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Evidence on optimal risk allocation models for Indonesian geothermal projects under PPP contracts

Suardi Nur [a], Bruce Burton [b,*], Ariel Bergmann [c,1]

[a] Department of Environmental Engineering and Net Zero Carbon (NZC) Research Center, Universitas Islam Negeri Al-raniry, Banda Aceh, Indonesia
[b] School of Business, University of Dundee, United Kingdom
[c] Centre for Energy, Petroleum, Mineral Law and Policy, University of Dundee, United Kingdom

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ABSTRACT

This study explores risk allocation in Indonesia's public-private partnerships for geothermal energy development. Such activity involves significant upfront investment, but no definitive and transparent risk-sharing mechanisms that suitably incentivise the private sector have emerged in the literature. In the study, we develop an evidence-based framework founded on principal-agency theorising that suggests an optimal allocation of risk between the public and private parties in these arrangements. A Delphi survey is employed to identify the views of a group of experts, with the evidence pointing to a clear pattern in identifying high-risk factors and optimal risk-sharing arrangements. Suggested risk-bearing levels for the Indonesian government range between 100% (for legal and regulatory exposures) to 0% in an operational and maintenance risk context. Risks relating to resource and exploration, finance and credit, as well as field development and construction issues, are viewed as being optimally shared between the parties, with the expert panel suggesting that the public sector should retain more exposure where high criticality risk factors exist. The proposed risk allocations reflect both evidenced outcomes and prior contention regarding the risks around geothermal investments and thereby provide the potential for developing meaningful schematics that enable Indonesia to exploit the resources concerned more fully.

1. Introduction

1.1. Research problem and context

This study explores the issue of risk allocation in Public-Private Partnerships (PPPs) in Indonesia's geothermal sector. On the basis of a Delphi study of expert opinions we first demonstrate that a series of significant risks are perceived to exist in this context, before drawing on the same body of opinions to explore optimal risk sharing arrangements between state and private actors. Indonesia has an estimated 23,966 MWe of geothermal resources (Directorate General for New and Renewable Energy and Energy Conservation, 2020) with Fauzi (2015) suggesting that two-thirds of such potential is in resources with temperatures greater than 190 °C. However, by 2019 use of these resources was well below its potential, with only 2108.5 MW (or 8.8%) of Indonesia's geothermal resources utilized to generate electricity (Nur et al., 2022).[2] The International Energy Agency define geothermal resources as the energy available in the form of heat contained within the earth's crust (accesible via regional heat flow or local magmatic intrusions) that can be exploited to generate electricity and other direct use applications such as district and water heating as well as agricultural and industrial processes (Rybach, 1981; International Energy Agency, 2010). The energy is stored in hot permeable large rock (the reservoir), typically capped by impermeable rock and connected to a surficial recharge area through hot springs or manufactured boreholes to form a recognizable geothermal system (Dickson and Fanelli, 2004).

In the 2014 National Energy Plan, the Indonesian Government announced that it was prioritizing geothermal energy to ensure that renewables contribute at least 23% of primary energy supply by 2025, with PPPs a critical element in the proposed route forward (IRENA, 2017). In terms of installed capacity, the government's target was 6000 MW by the year 2020 but this proved to be challenging from an early stage (Asian Devolopment Bank, 2015). Such difficulties are consistent with emerging evidence of a more general governmental inability to

* Corresponding author.
E-mail address: b.m.burton@dundee.ac.uk (B. Burton).

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[2] Although this represents the second largest global figure for installed capacity, behind only the United States (3700 MW).

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support energy generation via tax policies and financial incentives (Nugraha et al., 2017). GeothermEx (2010) argue that the main barrier to growth in geothermal projects is the high level of risk associated with such projects; in the absence of clear and transparent risk-sharing mechanisms, developers typically bear a disproportionately higher share of risk than with other investments (Castlerock, 2010; International Finance Corporation, 2013). Consistent with these contentions, JICA (2009) suggest that the two main barriers for geothermal development in Indonesia are: (i) the risk of underground resource exploration; and (ii) the burden of up-front investment.

Risk identification and analysis are essential in PPP contracts, as optimal risk allocation and efficient incentive mechanisms can be crucial to the success of these arrangements (de Bettignies and Ross, 2004; Jin, 2009). Therefore, while the process notionally requires a Pareto-optimal analysis of risk allocation and incentives (Maszoro, 2010) - as PPPs in practice are usually structured on an incomplete contract basis - the design of efficient incentive mechanisms can prove challenging as moral hazard and asymmetric information in the principal-agent relationship are often deeply embedded (Jin, 2009; Hart, 2017). In the type of principal-agent relationship underpinning PPPs - where the government is the principal and private firms are the agents - interests are likely to be incongruent (Jin, 2009). As all parties are assumed to focus on their own welfare, the government's focus is typically characterized as maximizing social benefits - in this case the provision of power for Indonesians - whereas the firms' priorities are to maximize owners' wealth. These issues underpin the conceptual framework employed in this study, with an optimal risk-sharing mechanism required where the Indonesian government retains enough of the risk involved in geothermal projects to properly incentivise the (profit-driven but risk averse) private sector.

Despite the drilling of 300 deep wells in the country by 2010, and 711 by 2018 (GeothermEx, 2010; Purwanto, 2018) the failure to disclose key information regarding geothermal project activity means that independent discussion and analysis of risk exposures in Indonesia has been rare (Asian Devolopment Bank, 2015). This gap in transparency is potentially significant given that exploration risk in Indonesia has been characterized as non-trivial in both green-field and newly-developed geothermal schemes (Robertson-Tait et al., 2015). To accelerate geothermal development in Indonesia, detailed analysis of an optimal framework for risk allocation between government and project developers is required (Hasan, 2013). In practice however, the process is a complex, multi-layered exercise with regulatory, contractual and financial aspects all requiring consideration (Klein, 1997). In this context, PPP arrangements are now often employed in infrastructure projects to ensure a balance in exposures across public and private sectors that underpins appropriate incentivisation (Klijn and Teisman, 2003). Incentivisation is vital in the Indonesian PPP context, as one of the essential issues in executing most PPP projects is a lack of practical viability (Surachman et al., 2022). Critically, governments can reduce the risk borne by the private sector via the provision of subsidies, guarantees and capital contributions (Klein, 1997) to ensure private sector participation in PPPs where the public sector retains bargaining power - i.e. a *participation constraint* (Laffont and Martimot, 2001).

Despite the increasing use of PPPs globally, their potential role in addressing energy needs in developing nations has not been investigated in detail with, as a result, some critical risk-sharing issues not explored. These gaps in transparency and understanding in the Indonesian context provide the motivation for this study's attempt to develop a framework for the optimal allocation of risk between public and private parties in PPP arrangements that might help the nation more fully exploit its geothermal resources.

1.2. PPPs and risk sharing

The theory of risk sharing and incentives in the context of principal-agent relationships, as proposed by Stiglitz (1974), Shavell (1979), Sappington (1991) and others, builds on the theory of the firm suggested by Coase (1937). According to Stiglitz (1974), the availability of incentive schemes can encourage the agent to bear a greater share of risk than would otherwise be the case. Sappington (1991) develops this argument by contending that, while incentives can be used to motivate the agent to perform in the principal's interest, to achieve the best possible outcome the principals need to establish incentives that are Pareto optimal according to the level of risk borne, irrespective of whether agents are risk-neutral or risk-averse (Sappington, 1991). Several studies have investigated the association between optimal risk allocation and incentives for infrastructure projects employing PPP frameworks (Hodge, 2004; Medda, 2007; Brandao and Saraiva, 2008). While the evidence suggests that PPP schemes are often used primarily to transfer some of the risk associated with the public provision of projects to the private sector, the extent to which they do this successfully is highly contingent on the nature of the project involved (Wibowo, 2006; Alonso-Conde et al., 2007). Given that the use of PPPs in modern geothermal projects has not been explored in great detail, the potential benefits that may flow from the Indonesian government's decision to encourage such activity require proper investigation and the current study attempts to address this need. The results should also contribute to ongoing debates about optimal risk sharing and incentives in PPP contracts.

The private sector has participated in financing infrastructure services across the world via a wide range of partnership forms (Broadbent et al., 2003). Private sector motivation to become involved in the provision of essential public infrastructures is driven by the profit offered in the PPP contract (Beecher, 2021). This potential profit is highlighted upfront in the bidding proposal in the form of the net present value or value for money of the project(s) concerned (Marques, 2021). On the other hand, public sector desire for cooperation with private firms reflects governmental need to reduce financial burdens while enhancing efficiency levels around large-scale infrastructure projects (Kang et al., 2012). Coincidence in these stimuli has led to recent growth in the use of the PPP model in various infrastructure-based procurement projects worldwide (Marques, 2021).

The term "PPP" has been used frequently since the 1990s (Gangwar and Raghuram, 2014),[3] with most definitions emphasizing a long-term contract between the private and public sectors intended to deliver public assets/services where both parties share the risk and responsibility (Roehrich et al., 2014). PPPs can also be perceived as cooperation between the private and public sectors in the form of a long-term agreement related to a mutual product or service where the parties agree to share risks, costs and benefits (Klijn and Teisman, 2003).[4] Although definitions of PPPs are consistent in broad emphasis, no consensus has yet emerged regarding the common defining features of all such initiatives (Kang et al., 2013; Gangwar and Raghuram, 2014). Whilst some scholars view PPPs as a governance tool that will eventually replace traditional methods of project procurement such as competitive tendering, others see the arrangements as essentially a language game played by governments when having recourse to private sector investment when realising key public services (Hodge and Greve, 2007). The World Bank (2017) adopts the risk-centered formulation provided by PPP Knowledge Lab, where the arrangement reflects:

[3] A variety of terms are used for PPP schemes in different parts of the world. For example, In the United Kingdom, the partnership model for public/private sector initiatives aimed at delivering public services is known as the Private Finance Initiative (PFI) (Spackman, 2002). However, in the United States of America, Canada and most other countries the partnerships are labelled Public-Private Partnerships (PPP or P3) (Vining et al., 2005); for simplicity and consistency the phrase Public-Private Partnerships (PPPs) is adopted here.

[4] The same authors, in Klijn and Teisman (2005), characterize PPPs as a form of co-production with intensive co-operation between public and private sectors designed to realize joint products, services or policies.

"A long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance" (p. 1).

