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The Early Recognition on Hot Dry Rock Systems in Indonesia: An Overview

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ABSTRACT

Indonesia has the biggest geothermal potential in the world since the location has a close relationship within the magmatic belts. However, the current development of geothermal in Indonesia is only about 2.286,05 MW of the existing reserves. The government has a program for energy transition to reduce greenhouse gas emissions, therefore it must maximize the potential of all the geothermal systems, one of which is hot dry rock geothermal. Hot Dry Rock (HDR) also known as Enhanced Geothermal System (EGS) is a geothermal mechanism with less or no natural fractures or fluid exists but has sufficient temperature located at the deep basement. This study tries to provide a review about the initial recognition of HDR potential in Indonesia based on the available published paper/journal/article, together with some preliminary suggestions regarding with the exploration and/or extraction strategies to encourage more researches about HDR in Indonesia to be conducted in the future. The authors emphasize that there are several challenges of HDR in Indonesia related to the advance data-technology that could result in high project cost. Author encourage the collaboration with oil and gas industry that has better data availability related to the basement condition in several area in Indonesia to support future HDR exploration.

1. INTRODUCTION

Indonesia's government is committed to supporting Net Zero Emission Target in 2060. One of its commitments is to increase renewable energy capacity in the power generation mix, including geothermal energy. Based on the Electricity Supply Plan of Indonesia (RUPTL), the utilization of Geothermal energy is expected to meet 5,799 MWe of the installed capacity in 2030. Up to mid-2022, there are 2,292 MWe installed capacity in Indonesia. That means there are still about 3,507 MWe to achieve the target in 2030. Until today, conventional high-temperature geothermal resources have been focused on the most developed geothermal resources in Indonesia (Putriyana, et al., 2022). To achieve the power generation mix and the net zero emission targets, Hot Dry Rock systems (DHR) may have to be considered due to its widely distribution characteristic, although it may take a long time for this system to be finally developed in Indonesia.

The Indonesian government through the Ministry of Energy and Mineral Resources (MEMR) is starting to plan to assess undiscovered geothermal resources, most notably 'uncommon' geothermal systems regarding its potential and distribution for the future development of geothermal resources in Indonesia. The MEMR study incorporates all of the geothermal resources potentials such as superhot/supercritical systems, geopressured & hot sedimentary aquifer, hidden/blind geothermal system, including hot dry rock system (another potential resources will be presented on the separate articles). This effort is a long-term plan of Indonesian government to increase renewable energy capacity in the power generation mix, especially geothermal as one of the commitments to support Net Zero Emission Target.

As described by Moeck (2014), HDR systems are widely distributed over the world, it resides as basement rocks and more preferable at the shallow basement. Thus, in theory, EGS offers the opportunity to access an enormous potential source of domestic clean energy including in Indonesia. Some pilot projects have been conducted in several countries worldwide, i.e small demonstration plants were operating in Soultz-sous-Forêt in the Rhine Graben on the French-German border, while Iceland and United States have ambitious projects on progress (Biello, 2008), while many other projects are currently underway, such as in Switzerland at Basil and Zurich, in Germany at Bad Urach, several locations in Japan, and in Cooper Basin of Australia (Tenzer, 2001 cited on Lund, 2007). But the research that have been conducted in Indonesia regarding with this system is still minimum. This study tries to provide a review about the initial recognition of HDR potential in Indonesia based on the available published paper/journal/article, together with some preliminary suggestions regarding with the exploration and/or extraction strategies to encourage more researches about HDR in Indonesia to be conducted in the future

