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JICA’s Global Geothermal Development Assistance

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ABSTRACT

The purpose of this paper is to explain the main ideas behind JICA’s assistance in developing geothermal resources globally. This paper discusses the main challenges that JICA’s assistance addresses with respect to geothermal development: (a) managing high resource development risks and (b) securing large upfront investment.

Public institutions have an important role to play especially in the early phases of a country’s geothermal development. They are in the position to take more up-front risks, diversify risks, and accumulate data on geothermal resources. If governments can improve capacity for conducting geological surveys, supervising drilling operations, and evaluating geothermal reservoirs, then the achievements in each of these areas can positively impact all geothermal development stakeholders.

Geothermal development requires diverse and highly qualified human resources that need to be trained in theory and in practice over a long period of time. Therefore, geothermal development organizations must have long-term plans for developing their staffs′ capacities. Overseas training is effective, but regional, national, and in-house training programs need to be established in order to train a wide range of qualified professionals.

Financial assistance and capacity development are both indispensable. Concessional financing for geothermal power plants is effective because more than half of the geothermal power’s generation cost is composed of capital cost.

In this paper, JICA’s energy policy as well as its philosophy for geothermal development will be discussed. Then, a brief history of JICA’s approximately six decades of global assistance will be provided. Finally, JICA’s on-going and planned geothermal projects will be explained.

1. INTRODUCTION

The Japanese government and JICA have assisted partner countries in developing geothermal energy since the 1970s. In 1970, the Japanese government and UNESCO supported Kyushu University to start a geothermal training program that ran until 2001 (Fukuda et al., 2000). From the 1970s to 2000s, JICA’s assistance abroad was concentrated mostly in Asia and Latin America. In the 2010s, JICA shifted its focus to include the Great Rift Valley in order to help its partner countries to unlock their large geothermal potential. In 2014, JICA started a scholarship program (“Kizuna” program) for geothermal experts to obtain masters and doctoral degrees as well as to gain hands-on experience through internships. In 2016, JICA launched three short-term training schemes in Japan: a six-month training course for geothermal engineers in Kyushu University (Itoi et al., 2020), a six-week training program for drilling managers, and a two-week executive program.

This paper discusses the main challenges that JICA’s assistance addresses with respect to geothermal development: (a) managing high resource development risks, (b) securing large upfront investment, and (c) improving cash flow alongside operation and maintenance of plants and reservoirs.

The paper begins with a broad overview of JICA and its energy policy, followed by a synopsis of its views on the advantages and challenges to exploiting geothermal energy. A brief history of Japan’s geothermal development is then discussed, followed by case studies highlighting JICA’s global assistance. The paper concludes by discussing further challenges JICA and the client countries confront in realizing the latter’s geothermal potential.

2. THE ADVANTAGES AND CHALLENGES OF GEOTHERMAL DEVELOPMENT

In this section, we will explain the advantages and challenges of geothermal energy and how JICA intends to tackle the latter. It will be followed by discussion on the government’s roles in leading surface surveys and taking upfront risk, the need for capacity development, and the role of concessional financing. It will then explain JICA’s assistance strategy for the global geothermal sector.

2.1 Advantages

Geothermal energy’s advantages are that it is cheap, clean, stable, and a domestic energy source. According to the International Renewable Energy Agency (2018), geothermal energy’s global weighted average levelized cost of electricity (USD 0.07/kWh) was lower than solar photovoltaic (USD 0.10/kWh) and slightly higher than hydropower and onshore wind (USD 0.05/kWh and 0.06/kWh respectively). Meanwhile, the amount of carbon emissions is as low as hydro, wind, and solar (IRENA, 2017).

Although there are high risks during the upstream development stages, geothermal energy can be used as a base load power for decades if it is maintained properly. As an example, Kenya's Olkaria I Units 1, 2, and 3 have generated power for more than three decades. The units will undergo rehabilitation, and we expect that the upgraded units will provide power for another three decades. For many countries, having a stable, non-variable, and domestic energy source is paramount to their national energy security.

2.2 Challenges and proposed measures

The main challenges pertaining to geothermal energy that JICA addresses are (a) high resource development risks especially during the test drilling stage, (b) large upfront investment, and (c) managing cash flow for proper operation and maintenance of plants and reservoirs. Improving the return on equity of geothermal projects is indispensable to promote this form of energy, all the more so now that it is increasingly competing against resources such as solar and wind that are more accessible due to rapid decline of production cost and short construction period.