The appropriate allocation of risk is regularly argued to be one of the critical success factors in successful delivery of PPP projects (see, e.g. Zhang, 2005; Zhao et al., 2010; Chou et al., 2012). In the construction industry, risks can arise from many sources including budget ceilings, construction time, construction cost, operation cost, politics and policies, market conditions, cooperation credibility and economic environment (Chan et al., 2011). When PPPs are used to facilitate the investment, additional complications are common including private partners' need for risk exposure compensation and variability in governmental bargaining power within related negotiations (Clifton and Duffield, 2006). Wang et al. (2016) report that the public sector typically has the stronger bargaining position in risk apportionment processes, with most risk therefore likely to be transferred to the private sector. However, to assure the success of PPP projects it is critical that an appropriate incentive structure is reflected in agreed allocations (Li et al., 2001); the financial equilibrium between parties implied by apposite risk sharing ultimately reduces project cost, ensuring that many infrastructure investments that might otherwise be seen as marginal are undertaken (Medda, 2007; Ameyaw and Chan, 2015).

2. Literature review

2.1. Principal agent theory and PPP arrangements

The primary objective of a PPP project is to access synergistic gains through risk transfer that reflects each partner's capacity and economic competence (Girmscheid, 2013). Girmscheid (2006) postulates three dimensions of risk allocation that support its role in cost reduction.

- Minimising the probability of unfavourable outcomes;
- Minimising the impact of unfavourable outcomes; and
- Reflecting risk coverage capacity in burden shares.

The framework is based on conventional theory of the firm and an emphasis on the net present value of future geothermal PPP profits undertaken jointly by government (as principals) and private firms (as agents) relative to that obtainable by private companies undertaking such projects on their own. Alternative theoretical approaches such as stakeholder theory have been adopted to explore PPP activity (e.g. by Shaoul et al., 2012 in the UK), but these debates have typically been sited in developed nations where accountability discharge is much more common, including at governmental level, than in emerging country settings (Burke and Demirag, 2016). Contract enforcement in the latter tends to be inconsistent, unless operating in tightly-defined situations where penalties for non-performance are regularly enforced (Josiah et al., 2010). We therefore assume that contracting parties within Indonesian PPP schemes behave in the manner suggested by conventional neoclassical theorising. In neoclassical theory, the firm represents a set of feasible production plans that are managed via buying and selling inputs and outputs in a spot market such that owners' welfare, which itself is represented by profit or by expected net present value of future profit, is maximised (Hart, 1989; William and Ross, 2005). The analysis is founded on an assumption that the price of final products are determined by production costs (William and Ross, 2005). Whilst this assumption may be outdated in many modern settings, Hakam (2019) argues that this conjecture is still valid in the context of Indonesia's electricity market.

Demsetz (2002) points to a weakness of neo-classical theory in its purest form relating to the structure of property rights, as well as contractual arrangements where the ownership and the management are separate - as is the case with PPPs. However, a number of attempts have been made to construct a theory of the firm that incorporates property rights into predictions about organisational behaviour (Coase, 1937; Alchian and Demsetz, 1973; Jensen and Meckling, 1976). These developments have implications for the analysis of risk sharing and incentives in the type of principal-agent relationship involved in PPPs and are thus of particular relevance to this paper. According to Sappington (1991), in modern regulated industries conventional principal-agent models do not on their own fully capture the structure and operation of the type of complex organisation now common in such settings. In this context, Shavell (1979), Sappington (1991) and De Palma et al. (2012) highlight the importance of risk sharing and incentivizing. According to Shavell (1979) and Oudot (2005), if the agent is risk-averse, there would be an advantage in providing them with tailored incentives, the central issue to the present study.

2.2. PPPs in infrastructure development

A precise definition of the term 'infrastructure' does not exist (Torrisi, 2009). However, an initial formulation proposed by Jochimsen (1966) defines the term as follows:

"… the sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of a suitable allocation of resources, that is complete integration and maximum level of economic activities" (translated in Torrisi, 2009, p. 100, p. 100)

According to Grimsey and Lewis (2004), this definition retains applicability as it recognizes the broader foundations of a market economy including physical structures, supportive institutions/policies, market-based behaviour, skills and enterprise. These authors employ this conceptualization as the basis for classifying projects as either 'economic' or 'social.' Economic infrastructure projects include bridge, road, transportation, power, water treatment and telecommunication investments while social infrastructure projects typically involve education, health, prison and tourism facility developments (Grimsey and Lewis, 2002, 2004; Jefferies and McGeorge, 2009).

Government is traditionally responsible for providing basic infrastructure facilities for a nation's citizens, but pressure on public debt levels associated with the prominence of a neoliberal agenda have driven high levels of PPP growth in many developed and emerging countries (Grimsey and Lewis, 2002; Shaoul, 2011). The additional burdens placed on public resources in the wake of the global financial crisis in 2008 has led to further increases in the prevalance of PPP in infrastructure projects, with the schemes often seen as a procurement alternative in the transport and energy sectors (Martins et al., 2014). Although many practitioners and researchers acknowledge that PPPs can relieve the pressure on limited state budgets by injecting private sector capital, assessment of PPP projects is often highly politicized as fundamental disagreements have emerged around the identification (and balancing the interests) of different stakeholders (Broadbent et al., 2003; Shaoul, 2011; Ng et al., 2012). The initial motivation for exploring PPPs as a method of delivering critical infrastructure is generally purported to be a desire to reduce governments' financial burden and enhance the efficiency of infrastructure project construction, with the parties agreeing to share risks, costs and benefits (Klijn and Teisman, 2005; Kang et al., 2012).

An issue acknowledged as critical in all modern debates about PPP support for infrastructure investment is the sharing of risks and the notion that joint production can best be achieved by mutual effort (Hodge and Greve, 2007). Diaz (2019) argues that arrangements such as PPPs or concessions for public investment can reduce the potential for moral hazard problems, provided that the potential economic and political influences on governmental decisions around contract execution are well understood. Long-term contractual schemes can then prove effective, mainly because of the structured risk sharing between parties that these facilitate (Fredebeul-Krein and Knoben, 2010). The official definition of PPPs in Indonesia, as set out in Presidential Regulation No. 38/2015, makes explicit mention of risk distribution in infrastructure projects in its characterization of the arrangements:

> "… Cooperation between government and a business entity in infrastructure provision for the public interest in accordance with the specification previously determined by the Minister/Head of Institution/Head of Region/State Owned Enterprise/Regional Owned Enterprise, which partially or fully uses Business Entity resources, with particular regard to the allocation of risk between the parties" (p. 3).

Governments in both developed and developing countries have used PPPs as leverage when attempting to attract private sector investment in infrastructure projects (Jayasena et al., 2022). However, infrastructure provision in developing countries, including Indonesia, has not been as fulsome as in the developed world (Maryati et al., 2021). Part of the reason for this difference is purported to be the need for governmental capacity to overcome various constraints, particularly those related to credibility issues, governance weaknesses and issues related to opaqueness in the establishment of risk bearing frameworks (Bashar et al., 2021).

2.3. Defining optimal risk allocation

The European Commission (2003) defines risk as:

> "Any factor, event or influence that threatens the successful completion of a project in terms of time, cost or quality" (p. 50).

According to Jin and Zhang (2011), risk allocation practices in PPPs are highly variable, intuitive, subjective and unsophisticated but are nonetheless key determinants of the likelihood of project success. Allocating too much risk to a private sector entity can result in an excessively high risk premium that may make the project more costly and decrease the project's value for money (VfM); conversely, transferring too little risk to the private sector will limit the extent of any VfM (U.S Department of Transportation, 2013). A detailed understanding of the implications of specific risk factors is necessary to assess the potential role of risk management processes (Tummala and Burchett, 1999) and in this context The Project Management Institute outlines the sequences involved as risk management planning, risk identification, risk analysis (qualitative and quantitative), risk response planning, and risk monitoring and control (Project Management Institute Inc, 2000). Once risks are identified and analyzed, they are allocated to the parties involved, in principle, on the basis that individual risks should be allocated to the party that can manage (i.e. influence and control) these at the least cost (Ke et al., 2010). Risk allocation aims to enhance economic efficiency by reducing long-term costs, providing incentives, improving service quality and ensuring more consistent and predictable expenditure (The European Commission, 2003; Girmscheid, 2013). However, economic efficiency requires optimal risk sharing between the partners (de Palma et al., 2012) and the need to improve understanding of this issue in Indonesia's geothermal sector is the primary motivation for the present study. As Arndt (2000) and Shrestha et al. (2017) note, optimal risk allocation represents decisions developed through a systematic process to allocate risk factor(s) or risk event(s) to a party or parties based on practice and economic principles that minimise the negative impacts on explicit and measurable project performance indicators such as project cost, leading in turn to improvements in project financial viability.

3. Empirical methodology

The optimal levels of risk allocation between public and private sectors in PPP projects is not always apparent because of the inherent complexities and interrelations involved from the outset, as well as the possibility that changes in project performance over time may lead to demand for the renegotiation of contractual agreements (Demirag et al., 2010). The conventional rationale in PPP projects is that the risk should be borne by the party best able to manage it, but much of the discussion regarding the ability of a party to manage and control exposure is highly speculative (Girmscheid, 2013). Applying this principle in real-world contexts can be difficult because of problems related to defining the level of risk sharing required (Arndt, 2000).[5] In addition, in renewable energy projects in developing nations, private sector activity is prone to opaqueness and uncertainty and so risk sharing with the public sector is likely to be critical to support the major investment required (Ameyaw and Chan, 2015; Hakam 2019). In the present study we develop an empirical model of optimal risk allocation in geothermal PPPs based on the Delphi technique. The Delphi method facilitates efficient group dynamics through an anonymous multi-stage survey process, with group feedback used as a control mechanism after each round (von der Gracht, 2012). Delphi surveys have been employed frequently for empirical data collection in management research relating to complex scenario modelling, where consensus or convergence of expert opinion is likely to be insightful (Hsu and Sandford, 2007; Hallowell and Gambatese, 2009). A Delphi approach was therefore considered appropriate here, where the focus is on the complex issue of risk allocation in Indonesian geothermal projects.

