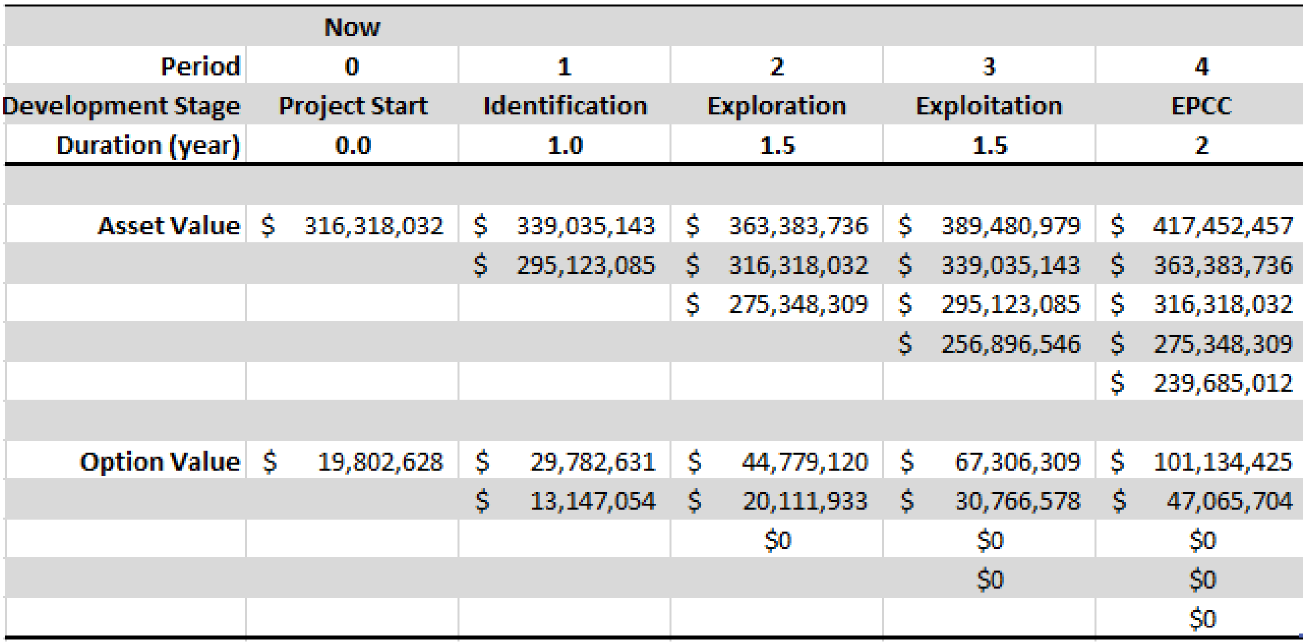
4. Results and discussion

A total expenditure of US$250,348,400 is required to develop a 55 MW geothermal power project, including US$3,200,000 for the identification phase, US$21,400,000 for the exploration phase, US$79,578,400 for the exploitation phase, and US$146,170,000 for the EPCC phase. Using Eq (1) and the parameter presented in Attachment 1, the project's current value was US$-9,078,073, US$65,969,632, and US$198,306,331 under the worst, moderate, and best scenarios, respectively.

Analyzing the above findings, when the NPV is negative, the decision-maker is more likely to reject the proposal. This is logical, given that the NPV criterion rule is a take-it-or-leave-it proposition. The negative value shows that the project devalues the firm's stakeholders. However, this decision is rather biased since it is based only on the information available at the time the NPV is estimated [54]. A binomial lattice was employed to determine the opportunities' flexibility. The primary estimated NPV under a moderate scenario served as a starting point and was then projected into the future by up and down factors. The final value of the option will be determined by the rol1-back algorithm.

The volatility of the project return was estimated at 2.83% using Eq (2) to compare the underlying asset value in the best and worst-case scenarios by using Eq (2). The estimated values for the up movement (u), down movement (d), and risk-neutral probability (q) are 1.0718, 0.9329, and 0.9626 respectively. By applying Eq (6), the option value of the project was estimated to be US$19,802,628.