Resource risks and financial risks are extremely high in the early stages of geothermal development. There are two specific bottlenecks: (a) low success rate of exploratory drilling for reservoir identification and (b) high drilling cost. According to Energy Sector Management Assistance Program (2012), both resource risk and financial risks are high up until the point where the resource is confirmed by test well drilling. Once the test well drilling successfully confirms the existence and exact location and potential of a geothermal reservoir, then the risk decreases significantly. Securing funding for this high-risk stage is challenging, as is successfully implementing a test well drilling operation once funds are secured. Meeting that second challenge will depend not only on technical drilling skills, but also on the quality of surface surveys, conceptual modeling, and institutional efficiency of the developing institution.

The following sections explains the important role of governments in promoting geothermal development, need for capacity development of geothermal professionals, and role of concessional financing in addressing challenges pertaining to geothermal energy.

2.2.1 Role of governments in early stages of development

Geothermal resource development risk is extraordinarily high. It is therefore difficult for private companies to take upstream risks unless they have enough financial capacity to be able to diversify their risk. Kaneko et al. (2020) explains that operators with enough financial means can spread risks by drilling in multiple locations, instead of drilling solely in one location. In that case, even if 6 out of 10 targeted drillings fail, the remaining 4 successful drillings would be sufficient to cover expenditures for the expected power plant.

Public sector can take or share upstream development risks that are usually too high for the private sector to cover. A series of surveys led by the Japanese government from 1980 to 2010 is a good example. From 1980s, Japan's New Energy and Industrial Technology Development Organization (NEDO) undertook a series of nation-wide surveys over three decades to create an inventory of prospective sites. This laid the groundwork for nearly two decades of accelerated growth in geothermal development (Figure 1). One of the lessons learned from this experience is that accumulation of high quality data of underground resources is important for geothermal development to prosper. Based on the Japanese experiences and similar cases abroad, it could be said that the following three measures could contribute to accelerating geothermal development.

(a) If the government proactively takes development risks in upstream development stages by conducting surveys and publishing their results, it can contribute to lowering the private sector's risks and encourage their participation.

(b) Government institutions are well positioned to take the risk of exploring underground resources. This risk can be significantly reduced by developing appropriate human resources.

(c) It is effective to provide financial support on favorable terms to governments for the exploration of geothermal resources.

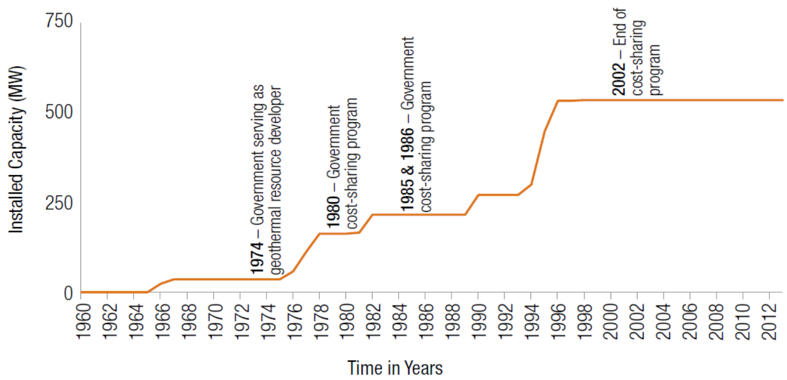

Figure 1: Installed Geothermal Power Capacity over Time in Japan (ESMAP, 2016).

Under these circumstances, which are marked by the transfer of risk and responsibility from the private sector to the public (governmental) sector - and apart from the necessary large-scale financial assistance - there is an urgent need to develop the capacities of core human resources in order to ensure further geothermal development. If governments can take the lead in improving the accuracy of geological surveys, developing supervising capacity for drilling operations, and evaluating geothermal reservoirs, then the achievements in each of these areas can positively impact all geothermal development stakeholders.

2.2.2 Need for capacity development

Geothermal development requires diverse and highly qualified human resources, i.e. financial planning and management, procurement, project management, contract management, drilling, safety, power plant design, construction, operation and maintenance, social and environmental management, etc. Also, geoscientists with both theoretical and practical training in geology, geochemistry, geophysics, and reservoir engineering are needed. But these human resources cannot be developed overnight. Therefore, institutions responsible for developing geothermal resources must have a long-term plan for developing their staffs' capacities.