Whilst this technique has a strong pedigree in related studies (e.g. Ameyaw and Chan, 2015; Soon et al., 2012; and Badawy et al., 2022) a number of limitations in its application have been identified and need to be acknowledged. For example, Woudenberg (1991), in his review of the Delphi method, argues that human judgement is necessary to draw conclusions where uncertainty exists and that statistical (aggregate) judgement based on the input of a group of people is more accurate than the conclusions of a random individual. As Woudenberg further points out, anonymity in the Delphi process prevents interaction among panelists that might increase the accuracy of group judgement to the extent that it compares with related methods such as the Nominal Group Technique (Woudenberg, 1991; Rowe and Wright, 1999). Relatedly, as Goodman (1987) points out, there is an inherent risk that anonymity can lead to a lack of accountability regarding the opinions expressed by the panelists. As the validity and accuracy of any Delphi study is contingent on the context of the work and the extent of participant expertise, selection methods need to be clear and justifiable (Goodman, 1987; Marchant, 1988). A further drawback with Delphi studies concerns interpretation of the findings, as participants are not given the opportunity to elaborate on their views (Hasson et al., 2000). As a result, it is critical that participants are selected on the basis of being able to provide meaningful responses from the outset of the process.

In Delphi studies, inferential statistics are rarely used, as the number of participants is generally lower than the sample sizes employed by inferential statistic surveys (Walker and Selfe, 1996). Hallowell and Gambatese (2009) note that most Delphi studies employ between 8 and 16 participants while Rowe and Wright (1999) highlight a number of articles that use fewer than 10 participants; these include: Dalkey and Helmer (1963) with 7 participants; Dietz (1987) with 8 and Rowe and Wright (1996) with just 5. More recently, Sossa et al. (2019) reviewed 57 Delphi-based articles and report that sample sizes of less than 10 are often utilized. Furthermore, the authors argue, there is no evidence that extending the number of participants from 7 to 10 improves empirical accuracy, with the relevance of individuals' expertise to the matter in hand being more important than the scale of the study. We are thus confident that our work, whilst inevitably limited in terms of participant number by the specificity of the topic under investigation, is valid in terms of generating informed viewpoints about the risk associated with geothermal energy projects. As Sossa et al. (2019) and Walker and Selfe

[5] Arndt (2000) insists that clearly defined risk allocation is required in project documents to reflect the intentions of the parties to the contract, but this needs to be built on measures that can be contractually enforced.

(1996) note, one implication of this methodological choice is that the Delphi-based evidence has to be analyzed using descriptive statistics rather than via inferential measures based on parametrics such as mean and standard deviation; again, however, the pedigree of Delphi studies based on the type of scale we employ suggests that this limitation is overcome by the need for meaningful perspectives to define the research endeavor.

A two-round Delphi questionnaire process was employed, taking place between September and December 2018. The questionnaire document consisted of three sections, the first of which asked about the profile of participants, including current sector and extent of experience in the geothermal field. In the second section, participants were asked to outline their views regarding the probability and impact of risk factors on geothermal project development in Indonesia. The third section then asked participants to indicate their opinions regarding the level of governmental risk sharing required to reduce the risks faced by private sector developers to acceptable levels, based on a series of pre-defined risk sharing measures. Participants were asked to assess the probability and likely impact of risk factors on a three-point Likert scale where 1 = low, 2 = moderate and 3 = high.[6] A total of 30 risk factors were identified following a comprehensive review of the literature, in particular detailed analyses by Deloitte Development LLC (2008); Sanyal (2014) and ESMAP (2016) as well as relevant project documents (including proposal and contractual agreements relating to the Seulawah Agam Geothermal Project).[7] These were then grouped into the seven categories set out in the Initial Risk Checklist depicted in Table 1. Prior to being confirmed for inclusion in the questionnaire, the risk checklist was reviewed by an expert with more than 20 years' experience in consulting on geothermal and energy projects across the world. Based on this feedback, three risk factors were removed leaving a final total of 27. Table 2 details the three factors that were excluded and the rationale in each case.

A total of 16 international experts in the geothermal energy field including industry professionals, financiers, consultants and government analysts were invited to participate in the Delphi survey. Nine positive replies were received, and these individuals all participated in the first round, although the number dropped to eight in the second round as participant ID03 did not submit a response.[8] The profile of the original nine participants is presented in Table 3. The average length of experience in geothermal industry/development and in PPPs/project financing was 14.5 and 8.3 years respectively and the average number of geothermal projects and/or PPPs that participants had been involved with was 7.6. Therefore, the aim of targeting individuals with informed opinions about the matters at hand appeared to have been achieved.

Geothermal developments generally require seven years of operation before the attainment of meaningful levels of commercial production (Dickson and Fanelli, 2004). Therefore, regardless of the length of the participants' experience in the geothermal sector, there is no guarantee that they will all have been involved in a complete development phase. For example, participant ID 03, a consultant with nine years of geothermal experience, had typically only been involved at specific points in the development process (although these included several key stages such as feasibility studies, techno-economic analysis, preliminary planning/conceptual engineering of power plant and well location, underground interfacing, power plant design, tendering and bid evaluation, site supervision and due diligence audits). The participants that work in the public sector (ID 01 and ID 09) and development banking (ID 06) were also less likely to have been involved in all stages of the process, while participant ID 04 was working at a corporate level relating to business development at the time of the study and was therefore not involved in any specific project but rather on a broad portfolio of such investments.

Table 1
Initial risk checklist.

Risk category	Code	Risk factors
Resource and exploration risks	RE-1	Reserve lower than expected (resource capacity)
	RE-2	Low reservoir temperature
	RE-3	Low permeability
	RE-4	Reservoir area smaller than expected
	RE-5	Exploration drilling risks
Field development and construction risks	FD-1	Engineering design failure
	FD-2	Production/injection drilling risks
Operational and maintenance risks	OM-1	Scaling and corrosion problems
	OM-2	Reservoir pressure or temperature decline faster than expected
	OM-3	Geothermal fluid chemical composition change
	OM-4	Risk of high NCG gas
	OM-5	Skilled workforce
Financial and credit risks	FC-1	Unable to finance the exploration stage
	FC-2	Unable to finance the field development stage
	FC-3	Interest rate change
	FC-4	Inflation rate
	FC-5	Currency exchange rate risk
Market risks	MR-1	Failed to finalize PPA
	MR-2	Low power demand in the country
	MR-3	Lack of uptake by the distributor
	MR-4	Lack of adequate transmission grid
Legal and regulatory risks	LR-1	Uncertainty in tax regulation
	LR-2	Uncertainty in tariff regulation
	LR-3	Delay in licensing
	LR-4	Uncertainty in permit procedures
	LR-5	Lack of supporting development incentives
Environmental risks	ER-1	Risk of H_2S impact on community
	ER-2	Land acquisition/resettlement issues
	ER-3	Noise
	ER-4	Vegetation clearing and deforestation

Note: This table details the 30 risk measures employed in the study and the seven categories to which these were assigned.

The ranking of risk factors was determined via a criticality index, a common approach when assessing the impact of individual types of risks (Theoharidou et al., 2009). The criticality index score for a risk factor indicates its impact on costs, time and scope/quality, as well as its probability of occurrence (Marcelino-Sádaba et al., 2014). The mean scores and standard errors resulting from the first and second rounds of the Delphi process here are reported in Tables 4 and 5, respectively. The criticality index score is based on the mean probability of occurrences *(P)* multiplied by the mean impact score *(I)* for specific risk factors generated in each case by the three-point Likert scale employed (as in Marcelino-Sádaba et al., 2014). Therefore:

$$C_i = P_i \; x \; I_i \quad (1)$$

where C_i represents the criticality index score for risk factor *i*.

[6] Likert scales have been used widely in risk assessment research in construction and infrastructure investment contexts (see, e.g., Wibowo and Mohamed, 2010; Xu et al., 2010; Ameyaw and Chan, 2015; Shrestha et al., 2017).

[7] The Seulawah Agam geothermal project in Aceh Province, Indonesia was examined as this is the only geothermal project in Indonesia to date that has adopted a structured and institutionalised PPP procurement scheme (Ministry of National Development Planning Republic of Indonesia, 2004). As far as the authors are aware, there is no other geothermal project in Indonesia that has incorporated PPP procurement.

[8] Hallowell and Gambatese (2009) note that most Delphi analysis employs between 8 and 16 and suggest that studies employing numbers within this range are empirically valid.

Table 2
Risk factors excluded after expert review.

Code	Risk factors	Expert opinion
OM-5	Skilled workforce	The “probability of occurrence” cannot be identified for this risk factor. It is likely that skilled staff will not be available, and the investor will have to train local people or bring in skilled people from other projects. As a rule, the investor may need to do both, i.e. bring in some experienced staff, at least at the beginning of the project, to initiate plant operation and lead the training.
LR-4	Uncertainty in permit procedures	There is no probability of occurrence for this risk factor. In permitting private sector involvement, Each country’s government will have identified the uncertainties and judged whether risk bearing is feasible. Such judgement may depend on investors’ local networking and relations with the governor or minister, giving a clear advantage to local companies.
LR-5	Lack of supporting development incentives	Incentives to develop may become necessary if geothermal projects become a political priority. However, if the tariff is adequate, no other financial incentives are necessary; legal and political certainty are the primary factors in practice.

Note: This table details the three risk measures excluded from the study after expert review.

Table 3
Respondent profiles.

ID	Working Sector	Years of experience in the geothermal industry/project development	Years of experience in PPPs or project financing	Number of geothermal/ PPP involvements
01	Public Sector (Regulator)	12	4	0
02	Indonesian Oil and Gas State Company	25	6	2
03	Consulting	9	26	40
04	Private Sector (Developer)	18	0	0
05	Consulting	12	10	4
06	Development Banking	5	10	10
07	Private Sector (Developer)	30	10	5
08	Private Sector (Developer)	10	2	4
09	Public Sector	10	7	3

Note: This table provides information about the experiential profiles of the nine participants in the Delphi analysis.

Risk factors with criticality scores >6.25 are classified as having “high” risk criticality. Risk factors with criticality scores between 4 and 6.25 are classified as “moderate” in terms of risk criticality, and all risk factors with a criticality score <4 are classified as “low.”[9] Participants were also asked to indicate the extent of governmental risk sharing required in PPPs to reduce the risk borne by geothermal project developers in Indonesia to acceptable levels based on a five-point Likert scale where 1 = 0% (i.e. all risk borne by the private sector); 2 = 10%–30%; 3 = 40%–60%, 4 = 70%–90%, 5 = 100% (all risk borne by the government). After the two-round survey was completed, the result was normalized on the following basis:

$$NV = a + (x - A) * (b\text{-}a)/ B\text{-}A \tag{2}$$

where:
NV = Normalized Value
a = minimum value (0%)
b = maximum value (100%)
A = minimum mean index.
B = maximum mean index
x = mean index of the respective risk-sharing measure.