2. OVERVIEW OF HOT DRY ROCK SYSTEM AND ITS GENERAL STATUS IN INDONESIA

EGS is a concept for extracting the heat from earth's crust at low permeability environment. The heat usually came from crystalline rocks such as granitic rocks with varied temperatures about 150° to 500°C and situated at about 5 to 6 km depths (Potter, et al., 1974 on Breed, et al., 2013). According to Ledésert and Hébert (2012), EGS was invented, patented and developed in the early 1970s at Los Alamos National Laboratory and was first called Hot Dry Rock geothermal system (HDR). As defined by these early researchers, the practical HDR resource is the heat contained in those vast regions of the Earth's crust that contain no fluids in place – the situation characterizing by far the largest part of the earth's drilling-accessible geothermal resources (Brown, 2009). But there is also condition

where the rock does not completely dry and contains some fluid,nown as Hot Wet Rock (Breede, et al., 2013). HDR has non-commercial conditions and needs reservoir creation in crystallin rocks or reservoir enhancement in tight, i.e. low permeability aquifer rocks. The permeability needs to be enhanced through technological solution such as fracturing and/or acidizing depending on formation characteristics (MIT, 2006; Breede, et al., 2013; Moeck, 2014). The fluids need to be injected both to improve the rocks' transmissivity andcharge' the system with 'geothermal fluid' (Moeck & Beardsmore, 2014). The heat must be extracted from the heat source by the following steps (Pruess, 2006).

1. Increasing permeability of the rock by injecting fluid to fracture the rock (fracking) or to re-open the existing fracture.
2. Maintaining the fracture opening by injecting fluids. The fluid will also function as heat transmitter when circulated back to the surface.

Different approaches might be needed to better understand the characteristic of the system. A good awareness of geothermal play in a geothermal investigation in Indonesia including HDR may help to expect essential parameters of the geothermal system (e.g. the occurrence of the system, heat source, heat migration & permeability pathway, fluid composition, etc.). Geothermal play can be defined as a model in the mind of geologist of how a number of geological factors might generate a recoverable geothermal resource at a specific structural position in a certain geologic setting (Moeck & Beardsmore, 2014; Moeck, 2014). According to geothermal play type by Moeck (2014), HDR or EGS can be classified into conductive geothermal play. This classification contains three different types, namely the intracratonic basin type, the orogenic belt type and the basement/crystalline rock type. These types are further considered with respect to the porosity-permeability ratio of the reservoir rock and the absence or presence of producible fluids in the reservoir (see Moeck, 2014).

HDR system in Indonesia may dominantly associate with the igneous-basement play type due to Indonesian close relationship with the magmatic belts within its region such as in Sumatra, Java, and part of Sulawesi. For this condition, to identify HDR resource potential, depending on the temperature, depth and lithological sequence, several geophysical methods can be used, such as magnetotelluric and gravity to detect the granitic body and reflection seismic to identify fracture zones, then the first exploration well relatively is drilled to obtain petrophysical and mineralogical parameters and to verify the stress field for stimulation concepts (Moeck, 2014). However, at the other region such as Kalimantan and Papua, the HDR might be associated with the other play types (i.e. sedimentary basin, orogenic belt, etc). Further assessment needs to be conducted to categorized geothermal play typing for the HDR systems in Indonesia. The knowledge of geothermal play will be very essential to economize the exploration process, to define the play risk, and increase the chances of reservoir discovery (Moeck, et al., 2021). But in general, areas that preferred to be EGS reservoir usually have following key criteria (Rybach, et al., 1978; Brown, et al., 2012; Moeck, 2014; Sun, et al., 2015):

1. The reservoir candidate should be impermeable and the fracture is minimum to keep the artificial system confined and to minimize the geothermal working fluid loss outside the system.
2. Area with higher heat anomaly is preferred (at least with geothermal gradient 40°C/km) in order to minimize the drilling depth to get optimal heat.
3. The targeted heat source must have sufficient rock formation that covers the system to prevent the heat released to the surface.
4. Good understanding of the stress field within the prospect area to better understand fracture distribution on the subsurface and reduce risk in fracking process.