Decades of overseas training in countries such as in Iceland, New Zealand, Italy, or Japan have been very effective in this regard. But overseas training is not sufficient to fill the large capacity gap of countries with geothermal potential. In order to fill the gap, there should be a regional training institution, as well as internal training system in each geothermal development organization so that a wide range of staff are trained on the job. JICA's technical cooperation with Kenya's GDC from 2014 to 2019) aimed to train the trainers so that they can produce and update their own training modules for the other company staff.

Improving drilling capacity can also reduce the risks of individual geothermal projects and improve profitability. The rationale for this is that capacity development contributes to improved drilling success rates, which could then minimize project delivery period and therefore cost. About 24% of the total installed cost of is for geothermal drilling (IRENA, 2017). A geothermal well can cost anywhere from three to eight million dollars. Improving drilling success rate and reducing unsuccessful wells can reduce the overall capital cost of the project. Saito and Sakuma (2002) conducted a comprehensive review of drilling problems due to human error that occurred within the geothermal group of Japan Metals & Chemicals Co., Ltd between 1988 and 2001. They categorized these observed problems into the following three main types; (a) leaving tools and/or equipment behind around the well, resulting in accidentally dropping them down the hole, (b) stuck pipe due to well walls collapsing, and (c) breakdown of machine or spare parts

Because these actions are human errors, they can be improved through capacity development training. Theoretically, if the frequency of human errors - such as dropping tools down wells - decreases, time wastage will decrease and the drilling period can be shortened. We therefore contend that capacity development contributes to improved drilling success rate and lowers the overall cost of geothermal wells. Saito and Sakuma then suggest ways to improve operation management, amongst which the following actions stand out: (a) training of drillers, (b) renew stabilizers and other machines and implement recording systems of these machines, (c) reconsider the frequency of drill string examination and examination standards, and (d) conduct regular maintenance.

JICA's on-going technical cooperation project (2013 to 2019) with Kenya's Geothermal Development Company (GDC) provides a good example of the effect of capacity development on drilling success rate as well as efficiency. By improving drilling success rate and efficiency of drilling, a developer will be able to save significantly on upstream development cost. In the JICA/GDC project, can , number of days to drill a well improved by 69%. The rate of penetration (ROP) of its drillers improved by two-fold in four years from a baseline of 25 ROP m/day to 50 ROP m/day in 2018. The accuracy of targeting improved as well. After the project GDC was 18% more likely to drill a well that discharged successfully. During the project, 13 wells were drilled with no failed (unproductive) wells. Also, the accuracy of drilling improved. GDC drilling crew are 8% more likely to reach the target depth. Before the project, there were one or two foreign drilling crews on site. After the project, GDC drilling crews are able to conduct drilling, including directional drilling, on their own. These improvements will translate into savings of several million dollars per well. That is why JICA emphasizes the importance of capacity development.

2.2.3 Role of concessional financing

Concessional financing for geothermal development is effective because more than half of the geothermal power's generation cost is composed of capital cost. According to Kaneko et al. (2020), the ratio of capital cost in generation cost of geothermal power plants is around 70%, whereas that of coal-fired plants is around 30% (more than half of coal-fired plant's generation cost is the fuel cost). Therefore, if concessional financing can bring down the capital cost of geothermal, then it will have a high impact on lowering generation cost.

For example, in Kenya, KenGen's geothermal power plants that utilized public concessional financing currently sells electricity around 4 cents/kWh lower than other geothermal IPPs in Kenya (Kaneko et al., 2020). JICA has financed 350MW, or 40% of total geothermal installed capacity in Olkaria (Olkaria I Units 4, 5, and 6, and Olkaria V)[1]. Moreover, Olkaria I unit 1 to 3 is under rehabilitation using JICA loan.

Financial assistance and capacity development are both indispensable. For example, even if finance is available, if the developing institution lacks the capacity to implement a project, it will experience difficulty such as delays, drilling failures, and cost overrun. Conversely, it would be difficult to start or continue a geothermal development project by solely implementing capacity development, since such projects require a huge amount of investment and can suffer from a lack of funds.

The next section will explain JICA's historical and current support to geothermal development.