In Delphi studies, consensus measurement plays a central role in data analysis and interpretation (von der Gracht, 2012). Thus, Cronbach’s Alpha and Kendall’s W were used to quantify the reliability of the data and determine the level of consensus between panelists. Cronbach’s Alpha reflects the degree of covariance between all participants’ scores and thus represents a measure of internal consistency. (Meijering et al., 2013). The extent of consensus was determined on the basis of Kendall’s W (‘coefficient of concordance’) statistic that gauges agreement across samples of rankings (Schmidt, 1997).

4. Results

4.1. Risk criticality

Inspection of Table 4 reveals that in the first-round survey, 6 ‘high,’ 9 ‘moderate’ and 12 ‘low’ criticality risk factors were identified. However, as Table 5 indicates, when participants were supplied with these results and asked to respond to the questions again in the second round, the number of ‘high’ criticality risk factors fell to 4, and the number of ‘low’ criticality risk factors increased to 14. This change in pattern of opinions suggests that the opportunity for reflection afforded by the Delphi process led respondents to reassess downwardly the overall level of risk involved with Indonesian geothermal PPPs. As discussed in detail below, while four of the six ‘high’ factors identified in the first round related to resource and exploration exposures, two of these (low reservoir temperature and low permeability) were not included after the second round. In terms of low risk, environmental exposures were particularly prominent, generating the lowest two figures after round one and the lowest three following round two. Fig. 1 provides a matrix depicting the risk criticality results after the second stage, with the highest exposures placed in the top-right of the schematic.

Inspection of Table 5 reveals that the Cronbach Alpha statistics for probability of occurrences and impact in the second-round analysis are 0.76 and 0.85 respectively suggesting a high degree of reliability in both cases. The Kendall’s W coefficients of 0.51 and 0.49 indicate a moderate degree of consensus (García-Crespo et al., 2010). Whilst the degree of consensus can be maintained by increasing the number of survey rounds, the trade-off between the need for greater consensus and feasibility (given potential complexities relating to the indulgence of panelists as well as the resources and additional time required) requires consideration (Schmidt, 1997). In any case, for all measures and scores, the statistics indicate an improvement in terms of both reliability and consensus in the second stage and the discussion now focusses on this evidence.

4.2. Key risk factors after second round

4.2.1. Risk factor (RE-1): reserve lower than expected

“Reserve lower than expected” was seen as one of the two most

[9] The category boundaries were established on the following basis: (i) to be in the “high” category the criticality index had to be greater than 6.25 (i.e. 2.5 - the mid-point between the two highest Likert scale responses - squared); (ii) to be in the “moderate” group the index had to be between 4 (i.e. 2 - the middle response in the Likert scale - squared) and 6.25. All index scores less than 4 were categorised as “low.” Whilst these choices are somewhat arbitrary in nature, the need for subjectivity in the prior setting of boundaries and Likert scales is widely documented in this field and the decisions made here are in line with earlier work which emphasizes the need for broad categories and the avoidance of over-specification.

Table 4
Critical risk factors following first round delphi survey.

ID	Risk Factors	*Probability*			*Impact*			Criticality (Probability*Impact)		Ranking
		Mean score	Std. error of mean	Std. deviation	Mean score	Std. error (mean)	Std. deviation			
RE-1	Reserve lower than expected	2.55	0.24	0.72	2.78	0.15	0.44	7.09	High	1
LR-2	Uncertainty in tariff regulation	2.50	0.19	0.53	2.75	0.16	0.46	6.87	High	2
RE-2	Low reservoir temperature	2.44	0.17	0.52	2.67	0.17	0.50	6.78	High	3
RE-3	Low permeability	2.50	0.19	0.15	2.62	0.18	0.51	6.55	High	4
FC-1	Unable to finance the exploration stage	2.44	0.24	0.72	2.67	0.17	0.50	6.51	High	5
RE-5	Exploration drilling risk	2.44	0.29	0.88	2.67	0.23	0.70	6.51	High	6
RE-4	Reservoir smaller than expected	2.55	0.25	0.71	2.62	0.18	0.51	5.89	Moderate	7
MR-1	Failed to finalize Power Purchase Agreement (PPA)	1.77	0.28	0.83	2.67	0.23	0.71	4.72	Moderate	8
LR-3	Delay in Licensing	2.20	0.28	0.83	2.11	0.26	0.78	4.64	Moderate	9
MR-4	Lack of adequate transmission grid	1.89	0.26	0.78	2.44	0.24	0.72	4.61	Moderate	10
OM-2	Reservoir Pressure/temp decline faster than expected	2.00	0.00	0.00	2.25	0.16	0.46	4.50	Moderate	11
FD-2	Production/injection drilling risks	2.00	0.19	0.53	2.25	0.31	0.89	4.50	Moderate	12
FC-2	Unable to finance field development stage	2.00	0.23	0.70	2.22	0.22	0.67	4.40	Moderate	13
FC-5	Currency exchange rate risk	2.10	0.26	0.69	2.00	0.22	0.56	4.20	Moderate	14
LR-1	Uncertainty in tax regulation	2.00	0.27	0.75	2.00	0.27	0.75	4.00	Moderate	15
ID	Risk Factors	***Probability***			***Impact***			Criticality (Probability*Impact)		Ranking
		Mean score	Std. error of mean	Std. deviation	Mean score	Std. error (mean)	Std. deviation			
OM-1	Scaling and corrosion problem	1.77	0.15	0.44	2.11	0.20	0.60	3.73	Low	16
ER-2	Land acquisition and resettlement issues	2.33	0.17	0.50	1.44	0.24	0.73	3.35	Low	17
FC-3	Interest rate change	1.77	0.28	0.83	1.89	0.20	0.60	3.34	Low	18
MR-3	Lack of uptake by the distributor	1.62	0.26	0.74	2.00	0.27	0.75	3.24	Low	19
ER-4	Vegetation clearing and deforestation	1.78	0.28	0.83	1.55	0.29	0.88	2.76	Low	20
FD-1	Engineering design failure	1.33	0.17	0.50	2.00	0.27	0.75	2.66	Low	21
FC-4	Inflation rate	1.50	0.19	0.53	1.62	0.18	0.52	2.43	Low	22
MR-2	Low power demand in the country	1.50	0.19	0.53	1.62	0.18	0.52	2.43	Low	23
OM-4	Risk of high NCG gas	1.25	0.16	0.46	1.75	0.31	0.89	2.18	Low	24
OM-3	Geothermal fluid chemical change	1.12	0.12	0.35	1.75	0.31	0.89	2.18	Low	25
ER-1	Risk of H_2S impact on community	1.25	0.16	0.46	1.50	0.24	0.75	1.87	Low	26
ER-3	Noise	1.22	0.15	0.44	1.33	0.25	0.71	1.62	Low	27
Kendal's W		***0.38***			***0.34***					
Cronbach's Alpha Coefficient		***0.51***			***0.70***					

Note: This table details the probability, impact and criticality data generated by the first round of the Delphi analysis for each of the risk measures employed.

significant risk factors in Indonesian geothermal projects by the experts taking part in the study. Following the second-round analysis, mean scores of 2.87 and 2.75 suggested a high likelihood and impact respectively for this risk factor with an overall index score of 7.89 resulting. These findings suggest that the expert opinions are in line with prior contention regarding problems with the process in Indonesia. For example, the geoscientific data provided by the nation's government during the concession tender process has been characterized as insufficient for bidders to evaluate the reserve capacity, potentially leading to miscalculation of reserve capacity in proposal documents (JICA, 2005; Fan and Nam, 2018).[10]

The issue of data accuracy and completeness in bidding credentials is also mentioned by Ibrahim (2015) in the context of Indonesian geothermal investment, with problems in tender documents having a long-term impact on developer outcomes. This factor is likely to be a key driver of differences between expected and proven reserves, given that the related risks around temperature and permeability were seen as only moderate by the experts participating in the Delphi analysis in the present study. The perspective on low temperature and permeability of reservoir as moderate risk factors can be justified as the geothermal systems in Indonesia are volcanic in nature. As noted by Fauzi (2015), two-thirds of Indonesian geothermal resources have temperatures greater than 190 °C. Permeability varies depending on the type of rock (Rowland and Simmons, 2012), with systemic geothermal reservoirs formed of igneous rock (e.g. in an Enhanced Geothermal System (EGS)) usually having limited permeability. As a result, in most such cases global permeability is controlled by fracture (Sausse et al., 2008).

In contrast, geothermal systems - where reservoir permeability is dominated by volcanic structure (particularly in quarter volcanic systems with tuff as the primary rock reservoir) - represent high permeability geothermal systems (Jatmiko et al., 2020). A natural geothermal system typically has permeability in the range of 1–100 milidarcy (mD) (Zhou et al., 2016). As most of the geothermal systems in Indonesia are in quarter volcanic geological settings, most of the related reservoirs have a high permeability structure (e.g. in the Mataloko geothermal field, where reservoir permeability ranges from 25 to 80 mD (Jatmiko et al., 2020). For other geothermal fields, the ability of water to flow

[10] To obtain more accurate data, the winning bidder will usually have to conduct a detailed investigation after they are awarded the rights (Ibrahim, 2015).

Table 5
Critical risk factors following second round delphi survey.