The value of the project option was then calculated accordingly by the lattice method, as shown below:



	Now				
Period	**0**	**1**	**2**	**3**	**4**
Development Stage	**Project Start**	**Identification**	**Exploration**	**Exploitation**	**EPCC**
Duration (year)	**0.0**	**1.0**	**1.5**	**1.5**	**2**
Asset Value	$ 316,318,032	$ 339,035,143	$ 363,383,736	$ 389,480,979	$ 417,452,457
		$ 295,123,085	$ 316,318,032	$ 339,035,143	$ 363,383,736
			$ 275,348,309	$ 295,123,085	$ 316,318,032
				$ 256,896,546	$ 275,348,309
					$ 239,685,012
Option Value	$ 19,802,628	$ 29,782,631	$ 44,779,120	$ 67,306,309	$ 101,134,425
		$ 13,147,054	$ 20,111,933	$ 30,766,578	$ 47,065,704
			$0	$0	$0
				$0	$0
					$0

Figure 3. Binomial lattice for asset value and option value.

The binomial lattice method shown in Figure 3 was used to determine the underlying asset and option values at each phase. As a starting point, investing US$3,200,000 to identify the prospect generates an option value of US$19,802,628. These figures show that the project is likely to proceed to the exploration phase. Value on each node in the underlying asset lattice was generated by multiplication of underlying asset at year 0 (US$316,3 million) with upside factor (u) and downside factor (d). The asset value figure shows the evolution of underlying asset value from year 0 until year 6 which is primarily driven by uncertainty (σ). During exploration, in the ideal situation and less favorable situation, the project's option value would still be higher compared to the investment cost. In this situation, the project will proceed to the next level, which is the exploitation phase. However, if uncertainty persists, the corporation may take action to gather more data to resolve the uncertainties before moving forward or even decline to continue further like in the case of failed well drilling which will impact to a less targeteded capacity. Similarly, for the next phases. If the project uncertainty is clear, the project will continue. If the project becomes unfeasible, the company could decline to invest further from the exploitation to the EPCC phase.

A greater value to the company and more flexibility to the management which is given in this case study will assist management to take a decision not to exit or continue in the early stage and continue until the construction EPCC phase. It gives crystal clear guidance for the management to find the best decisions given the movement of underlying asset's value in the whole project's lifetime. This advantage is what the traditional DFC model doesn't have.

5. Conclusions

The business environment is a highly mobile reality. Uncertainty and risk abound when decisions have to be made. Most of the time, decision-makers need to make and change decisions when new information becomes available. Using a deterministic tool such as DCF may result in an underestimation of the value of a particular project. ROA as an alternative technique for evaluating a project can accommodate inherent project choices. It will not boost the value of the project. It only increases the value of flexibility within projects. As a result, applying ROA to valuation can change decision-makers toward strategy, as opposed to using traditional DCF methods, which tend to avoid uncertainty.

Taking investment in stages allows decision-makers to decide whether to enter the market fully to capture economies of scale or to delay or abandon the project. The option to delay valuation is available in the case of assets that are not viable today but could be in the future. The abandon option allows decision-makers to exit when exploration or exploitation phases yield poor results or when market uncertainty persists. In a high uncertainty environment, it is important to possess the flexibility to maximize profits in favorable situations and minimize losses in adverse scenarios.

This paper has enriched the literature on the use of the real options valuation technique to appraise investment in geothermal projects. In particular, by focusing the investigation on four types of uncertainties, namely the capacity factor, the electricity price, make-up well drilling costs, and O&M costs. By doing so, this paper has captured the highly mobile reality of developing geothermal which is still lacking previously.

This paper has shown how ROA can provide alternative insights on how a geothermal power generation project should proceed. Using the DCF method solely might lead to a wrong decision. Additionally, it assists the company in mapping their optimal scenarios and identifying the primary sources of flexibility in a specific project, thereby improving the project's outcome by implementing the appropriate strategy. It provides a complete figure of strategy for the whole lifetime of a geothermal project. In this case, the decision not to exit or continue in the early stage and continue until the construction EPCC phase will be advantageous. However, it would be much better if exploratory modeling could be integrated with the analysis of uncertainties across a wide set of future scenarios.

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Conflict of interest

All authors declare no conflict of interest in this paper.

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