3. JICA'S ASSISTANCE STRATEGY FOR THE GEOTHERMAL SECTOR

JICA is a bilateral agency in charge of administering Japan's Official Development Assistance (ODA). JICA has 96 field offices worldwide. JICA is guided by the Japanese government's Development Cooperation Charter (Feb. 2015). JICA's budget during

[1] calculated by total certified geothermal capacity by KPLC

Japanese fiscal year 2019[2] was approx. 1,784 billion Japanese Yen (approx. 16.2 billion USD[3]). JICA has three main instruments for its cooperation: (a) finance and investment (sovereign concessional loans and private sector lending and investment), (b) grant aid, and (c) technical cooperation. JICA combines these three instruments and tailors them to the needs of individual client countries.

The Japanese government is committed to promote geothermal energy development. For example, at the Sixth Tokyo International Conference on African Development (TICAD VI) [4] held in Nairobi, Kenya in August 2016, Prime Minister Abe announced that Japan will assist its partner countries in delivering electricity derived from geothermal sources to 3 million households by 2022[5]. In 2018, the Japanese government became an official member of Global Geothermal Alliance (GGA) that aims to increase geothermal electricity capacity by five-fold and direct use by two-fold.

JICA's strength is that it can support its client countries in the whole value chain of geothermal development. Starting from master-planning, surface surveys, test drilling, feasibility planning, construction of power plants, and operation and maintenance. In the upstream phase (from surface survey to test well drilling) where resource and financial risks are highest, JICA usually provides grant-based assistance. If several test wells are successful, in countries that are eligible for JICA's sovereign loans, JICA can negotiate providing loans for further production drilling as well as plant construction.

JICA's main tools for assistance are (a) technical cooperation (such as master planning, surface surveys, capacity development projects, training programs), and financial assistance through (b) grants and/or (c) finance and investment cooperation (including ODA Loans and Private-Sector Investment Finance). JICA's six activities for mitigating risks and removing barriers associated with geothermal development are;

(1) **Geothermal development policy and master planning** to prioritize potential geothermal development sites in a country. JICA also provides technical advice to promote public-private-partnerships (PPP) and stimulate private investment (example: Indonesia, Kenya, Peru, Ethiopia, Rwanda).

(2) **Surface surveys and exploratory drilling projects** that contribute directly to identifying geothermal resources. Since 1973, JICA has assisted its partner countries to conduct 19 geothermal resource surveys (some including test well drilling) in 13 countries (Guatemala, Chile, Kenya, Philippines, Indonesia, Argentina, Thailand, Mexico, Turkey, China, Peru, Ethiopia, and Rwanda, in chronological order. TENPES, 2017). JICA is currently supporting exploratory drilling in four countries (Ecuador, Nicaragua, Ethiopia, Djibouti. Ecuador has completed its first well). In order for JICA to improve the success rate of exploratory drilling, JICA conducts a rigorous surface survey to develop a conceptual model as well as exploratory drilling plan. Then it convenes an external advisory group made up of professors and well-experienced developers and drillers to solicit vital technical advice on selected targets and drilling plans in these countries.

(3) **Finance and Investment Cooperation** for steam field development, and power plant construction projects (Philippines, Indonesia, Costa Rica, Nicaragua, Bolivia, and Kenya). JICA's ODA Loans and Private-Sector Investment and Finance have so far contributed to approximately 1,536 MW[6] of installed capacity in its client countries (of which 440MW are rehabilitation of existing plants). Considering that the world's geothermal installed capacity is 15, 406 MW (ThinkGeoEnergy, 2020), JICA has contributed to actualization of around 10% of the global geothermal capacity. Currently, a further 291 MW are currently in development (of which 51 MW are rehabilitation) using JICA ODA loans.

(a) **JICA ODA loans:** So far, total signed ODA Loan agreements are around 388 billion yen (3.5 billion USD equiv.). JICA's ODA loan is quite concessional and it can be as low as 0.01% interest, 40 years repayment period, with 10 years grace period. JICA is currently diversifying and expanding its portfolio. In the past decade it has increased its lending four-fold from 57 billion yen to 225 billion yen.

(b) **Private Sector Investment Finance (PSIF)**. In 2017, through a fund capitalized by JICA and managed by the Asian Development Bank (ADB), Leaading Asia's Private Infrastructure Fund (LEAP)[7], the ADB signed a 109 million USD financing package for the Muara Laboh geothermal power generation project in western Indonesia. The finance package includes 20 million USD loan from LEAP.

(4) **Grant aid** can also be provided for small scale well-head geothermal power plants (Ethiopia)..

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[2] The Japanese fiscal year is from April 1 to May 31.