ID	Risk Factors	*Probability*			*Impact*			Criticality (Probability*Impact)		Ranking
		Mean score	Std. error of mean	Std. deviation	Mean score	Std. error (mean)	Std. deviation			
RE-1	Reserve lower than expected	2.87	0.12	0.35	2.75	0.16	0.46	7.89	High	1
LR-2	Uncertainty in tariff regulation	2.75	0.16	0.46	2.87	0.12	0.35	7.89	High	2
RE-5	Exploration drilling risks	2.62	0.18	0.51	2.75	0.16	0.46	7.20	High	3
FC-1	Unable to finance the exploration stage	2.75	0.16	0.46	2.37	0.26	0.74	6.51	High	4
RE-3	Low permeability	2.50	0.19	0.53	2.37	0.18	0.51	5.92	Moderate	5
RE-4	Reservoir area smaller than expected	2.37	0.18	0.51	2.37	0.18	0.51	5.62	Moderate	6
LR-3	Delay in Licensing	2.25	0.25	0.70	2.50	0.19	0.53	5.62	Moderate	7
RE-2	Low reservoir temperature	2.12	0.23	0.64	2.62	0.18	0.51	5.55	Moderate	8
MR-3	Lack of uptake by the distributor	1.87	0.29	0.83	2.87	0.22	0.64	5.37	Moderate	*9*
OM-2	Reservoir Pressure/temp decline faster than expected	2.12	0.12	0.35	2.25	0.16	0.46	4.77	Moderate	10
MR-4	Lack of adequate transmission grid	1.87	0.22	0.64	2.50	0.16	0.46	4.67	Moderate	11
FD-2	Production/injection drilling risks	2.12	0.12	0.35	2.12	0.29	0.83	4.49	Moderate	12
ER-2	Land acquisition/resettlement issues	2.37	0.26	0.74	1.75	0.25	0.70	4.14	Moderate	13
ID	Risk Factors	*Probability*			*Impact*			Criticality (Probability*Impact)		Ranking
		Mean score	Std. error of mean	Std. deviation	Mean score	Std. error (mean)	Std. deviation			
FC-5	Currency exchange rate risk	2.12	0.22	0.64	1.87	0.12	0.35	3.96	Low	14
LR-1	Uncertainty in tax regulation	1.87	0.22	0.64	2.12	0.22	0.64	3.96	Low	15
MR-1	Failed to finalize Power Purchase Agreement (PPA)	1.62	0.32	0.91	2.25	0.18	0.51	3.64	Low	16
FC-3	Interest rate change	1.87	0.22	0.64	1.87	0.12	0.35	3.50	Low	17
OM-1	Scaling and corrosion problem	1.62	0.18	0.51	2.12	0.12	0.35	3.43	Low	18
FC-2	Unable to finance field development stage	1.62	0.18	0.51	2.00	0.19	0.53	3.24	Low	19
MR-2	Low power demand in the country	1.50	0.19	0.53	2.12	0.18	0.51	3.18	Low	20
FD-1	Engineering design failure	1.62	0.18	0.51	1.87	0.22	0.64	3.02	Low	21
FC-4	Inflation rate	1.50	0.18	0.51	2.00	0.19	0.53	3.24	Low	22
OM-4	Risk of high NCG gas	1.25	0.16	0.46	1.50	0.26	0.75	2.24	Low	23
OM-3	Geothermal fluid chemical change	1.12	0.12	0.35	2.00	0.18	0.53	2.24	Low	24
ER-1	Risk of H_2S impact on community	1.25	0.16	0.46	1.37	0.26	0.74	1.71	Low	25
ER-3	Noise	1.25	0.16	0.46	1.37	0.26	0.74	1.71	Low	26
ER-4	Vegetation clearing and deforestation	1.50	0.18	0.53	1.12	0.12	0.35	1.68	Low	27
Kendal's W		***0.51***			***0.49***					
Cronbach's Alpha Coefficient		***0.76***			***0.85***					

Note: This table details the probability, impact and criticality data generated by the second round of the Delphi analysis for each of the risk measures employed.

through the rock is reflected in its transmissivity, i.e. permeability multiplied by thickness of reservoir, with Darcy. meter (D.m) as the unit. For instance, the Kamojang geothermal field has transmitivity of 0.5–140 D.m, while the Awibengkok (Salak) has transmissivity extending to 150 D.m (Boedihardi et al., 1993). A lower transmissivity can be found at the Sibayak field where maximum transmissivity is around 13 D.m (Dwikorianto, 2001). A survey conducted by Bjornsson and Bodvarsson (1990) summarizes the permeability and transmissivity of various global geothermal fields, as shown in Table 6. Given this context, the participants' perception about the possibility of low temperatures and the permeability of geothermal resources was included as a moderate risk factor in the empirical analysis.

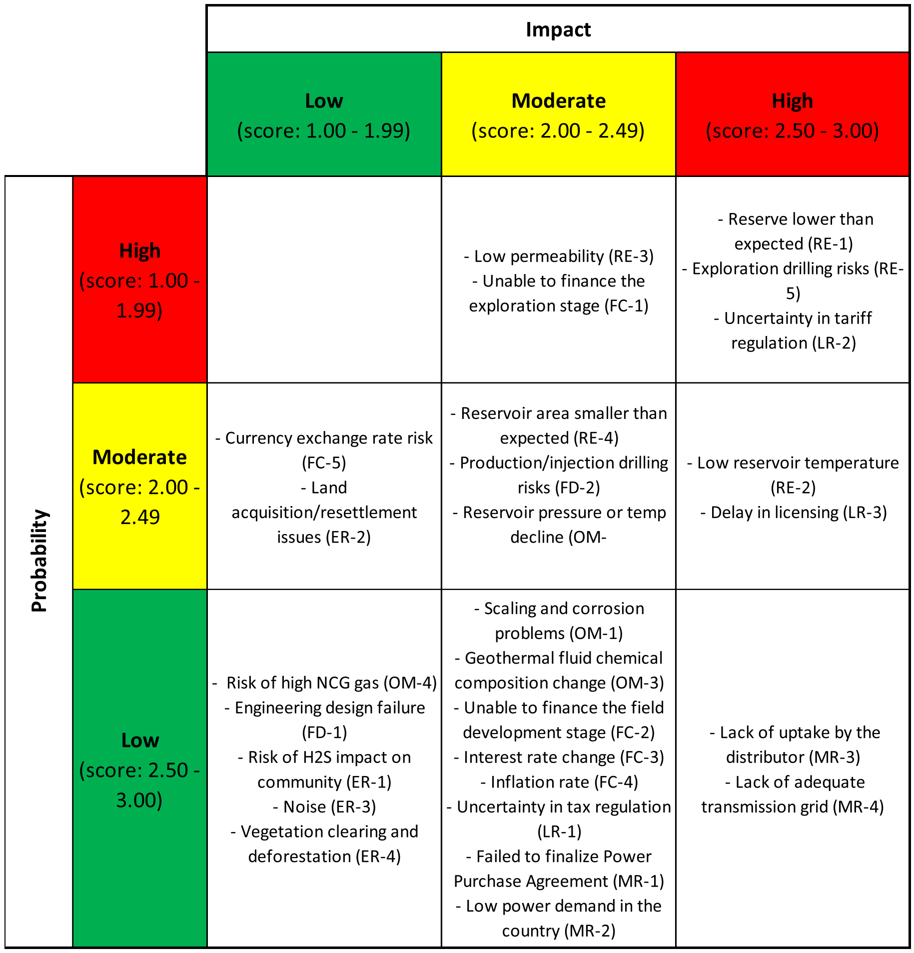
The evidence relating to reserve estimation is particularly concerning given that, according to Castalia Strategic Advisors (2008), inaccuracies in this regard can significantly impact overall field development costs as they directly influence production, injection and make-up wells, as well as the steam fields above ground and power generation facilities. The potential consequences for Indonesia are particularly serious given Sanyal (2014)'s assessment of drilling data for geothermal projects. The results indicate that Indonesian projects typically have a capacity of 7–9 MW/well compared to a worldwide average of 4–6 MW/well, as well as higher typical reservoir temperatures of 230–250 °C.

4.2.2. *Risk factor (LR-2): uncertainty in tariff regulation*

The criticality index list was jointly headed by uncertainty in tariff regulation, with probability and uncertainty scores of 2.75 and 2.87 respectively (the criticality score of 7.89 was the same as for RE-1, although the two contributing figures were reversed). This pattern in expert opinion again points to the restrictive impact of a number of issues in Indonesia, notably the ongoing change process in regulatory frameworks over recent years.[11] In order to find an appropriate balance between tariffs and the relative risks borne by PLN[12] and government subsidies, Indonesia's Ministry of Energy and Mineral Resources (MEMR) has amended pricing policy concerning geothermal tariffs

[11] According to Klein (1997), even though a government has authority to amend and adjust regulation, inappropriate changes that affect market behaviour can lead to severe legal and political risk that may in turn increase exposure to moral hazard and adverse selection problems.

[12] PT Perusahaan Listrik Negara (PLN) is Indonesia's second largest state owned company, formally tasked with the supply of electricity to the Indonesian people (Baker & McKenzie, 2014).



Note: This figure depicts the results from the Delphi analysis relating to risk probability and impact

Fig. 1. Risk criticality matrix. Note: This figure depicts the results from the Delphi analysis relating to risk probability and impact

Table 6
Permeability of global geothermal fields.

Field	Country	Permeability (mD)	Permeability-Thickness (D.m)
Krafla	Iceland	2–10	1–3
Laugarnes	Iceland	15	15
Laugaland	Iceland	2	2
Nesjavellir	Iceland	1–5	3–6
Svartsengi	Iceland	100–150	–
Olkari	Kenya	3–8	1–5
Cerro Prieto	Mexico	10–30	4–40
Broadlands	New Zealand	30	–
Wairakei	New Zealand	35–40	20–100
BacMan	Philippines	20	30
Tongonan	Philippines	10–50	10–50
The Geyser	USA	50–100	1–50
Baca	USA	3–10	1.8

Note: Source - Bjornsson and Bodvarsson (1990).

several times over the past decade. In 2011, a ceiling-based system was introduced[13] with the price capped at US$ 0.097/kWh (subject to negotiation with PLN), capacity of 110 MW and the assumption that developers take all risks including those related to exploration, regulatory, political and commercial uncertainties (Wahjosoedibjo and Hasan, 2018).[14] In 2012, the Feed in Tariff model was introduced, but was swiftly cancelled as it was not in line with Geothermal Law No. 27/2003, which states that geothermal concessions must be competitively tendered such that the winning bidder is decided primarily on the basis of price. To reflect this principle, two years later regulation 17/2014 introduced a new ceiling tariff model, this time centered on the price implications of PLN's average cost of electricity production in a given region as well as commercial operation dates (Campen et al., 2017). This change was intended to address inflation risk resulting from long project lead times, but PLN cost constraints led to a further change in 2017 whereby the tariff negotiated in the PPA could not exceed the Average Generation Cost (or BPP)[15] of PLN for the respective region.[16] According to Wahjosoedibjo and Hasan (2018) the 2014 tariff model can be economically attractive for geothermal developers, provided that the

[13] Via Regulation No. 02/2011.

[14] This tariff model was criticized as it did not deal explicitly with the issue of tariff escalation (Baker and McKenzie, 2014).