In Indonesia, there is just a few numbers of studies that discuss the potential of hot dry rock or enhanced geothermal system and it is still in very early or preliminary stage, i.e Sihombing, et al. (2015), Prabowo, K., et al. (2015), Hendrawan, R.N. and Draniswari (2016). Due to minimum research about the HDR systems in Indonesia, the characteristic of the resources in Indonesia is not well understood and the knowledge of its potential and distribution is still currently unknown. In addition, as already explained, HDR system or EGS may have certain risks regarding its characteristic (low permeability) and the need for advanced technology (fracturing permeability at big depths). An absence of surface thermal discharges as initial feature to indicate the occurrence of geothermal resources could be also a challenge to discover the system. Exploration and/or extraction techniques such as applied in the conventional temperature system might be different. These kinds of things will lead to very high resource risk that also will have an impact to its economic value and cause the development of the system may less attractive.

3.SOME PRELIMINARY STUDIES ABOUT HDR/EGS POTENTIAL IN INDONESIA

According to Hendrawan and Draniswari (2021), the Indonesian basin setting is prolific for developing the EGS system since it experienced complex tectonic conditions with the thick sedimentary formation that could have good heat generation. The EGS/HDR potential in Indonesia has been studied in North Sumatera Basin, South Sumatera Basin, West Java Basin, East Java Basin, and Tarakan Basin. The distribution of Indonesian EGS/HDR potential is shown in *Figure 1* (Hendrawan and Draniswari, 2021; ESDM, 2023).

The research by Hendrawan and Draniswari (2021) shows that South Sumatera Basin is the largest HDR/EGS (928.4 m^2) potential area in Indonesia, while the highest potential occurred in North Sumatera Basin (112.8 MW). The research also found that the basement depth is the primary factor of EGS/HDR potential calculation and it is supported by lineament distribution, structural characteristics, and lithology. The EGS/HDR potential is likely associated with the extensional part and the depocenter of the basin due to better heat generation conditions.

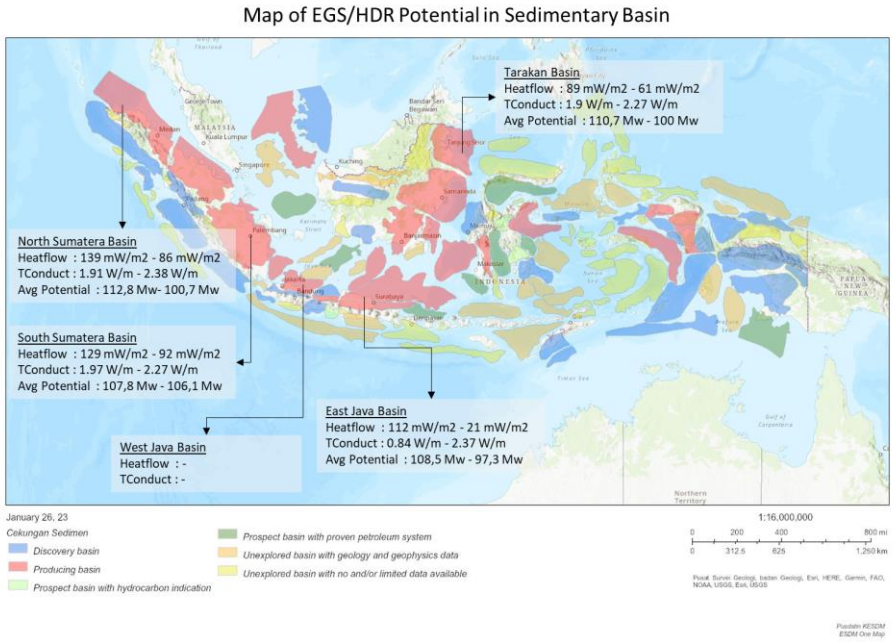

Figure 1 **Map of EGS/HDR study in Indonesia sedimentary basin (modified from Hendrawan and Draniswari, 2021).**