[3] Exchange rate: 1 USD=110 JPY

[4] The conference was led by Japan and co-organized with the UN, UNDP, the World Bank, and the African Union Commission (AUC). The Japanese government's delegation to TICAD VI was headed by Prime Minister Abe. 53 African countries were represented at the conference and a business mission with leaders from 77 organizations, including Japanese businesses and universities, accompanied the delegation https://www.mofa.go.jp/af/af1/page3e_000551.html

[5] https://www.mofa.go.jp/afr/af2/page4e_000496.html

[6] Breakdown by countries: Philippines 725.97MW(53%), Indonesia 185MW(14%), Kenya 350MW(26%), Costa Rica 110MW(8%)

[7] LEAP was established in March 2016. The fund is an infrastructure co-financing fund, expected to leverage and complement ADB's existing nonsovereign platform to fill financing gaps and increase access to finance for infrastructure projects in the region..The Fund is capitalized by $1.5 billion in equity from JICA.

(5) **Capacity building and human resource development** to train a range of personnel related to geothermal development. There are short-term training courses of less than one year in Japan: (a) 6 months course for geothermal resource engineers, (b) 6 weeks course for drilling managers, and (c) 2 weeks course for executives. It also provides long term training for public sector officers to obtain masters and doctoral degrees in Japan. JICA also implements technical cooperation projects, sending teams of experts to develop capacities of geothermal development institutions and ministries of energy (Kenya, Indonesia).

(6) **Joint research development** in exploration technology to improve success rate of exploration and establish a monitoring system for long-term utilization of reservoirs (El Salvador and Indonesia. Project currently being prepared in Kenya).

4. GLOBAL GEOTHERMAL DEVELOPMENT ACTIVITIES

This section will provide an overview of JICA's activities in three regions—Latin America, Asia, and Africa.

4.1. Latin America

JICA has a long history of geothermal development assistance in Latin America starting in the late 1970s in Chile. So far, JICA has directly supported 10 countries (Mexico, Guatemala, El Salvador, Nicaragua, Ecuador, Costa Rica, Peru, Bolivia, Argentina, and Chile) to develop their geothermal potential. On top of that, surveys have been conducted in Saint Vincent-Grenada, CARICOM, and in Colombia to seek potential for collaboration. Brief outline of activities is described below.

i) Finance

JICA's first successful power plant in Latin America was Mira Valles power plant in Costa Rica. Based on the feasibility study conducted in 1982, Overseas Economic Cooperation Fund (OECF), one of the predecessors of JICA, signed an ODA loan agreement with the Costa Rican government to develop 55MW of geothermal power. The power plant came in to operation in 1994.

A total of around 160 billion Japanese yen (approx 1.45 billion USD) of loan agreements have been signed with Costa Rica (1985, 2014, 2017) and Bolivia (2014 and 2016). Currently, 110 MW of JICA supported geothermal power is in operation in Costa Rica (55MW at Mira Valles and 55MW at Las Pailas II). Additional 155MW of geothermal power is currently being developed in Costa Rica (Borinquen, 55MW) and Bolivia (Laguna Colorada, 100MW).

In Ecuador and Nicaragua, JICA is taking upstream risks by conducting grant based test well drilling. In Chachimbiro in Ecuador, JICA supported drilling of a successful test well in 2018 (expected capacity is 50MW). In Mombacho, Nicaragua, JICA is preparing to conduct test well drilling. The expected capacity of the site is around 30MW. If the test wells succeed in identifying geothermal resources, then JICA will consider providing concessional ODA loan including drilling additional evaluation wells as well as designing of the power plant.

ii) Exploration

Since 1978, JICA has conducted grant based geothermal resource surveys in Chile (1978-1981), Mexico (1987-1988), Argentina (1987-1992), and Guatemala (1998-2001). In Amatitlan Guatemala, JICA's survey implemented by West Jec identified 40 MW of geothermal potential. The geothermal site was offered to IPPs, and awarded to Ormat.

In Peru, JICA conducted a master plan survey from 2010 to 2012. Based on its findings, JICA is currently discussing with the Peruvian government to start a capacity development project with Geological Mining and Metallurgical Institute (INGEMMET).

In El Salvador, University of El Salvador, La Geo, Tohoku University and other Japanese institutions are conducting a joint research project under SATREPS scheme (2017-2022). The project aims to reduce exploration cost and time by developing a new geothermal exploration method using thermo-luminescence technique that can delineate extension of geothermal activities using by capturing geothermal signs over a wide range of areas. The joint team is accumulating existing exploration data in GIS and integrate the new data with simulation technology for geothermal reservoir hydrothermal flow evaluations using big data analysis technologies.