[15] In Indonesian *Biaya Pokok Pembangkitan*

[16] This pricing system has been opposed and criticized because of the perceived favouring of PLN interests (Halimanjaya, 2019). In addition, as the BPP differs for each region, in Java-Bali and Sumatra, where electricity generation is dominated by coal power plants, the BPP is lower, potentially resulting in reduced geothermal tariffs and underinvestment in these regions (McCormack and Mandelli, 2017).

government provides a suitable level of incentives to reduce upfront costs (e.g. incentives for exploration, tax holidays, accelerated depreciation, exploration risk insurance mechanisms, low interest rates and low land acquisition costs).

The recent change of electricity tariff from geothermal energy is stipulated in Presidential Regulation No. 112/2022 on Acceleration of Renewable Energy Development for Electricity Supply. The geothermal selling tariff now employs ceilings based on the installed capacities of geothermal power plants, adjusted according to a power plant location factor. The newly issued tariff is presented in Table 7. Thus, although Indonesian authorities continue to alter the underlying tariff system, the expert opinions revealed via the Delphi analysis suggest that if these moves are designed to provide the incentives needed for a sustainable risk-sharing framework, this has yet to be fully realized.

4.2.3. Risk factor (RE-5): exploration drilling risk

Exploration drilling was the only other factor to generate a criticality index score of more than 7 (with mean scores for probability and impact of 2.62 and 2.75 respectively). This perception is consistent with the contention that risk exposures related to drilling are higher for geothermals than for petroleum and oil or gas projects because of issues around temperature, fluid corrosiveness and rock structure (Castalia Strategic Advisors, 2008), with Geothermex (2010) reporting that the failure rates for exploration drilling in Indonesia can be as high as 40%. Castalia Strategic Advisors (2008) estimate that for Indonesian geothermals based in greenfield sites the required rate of return is typically high, at around 16%, although in brownfield sites - reflecting lower contractual and institutional uncertainty around existing steam fields - the rate is usually closer to 14%. To address this issue, in 2017 the Indonesian government, supported by the World Bank through the Geothermal Energy Upstream Development (GEUD) Program, attempted to develop a strategy to reduce exploration risk sponsored exploration drilling in unassigned geothermal working areas (Green Climate Fund, 2018). If successful, this program is expected to make an essential contribution to risk mitigation in the geothermal sector; the evidence here suggests that this aspect of risk is acknowledged by experts as a major issue and attempts to address the problems have the potential to make a substantive difference. Geothermal drilling insurance has been implemented in Turkey, East Africa and Latin America in recent years, but has failed to develop traction in Indonesia because of the high returns required (ESMAP, 2016). Hasan (2013) argues that this problem is likely to persist because reliable data on drilling success ratios in Indonesia is not available, hampering attempts to calculate accurate premia figures.

4.2.4. Risk factor (RC-1): financing the exploration stage

The Delphi panelists assessed financial availability in the exploration stage as the other 'high' risk factor (the only other factor with a criticality index score of more than 6), with a probability score of 2.75 and impact score of 2.37. Again, the perceptions of the experts aligned closely with practicalities. For example, compared to regional norms Indonesia's capital market is small and illiquid (Green Climate Fund, 2018) and the exploration stage is therefore financed primarily by a mix of equity and loans from parent companies. As it is difficult for developers to obtain commercial loans from lenders to fund the sizeable upfront investment involved in energy production, many of the projects that are granted initial permits are never embarked upon; even a 200 MW power plant requires US$ 120 to 320 million in terms of upfront financing, equivalent to approximately 20–40% of overall cost (Quinlivan, 2015). Problems are exacerbated in Indonesia because, as Geothermex (2010) note, geothermal projects in Indonesia have success rates of less than 40%; Detik Finance (2019) report that a total of 14 Indonesian geothermal concessions, with a joint capacity of 1100 MW, had been granted operating permits but still failed to reach completion. Such outcomes suggests that the Geothermal Fund Facility (GFF) of US$ 145 million launched by the Indonesian government in 2011 to address these types of financing problems (Wahjosoedibjo and Hasan, 2012)[17] did not prove effective in its early years.

Taking overall account of the four risk factors generating the highest critically index scores in the Delphi survey it is evident that the experts' identification of the issues with significant exposures fits with the practical realities of Indonesia's modern geothermal sector. This alignment suggests that their perspectives relating to risk allocation modelling, as set out in the next section of the paper, are based on informed understanding of the processes and outcomes on the ground.

4.3. Risk allocation model

In this section, we set out the results from the Delphi analysis regarding experts' views on optimal risk sharing between public and private partners in Indonesian geothermal energy PPPs. As discussed above, the appropriate basis for risk allocation in PPPs is not always apparent because of the multi-faceted nature of the exposures involved (as reflected in the first part of the Delphi inquiry). A series of eleven risk sharing measures, spread across five of the risk categories employed earlier in the study,[18] were used in this part of the analysis with the choice designed to reflect contention in the literature regarding ways in which the exposures might be addressed.

The specific risk sharing measures employed are summarized in Table 8. These were developed based on a detailed analysis of PPP contractual agreements (i.e. shareholder and loan agreements) as well as tender documents relating to the Seulawah Agam geothermal project. The identification of risk sharing measures and incentives should reflect the context and behaviour of contractual parties, with the welfare system and democratic robustness in the country concerned also relevant to PPP projects (Van Boxmeer and Van Bechoven, 2005). It was therefore considered essential to examine the risk sharing structure of an existing project in Indonesia for the purpose of developing a suite of appropriate measures and this aim is reflected in the measures in the table.

The results from the first and second round of the Delphi analysis are summarized in Table 9 and Table 10 respectively. Inspection of the tables indicates participants' overwhelming support for the view that risk relating to permit and license support should be borne by the public sector, with the normalized data suggesting that all exposures of this type should be assumed by the state. The other areas where the results are consistent with a perception that most risk should be allocated to the Indonesian government related to the reliability of surface exploration data, with a mean score after the second Delphi round of 3.13 (normalized, 65%), plus the reliability of subsurface data and interest rate subsidies both of which scored 3.00 (normalized, 62%). Government contribution to risk sharing was also supported for exploration drilling (2.50, 46%), production and injection well drilling (1.75, 23%),

[17] The fund allocated for this facility originated from the state budget, channeled as a revolving fund for developers or investors of pre-selected green field geothermal sites. If the selected green field confirms a viable proven reserve, the winning bidders are required to pay compensation to the government through PT Sarana Multi Infrastruktur (SMI). Otherwise, the exploration cost is shared between the government and SMI (Wahjosoedibjo and Hasan, 2012).

[18] Two of the risk categories employed in the first part of the analysis were excluded here. First, most of the exposures related to the market risk area are demand-side and external to the projects involved (i.e. low power demand, lack of uptake by electricity companies, failure by uptakers to develop working transmission line(s) plus issues related to PPA negotiations with the uptaker) where contractual parties cannot directly influence either the probability or impact of the exposures involved. Based on the principal-agent approach underpinning the present study, this type of risk factor cannot be allocated (assigned or shared) to any party in a meaningful way. Similarly, environmental risks are excluded as it is assumed that the related risk can be mitigated by using technology (e.g. developments aimed at reducing the noise and impact of H_2S discharge) or by specific policies (e.g. around deforestation and settlement issues).

Table 7
Recent (September 2022) selling price of geothermal electricity.

Capacity (MW)	Ceiling Price							
	Up to 10 MW		>10 MW–50 MW		>50 MW to 100 MW		>100 MW	
	year 1–10	year 11–30	year 1–10	year 11–30	year 1–10	year 11–30	year 1–10	year 11–30
Price ($/kWh)	9.76 x F	8.30	9.41 x F	8.00	8.64 x F	7.35	7.65 x F	6.50

Note: F is the power plant site location factor; F ranges from 1.00 to 1.50.

Table 8
Risk sharing measures.

Risk Category	Proposed Risk-Sharing Measure
Resource and exploration risks	Improved reliability of surface exploration data
	Improved reliability of subsurface data
	Exploration drilling incentives
	Improved feasibility studies
Field development and construction risks	Production and injection wells drilling incentives
	Land acquisition support
	Access road support
Operational and maintenance risks	Resource degradation risks mitigation
	Scaling and corrosion mitigation
Financial and credit risks	Interest rate subsidy
Legal and regulatory risks	Permit and licensing support

Note: This table sets out the proposed risk-sharing measures for each of the five risk categories.

criticality risk factors, the participants generally suggest lower risk-sharing levels (below 25%). The implications of the evidence for each of the five risk areas is now discussed.

4.3.1. Legal/regulatory risk

In the context of geothermal PPP projects, the participants' views were consistent with the notion that legal/regulatory risk should be borne entirely by the government. The study explored the role of three potential risk factors in this area: (i) uncertainty in tax regulation; (ii) uncertainty in tariff regulation; and (iii) delays in licensing. The findings indicate that uncertainty in tariff regulation is a high criticality risk factor, whilst delay in licensing is a moderate criticality risk factor. Surprisingly, uncertainty in tax regulation is perceived as a low criticality risk factor for geothermal projects in Indonesia. More generally, the experts' perception of this area as involving high risk criticality and a need for heavy public sector involvement is consistent with the contention that uncertainty in regulation can lead to high levels of legal risk exposure (Grimsey and Lewis, 2002). The risk usually arises from the possibility of changes in the implementation of the rules that can affect market behaviour (Irwin, 2007). While there is no concrete formulation or mechanism for the allocation of such risk (Vega, 1997) the public sector has more influence on this exposure, assuming that the private sector cannot directly influence regulatory decisions (Arndt, 2000). Therefore, under adverse selection, risks related to legal and regulatory issues have been theorized as being efficiently retained by the public sector (de Bettignies and Ross, 2004; Irwin, 2007) - a contention entirely in line with the experts' views here regarding Indonesian geothermal projects.

As noted earlier, the risk sharing measure employed in this context was permits/subsidy support, consistent with analysis of the Seulawah Agam project, but also with Winters and Cawvey (2019)'s contention that this factor is a critical determinant of legal and regulatory risk exposures. Support for permits and licenses would by its very nature have

Table 9
Empirical findings after first round of delphi survey regarding the level of government risk sharing required.