Aside from Sumatra, Prabowo et, al. (2015) also indicates the potential of HDR development in the Tarakan Basin, Kalimantan, with total potential is about 9 to 192 MW. The potential market demand as a non-technical aspect in the Tarakan basin also shows promising conditions. The current electrification in the Kalimantan area is mainly supported by coal-fired power plants that have issues related to excessive carbon emission. Government of Indonesia is planning to accelerate the phasing out of coal as electricity base load, which could provide the potential of geothermal utilization, especially EGS/HDR, as new baseload to fulfill the future electricity demand in Kalimantan area. EGS/HDR also coult utilize the carbon from the coal-fired plant as a working fluid for the EGS/HDR utilization (Sihombing, et al., 2015)

Kommentiert [GS1]: Reference and needs broader explanation

4.CURRENT LIMITATION FOR HDR/EGS DEVELOPMENT

Although EGS has many advantages, many issues need to be solved before this energy can be utilized extensively. The main barriers are cost and technology. Technical and economic problems linked to such deep drillings (Rafferty, 1998 on Ledésert and Hébert, 2012), where the EGS requires reaching the zones where the heat is high enough for electricity production, at great depth. Drilling deep to subsurface and fractured the hot rock with large volume of water, requires pumps that can withstand high pressure and temperature at depth. Accurate knowledge is also required to create "man-made" reservoir through hydraulic fracturing to pinpoint where fractures are re-opened or created (U.S. DOE, 2012; Moeck, 2014). It must be done accurately to prevent reservoir characterization from extending too much, leading to water losses and affecting sustainability of EGS. In addition, seismic risk has to be fully taken into account when EGS programs are to be developed in urban areas to produce both electricity and central heating (Giardini 2009, cited on Ledésert and Hébert, 2012). A project in Basel (Switzerland) had to be stopped because three earthquakes measuring more than 3-richter scale, that generated by hydraulic stimulation in a naturally seismic area (Biello, 2008; Ledésert & Hébert, 2012).

Authors identify the challenges to the HDR/EGS development in Indonesia at least related to 1) technological complexity that led to high project cost and 2) the suitability of HDR/EGS to current state geothermal law. The HDR/EGS required advanced subsurface study to characterize the natural fracture network and stress characteristic for fracturing purposes such as high-resolution 3D seismic, image log, and petrophysical log (Moeck, 2014). Those advance and high-cost studies, especially for 3D seismic, not commonly conducted in Indonesian-developed geothermal fields resulted in a high required additional cost to explore HDR/EGS in previous geothermal areas. Otherwise, those data are available in oil and gas fields especially that targeting fractured basement play (i.g Jabung field-South Sumatera basin, Saka Kemang field-South Sumatera basin), which is located in similar area with HDR/EGS potential area based on Hendrawan & Draniswari (2021)

Current Indonesian regulation by Law 21/2014 defines the geothermal systems as the basis for determining prospect area should be consisted of several aspects such as heat sources, reservoir, recharge area, capping, upflow, and outflow that concentrate on the reservoir with significance as source of energy. The definition might not be applicable to HDR/EGS system that has difference

characteristics to conventional geothermal system. It could raise additional uncertainty related to the legal aspect. At least several preliminary approaches may reduce those challenges, such as:

- The collaboration between oil/gas and geothermal stakeholders to explore HDR/EGS potential in area that overlap with oil/gas fields. The HDR/EGS prospecting in the area that already has required data would not put significant additional cost, especially for the data acquisition.
- Further review related the suitability of the current state of geothermal law to HDR/EGS characteristics to reduce the uncertainty about the legal basis of HDR/EGS development. A more apparent legal basis is vital to future development.

5.CONCLUDING REMARKS

Indonesia shows promising preliminary potential for EGS/HDR resources in several area such as North Sumatera Basin, South Sumatera Basin, and Tarakan Basin. The further development of EGS/HDR would faces several challenges related to the technological complexicity, advance survey and , and high cost project. The further development of EGS/HDR research could be improved by collaboration with upstream oil/gas industry to obtain more reliable data related to the basement condition in several area and also conduct review to current geothermal law with objective to reduce the uncertainty related to legal aspect of EGS/HDR development.

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