Risk Area	Risk Sharing Measure	Mean Score	Std. error of mean	Std. deviation	Extent of government risk sharing required (Normalized, 1 = 0%, 5 = 100%)
Resource and exploration risks	Improved reliability of surface exploration data	3.56	0.47	1.42	76%
	Improved reliability of subsurface data	3.11	0.51	1.54	62%
	Exploration drilling incentives	2.44	0.50	1.51	41%
	Improved feasibility studies	1.67	0.33	1.00	17%
Field development and construction risks	Production and Injection wells drilling	1.33	0.16	0.50	7%
	Land lease and acquisition	1.67	0.44	1.32	17%
	Access roads and well infrastructures	1.67	0.29	0.87	17%
Operational and Maintenance risks	Resource degradation risks mitigation	1.11	0.11	0.33	0%
	Scaling and corrosion mitigation	1.11	0.11	0.33	0%
Financial and credit risks	Interest rate subsidy	2.67	0.50	1.50	48%
Legal and regulatory risks	Permits and License supports	4.33	0.33	1.00	100%
Kendall's W	*0.56*				
Cronbach's Alpha Reliability	*0.711*				

Note: This table details the first-round Delphi results regarding levels of government risk sharing required in Indonesian geothermal PPPs.

land acquisition (1.75, 23%), access road and well infrastructure (1.63, 19%), and feasibility study quality (1.63, 19%). The risk relating to operational and maintenance risks (resource risk degradation plus scaling and corrosion problems) was seen as being best borne entirely by the private sector.[19]

An empirical model of risk allocation is shown in Table 11, where the findings from the entire Delphi study are brought together. Inspection of the table reveals that for each of the five risk areas, a link was evident between the identification of high criticality and significant levels of proposed public sector risk bearing. For the risk areas without high

[19] The reliability of the results and the degree of consensus are measured using Cronbach's alpha and Kendal's W coefficient respectively. Whilst Kendal's W coefficient improves from 0.56 in the first-round survey to 0.61 in the second-round, the Cronbach's alpha coefficient is reduced to 0.69 from 0.71, although it remains within the recommended range (de Vaus, 2002).

Table 10
Empirical findings after second round of delphi survey regarding the level of government risk sharing required.

Risk Area	Risk Sharing Measure	Mean Score	Std. error of mean	Std. deviation	Extent of Government risk sharing required (Normalized, 1 = 0%, 5 = 100%)
Resource and exploration risks	Improved reliability of surface exploration data	3.13	0.44	1.25	65%
	Improved reliability of subsurface data	3.00	0.50	1.41	62%
	Exploration drilling incentives	2.50	0.42	1.19	46%
	Improved feasibility studies	1.63	0.37	1.06	19%
Field development and construction risks	Production and Injection wells drilling incentives	1.75	0.25	0.70	23%
	Land lease and acquisition support	1.75	0.49	1.39	23%
	Access road supports	1.63	0.26	0.74	19%
Operational and maintenance risks	Resource degradation risks mitigation	1.13	0.12	0.35	0%
	Scaling and corrosion mitigation	1.00	0.00	0.00	0%
Financial and credit risks	Interest rate subsidy	3.00	0.27	0.76	62%
Legal and regulatory risks	Permits and licenses support	4.25	0.25	0.71	100%
Kendall's W	*0.61*				
Cronbach's Alpha Reliability	*0.69*				

Note: This table details the second round of Delphi results regarding levels of government risk sharing required in Indonesian geothermal PPPs.

Table 11
Proposed Risk-sharing Structure for Indonesian Geothermal PPP projects

Risk Area	**Risk Factor**	**Perceived Magnitude**		**High Criticality Risk Factors Perceived**	**Proposed Risk-sharing Measure**	**Proposed Risk Allocation (Normalised Value)**	
		Impact	**Probability**			**Pub.**	**Priv.**
Resource and exploration risks	Reserve lower than expected	High	High	- Reserve lower than expected (RE-1)	Improved reliability of surface exploration data	65%	35%
	Low reservoir temperature	High	Moderate	- Exploration drilling risk (RE-5)	Improved reliability of subsurface data	62%	38%
	Low permeability	Moderate	High		Exploration drilling incentives	46%	54%
	Reservoir area smaller than expected	Moderate	Moderate		Improved feasibility studies	19%	81%
	Exploration drilling risks	High	High				
Risk Area	**Risk Factor**	**Perceived Magnitude**		**High Criticality Risk Factors Perceived**	**Proposed Risk-sharing Measure**	**Proposed Risk Allocation (Normalised Value)**	
		Impact	**Probability**			**Pub.**	**Priv.**
Field development and construction risks	Engineering design failure	Low	Low	No high criticality risk factor perceived	Production and injection wells drilling incentives	23%	77%
	Production/injection drilling (field development) risks	Moderate	Moderate		Land lease and acquisition support	23%	77%
					Access road support	19%	81%
Operational and maintenance risks	Scaling and corrosion problems	Moderate	Low	No high criticality risk factor perceived	Resource degradation risks mitigation	0%	100%
	Reservoir pressure or temp decline	Moderate	Moderate		Scaling and corrosion mitigation	0%	100%
	Geothermal fluid chemical composition change	Moderate	Low				
	Risk of high NCG gas	Low	Low				
Risk Area	**Risk Factor**	**Perceived Magnitude**		**High Criticality Risk Factors Perceived**	**Proposed Risk-sharing Measure**	**Proposed Risk Allocation (Normalised Value)**	
		Impact	**Probability**			**Public**	**Private**
Financial and commercial risks	Unable to finance the exploration stage	Moderate	High	Unable to finance the exploration stage (FC-1)	Interest rate subsidy	62%	38%
	Unable to finance the field development stage	Moderate	Low				
	Interest rate change	Moderate	Low				
	Inflation rate	Moderate	Low				
	Currency exchange rate risk	Low	Moderate				
Legal and regulatory risks	Uncertainty in tax regulation	Moderate	Low	Uncertainty in tariff regulation (LR-2)	Support for Permits and Licenses	100%	0%
	Uncertainty in tariff regulation	High	High				
	Delay in licensing	High	Moderate				

Note: This table combines the evidence from the Delphi analysis relating to risk magnitudes and proposed risk allocation an influence on tariff uncertainty by building in a measure of capital security, pointing again to a perceived link between risk criticality and the need for government involvement. In this context, the process around land acquisition for Indonesian infrastructure projects is highly complicated, lacking both transparency and rigor (Fan and Nam, 2018), and with highly complex legal and policy frameworks such that government support is essential. The views of the experts involved in the Delphi analysis were consistent with the notion that full insultation for private sector actors around this type of risk is important.

4.3.2. Resource/exploration risk

As regards resource and exploration risks, four risk-sharing measures were identified and included in the Delphi analysis: (i) improved reliability in surface exploration data; (ii) improved reliability in subsurface exploration data; (iii) incentives for exploration drilling; and (iv) higher quality feasibility studies. The participants suggested that the extent to which governments should take on project risk varies across the proposed measures. It was thought appropriate for the government to take on around two-thirds of the risk relating to the data reliability issues and just below 50% of exposure relating to exploration drilling risk. In contrast, the vast majority of risk relating to the quality of feasibility studies was seen as being suitably retained by the private sector. This variability in perceived optimality is consistent with complexities on the ground, notably evidence relating to a recent drilling program designed by the Japanese Government where developers benefitted from a cost-sharing scheme that involved support at the 50% level for exploration wells, but just 20% for production and injection wells (Robertson-Tait et al., 2015).

More generally, the link between a perception of high risk and the need for state intervention is evidenced again, with the three areas where significant government support was suggested aligning closely with the critical risk issues of reserve levels and drilling risk reported in Table 5. Raising the necessary capital from commercial sources can be challenging for private developers at this stage and most of the sector has to reach out to expensive equity providers (Quinlivan, 2015). Thus, risk exposure related to the unreliability of predicted resource data can be a relevant constraint on private sector propensity to become involved in geothermal projects (Nugraha et al., 2017). As Laffont and Martimot (2001) suggest, even when adverse selection conditions are recognized, agents require optimal incentives to motivate them and the evidence provided here regarding expert opinions is in line with this contention.

In geothermal projects, surface and sub-surface investigations are estimated to cost US $0.5 to 2 million depending on the number and type of surveys involved (Quinlivan, 2015). Exploration drilling wells can typically cost up to US $10 million each - with two or three often required - depending on the depth of the well, whilst a feasibility study can cost up to another US $1 million (Robertson-Tait et al., 2015). The apparent perception amongst the experts who took part in the Delphi analysis, where significant state risk-bearing in this context was thought appropriate, is thus commensurate with operational realities, i.e. the need for significant incentivizing of private sector geothermal developers. In Indonesia, the government has committed to provide developers with tax facilities to encourage the development of geothermal energy, but this strategy has not always proved effective in terms of reducing resource risk (Nugraha et al., 2017). Robertson-Tait et al. (2015) argue that the benefits of such incentives are often realized only in the later stage of development and are therefore potentially insufficient to offset early-stage resource risk. In this context, it is notable in the Delphi results that the highest recommended levels of state risk sharing related to data accuracy rather than drilling incentivizing. This perception becomes particularly striking as the Indonesian government, drawing on experiences from the US and Japan, has prioritized a drilling cost-sharing program to reduce exploration drilling risk borne by the private sector (Matek, 2014). As ESMAP (2016) note, cost-shared drilling can catalyze private investment in geothermal development, but this is most likely to be effective when grants designed to enhance the quality of data emerging from surface studies are part of the overall package (IRENA, 2016). In the US, the Geothermal Loan Guarantee Program (GLGP) has been used to reduce private sector financial risk at the exploration stage (Bloomquist, 2003) but only a limited number of developers utilized this facility because of concern about the probability of default that in turn reflected uncertainty around data projections at the exploration stage (Robertson-Tait, 2008). Given these complexities and inherent risk exposures, the experts' view whereby close to two-thirds of the risk related to reliability data should be subsumed by the state appear to be underpinned by outcomes on the ground. The expressed opinions are also consistent with the approach adopted by the Indonesian government where the Seulawah Agam geothermal project has been used as the pilot for a PPP-based cost sharing drilling model. To address risk regarding the accuracy of project data projections, the government provides a convertible grant (and additional equity contributions) to reduce developer exposure. In the case of successful exploration, this grant is then converted into a shareholding, additional to the equity contribution, with the Aceh Province State Owned Company (PDPA) holding 25% of shares at the exploration stage.

4.3.3. Field development and construction risks

Three variables were mobilized to capture risk relating to field development and construction: production and injection well drilling incentives; land lease and acquisition supports; and access road support. Again, the expert opinions imply that links exist between suggested allocations and the prevalence of critical risk factors. In this case none of the latter were identified, with government risk-bearing of less than one quarter (19%–23%) being proposed in each case i.e. low, but not entirely absent, public risk sharing. Unlike at the exploration stage, when field development and construction is in process, most projects are to some extent 'bankable' and able to access commercial loan financing (Pizzutilo and Calò, 2015). However, the expert views here are suggestive of a perception that some limited government support might be needed to buttress activities in the three related areas.

Typically, the risks associated with steam field development are managed by developers via a set of contracts such as drilling and well-testing contracts (Hasan, 2013). In contrast, most of the risks associated with power plant construction are generally transferred to a third party via an EPC contract (Kane and Stiffler, 1999). The risks associated with field development and construction are therefore generally lower than those associated with drilling outcomes, although in practice there is overlap between these issues with, for example, developers requiring substantial land resources and high-quality roads that facilitate efficient mobilization of drilling equipment (Quinlivan, 2015). The existence of this type of relationship between resource production elements is consistent with the evident perception amongst the experts that although most risk exposure is best borne by private firms, state authorities should provide some (non-trivial) support.

The issues related to land acquisition and access roads have been highlighted by Castlerock (2010) who argues that the problems require support from government to deal with the complex procedures and extra cost burdens involved. The complexity of procedures relating to land acquisition in Indonesia has caused construction delays for some projects, with the absence of the high-quality roads needed to transport equipment to sites compounding the problem (Fauzi, 2015; IRENA, 2017). In typical geothermal projects, the lands required for field development and power plant construction, including piping lines, are in the range of 0.4–3.2 ha per megawatt (Office of Energy Efficiency and Renewable Energy, 2019 n.d.). Soltani et al. (2021) note that for a flash-type geothermal power plant, 7460 m^2 of land per mega-watt is required for wells and piping etc. In Indonesia, the land requirement is around 1 ha per MW; for instance, the development of the 92 MW geothermal power plant at Rantau Dedap required a total of 124 ha of land. Meanwhile, the construction of a facility with a 220 MW total planned capacity at the Lumut Balai geothermal power plant needs 242 ha of land, inclusive of the requirement for drilling, cutting and material disposal.

The land acquisition process in Indonesia is further complicated by laws that involve the resettlement of affected indigenous people *(masyarakat adat)*, with the social and economic benefits of any such development required to be demonstrably extensive (PT. Sarana Multi Infrastruktur., 2019). These multi-layered intricacies suggest a clear rationale for the experts' perception that - although not to the extent as was the case at the exploration stage - some state support is required as projects proceed to development and construction phases.

4.3.4. Financial and commercial risk

Interest rate subsidy was employed as the key risk measure in this context and, as elsewhere in the survey, significant governmental risk bearing (in this case 62%) was suggested where the measure closely aligned with identified high critical risk factors - in this case a lack of finance at the exploration stage. From the perspective of lenders operating in environments where issues around moral hazard and adverse selection are likely to be relevant, early stage geothermal projects can be particularly risky (Hasan, 2013), even in developed countries that have broader access to capital markets (Robertson-Tait, 2008).

Financing for geothermal exploration has been a key area of debate in Indonesia for many years, with 25% of projects abandoned at the exploration stage (Murdiantoro, 2018). Much of this failure reflects firms' recourse to equity fund raising with high risk premia or, for larger companies, (often poorly-capitalized) balance sheet financing (ESMAP, 2012). Therefore, the availability of investment support in the early development stage is vital. In this regard, the German government introduced the Market Incentive Program (MAP) for deep geothermal projects in 1999, where long term loans - with a subsidized interest rate - are made available for exploration drilling (Hasan, 2013). The loans available cover up to 80% of exploration drilling costs with interest rates that take account of the uncertainty involved (Schachtschneider, 2013). Critically, in the case of project failure (e.g. dry hole discovery), the loan does not need to be repaid (Sander, 2016). Here, the experts' views suggest a need for state support in the form of a subsidy that would cover more than 60% of the risk involved, indicating that the type of initiative found in Germany might have relevance in an Indonesian PPP setting.

4.3.5. Operational and maintenance risk

The nature of activities in the operational and maintenance stage include the drilling of make-up wells, monitoring, anti-scaling chemical treatments, as well as maintenance of steam line, access roads and other plant facilities (Firdaus, 2000). The existence of chemical constituents in geothermal steam are a critical factor in this context as electricity production is directly affected by steam purity which itself is hard to control as it is strongly affected by geological structure, reservoir type and volcanic activity (Firdaus, 2000). In addition to the presence of steam contaminants (such as chloride and silica) that cause corrosion and scaling in power plant facilities, natural resource decline rates are also a significant problem in the operation and maintenance of geothermal fields (Matek, 2014). Most geothermal fields in Indonesia have moderate to high levels of resource decline rate, with capacity expansion also influencing the fall-off in rates. For example, in 1999 the Kamojang field evidenced a low decline rate of 4.2% but experienced significant increases reaching 9% in 2017 as activity grew (Sanyal, 2000; Nugraha et al., 2017). Higher decline rates can lead to the faster drilling of make-up wells to maintain production at close to initial levels; as a result, more intensive reservoir monitoring is required (Matek, 2014).

As with field development and construction, the absence of any critical risk factors for operational and maintenance risk in Indonesian geothermal PPPs coexists with a perception amongst the experts that exposures of this type are best borne by private sector actors, although in this case it was believed that the full risk exposure should be allocated to the firms involved. Within an agency framework, private companies (as agents) have obvious informational advantages relating to operational and maintenance activities in energy initiatives (Hakam, 2019); the Delphi findings suggest a view amongst participants that these circumstances align with support for the private sector bearing all risks. As the discussion above indicates, the type of exposures involved are typically those where detailed operational knowledge around microlevel scientific processes is critical and the information asymmetry very marked, so much so that the state is not believed by the expert panel - contrary to all other risk areas - to be in a position to offer any support.

5. Conclusion and policy implications

This study provides a detailed analysis of risk exposures around geothermal PPPs in Indonesia. We conceptualise the PPP arrangement as a principal-agent relationship emphasizing incentivisation via optimal risk allocation. Applying the principal-agent framework to risk allocation has been shown to explain the asymmetric information issues in PPP contracts (Shrestha, 2015). In a PPP project, cost and risk are carefully examined and allocated to contracting parties through a concession agreement (ESMAP, 2012) but in conventional geothermal tendering processes the (risk-averse) private sector is exposed to very high exposure levels from the exploration stage onwards (Arndt, 2000). Therefore, if Indonesia is to achieve the growth in geothermal PPPs envisaged by government, sharing mechanisms where the state bears varying levels of risk require careful analysis. Within this framework, the principal (i.e. the state) assumes management of the relationship to achieve an efficient outcome, including overseeing competitive tendering processes that identify competent agents, monitoring the project to ensure delivery and designing an incentive system in the form of risk-sharing mechanisms that attract private companies and thereby create robust competition (Shrestha, 2015). The present study has explored expert views regarding the nature and potential allocation of the primary risks central to this process.

We employed a two-round Delphi survey to analyze the risk factors involved in Indonesian geothermal projects and the optimal basis for allocation of the exposures between government and private firms. After the second round in the process, the participants recognized 4 'high', 9 'moderate' and 14 'low' criticality risk factors. The four high criticality risk factors are related to reserves being lower than expected, doubt relating to tariff regulation, risk exploration drilling uncertainty and an inability to finance the exploration stage. A consistent theme in the perspectives offered by the experts was a strong link between the extent of government risk sharing suggested and the prevalence of risk criticality. For example, it was thought appropriate that all risk relating to legal and regulatory issues should be assigned to the public sector (via support for permits and licenses), whilst factors relating to operations and maintenance - where no high criticality risk factors were identified - was best borne entirely by the private firms involved. As regards resource and exploration risks (where two high criticality risks were suggested) state risk-bearing of more than 60% was suggested in two areas relating to data reliability, whereas for field development and construction risks - where no high criticality risks emerged - proposed government risk allocations of less than 30% were evidenced in all areas. In each case the expert perceptions appeared to align with prior contention in the literature, such that the proposed allocation may provide an informed basis for future PPP geothermal developments that provide Indonesia with a significant, stable flow of power supply going forward, one that better reflects the nation's natural resource levels.

These findings provide a potential roadmap for Government policy in the area. Notwithstanding the limitations associated with the Delphi method that we acknowledge above, the expert views presented here converge in a coherent manner around the notion that areas of geothermal activity associated with high risk require majority state involvement (possibly extending beyond two-thirds of any total resource requirement) whereas less than half this level might be appropriate for project aspects associated with lower risk. Without the emergence of this type of framework, our evidence suggests that the potential benefits to the Indonesian citizenry of its natural geothermal resources are unlikely to be fully realized.

Although any such arrangements will require time to take effect on the ground - and for their impact to be felt - the potential for increased commitment to geothermal projects by state and private parties in Indonesia that both stand to gain from a more appropriate risk-sharing framework appears to be significant. Indeed, the evidence presented here might help provide a basis for authorities' attempts to assuage any hesitancy on behalf of the main parties to engage further in the sector by indicating that a solution exists which enhances the prospects of both governmental and corporate investment generating financial rewards (that reflect de-facto risk exposures) while improving resource outcomes for Indonesia as a whole. As the feed-in tariff for geothermal energy may not be economically attractive for private investment (Yuliani, 2016) the possibility of the government bearing some of the risks normally faced by the private sector through a PPP contract can be critical in encouraging corporate involvement in such investments. In this context, the PPP financing model can effectively buttress the economic viability of geothermal projects via appropriate upstream cost and risk sharing, until the economic value of the feed-in tariff - typically between US$ 11 cents and 17.7 cents/kWh, dependent on field characteristics (Setiawan et al., 2022) - can be achieved. In practice such levels are likely to prove challenging to achieve given the current structure of feed-in tariffs on the ground (Darma, 2016; Setiawan et al., 2022), suggesting that state support may be required over the longer-term.

Whilst it is clear that the challenges facing the geothermal sector in Indonesia are manifold, the findings suggest that an appropriate risk sharing framework that unlocks the potential of PPP to support geothermal investment can be identified and utilized going forward. As Fan and Nam (2018) note, Indonesia's geosciences sector requires development in a wide range of systemic areas, including issues relating to its economic, social, environmental, legal and regulatory contexts if significant social change is to be effected. Whilst the present study does not address these embedded structural issues - and we acknowledge the subjectivity involved in a number of areas in our approach, notably the method employed to identify potential risk factors - the evidence suggests that a tailored approach to risk allocation in the nation's PPP geothermals' programme has the potential to benefit Indonesia's citizenry by taking advantage of key natural resources much more effectively.

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

Data will be made available on request.

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