4.2 Asia

JICA's geothermal development assistance to Asian counterparts started in the late 1970s. In Asia, JICA's largest clients are currently Philippines and Indonesia. In Philippines, a total of 904.4MW of geothermal power in operation was supported by JICA. In Indonesia, a total of 130MW was supported by JICA. Additional 240MW is in development.

4.2.1. Philippines

In the Philippines, 1980s and 1990s were when geothermal development accelerated due to the governments supportive policies. During this period, JICA provided concessional ODA loans to develop 805.97MW of geothermal power. This is equivalent to around 42% of Philippines's geothermal installed capacity (1,918 MW as of Jan 2020). The geothermal power projects that JICA supported are: Northern Negros (49.4MW, COD:2007), Mak-Ban (rehabilitation, 220MW. Completion: 2006), Tiwi (rehabilitation: 220MW, completion: 2006), Palinpinon II[8] (80MW, COD 1995), Pailinpinonn I (112.5MW), and Tongonan (112.5MW).

[8] JICA (OECF at that time) co-financed with the World Bank. Japanese side financed the steam gathering system, wells (8 total), and transmission line.

The power plants that JICA supported were initially operated by NPC and PNOC-EDC until 2001 when the EPIRA law was enacted. After EPIRA, NPC and PNOC-EDC were privatized and the operators of the power plants changed to AP Renewables Inc. and First Gen.

4.2.2. Indonesia

In Indonesia, geothermal energy is expected to play a major role in the electricity supply as base load energy. Indonesia has second largest geothermal energy resources in the world at 23,966MW. As a result of steady efforts by the Indonesian government in the 2000s, the policies and institutions in geothermal sector have improved, resulting in increased investment into the sector. Between 2007 and 2017, installed geothermal capacity grew nearly two-fold from 980 MW to 1,805 MW. JICA ODA loan projects have so far contributed to an installed capacity of 240 MW, or approximately 15% of total installed capacity (2,133 MW) in Indonesia. JICA has been providing comprehensive support to the Indonesian government, contributing in solving three main challenges; i) finance, ii) policies and institutions, and ii) human resource.

i) Finance

Total commitment of Japanese ODA loan in geothermal development amount to approximately 110 billion JPY (1.1 billion USD equiv). JICA started providing ODA loan for geothermal power plants developed by a state owned power utility, (PT. PLN), in Lahendon (20MW) in 2004 and Uluelu (110MW) in 2005. Both projects (130 MW in total) are currently in operation.

In 2011, JICA expanded its recipient to PT.PGE, a geothermal subsidiary of PT. Pertamina, to develop power plant in Lumut Balai (110MW) which was a first case for JICA to cover steam gathering facility in Indonesia. In addition, to accelerate geothermal development, both the Japanese and Indonesian governments agreed to implement the Geothermal Development Acceleration Program (GDAP) in 2011, which is an umbrella financing framework of future individual loan project up to approximately 55 billion JPY. Under this innovative umbrella agreement, two projects in Hululais (110 MW) and Tulefu (20MW) are in preparation. A total of 240 MW of expected geothermal power is in development in Lumut Balai, Huluais, and Tulefu.

In addition, in 2017, through a fund capitalized by JICA's Private Sector Investment and Finance (PSIF) and managed by the Asian Development Bank (ADB), Leaading Asia's Private Infrastructure Fund (LEAP), the ADB signed a 109 million USD financing package for the Muara Laboh geothermal power generation project in western Indonesia. The Muara Laboh geothermal power plant officially started its commercial operation at capacity of 85MW.

ii) Policies and institutions

JICA has contributed policy reforms of Indonesian government especially in roadmap, tariff pricing and exploration risk mitigation, in order to open the investment opportunity to both public and private entities. Along with first revision of the geothermal law in 2003, JICA commenced technical cooperation to prepare a geothermal masterplan in 2006 with the Ministry of Energy and Mineral Resources in Indonesia. The master plan prioritized each geothermal resource area in Indonesia, showing a roadmap for geothermal energy development to reach its target of 9,500MW by 2025. The Indonesian government undertook a second revision of geothermal law in 2014.

From 2014 to 2020, JICA and the Indonesian government implemented the *Project to Develop Medium and Long Term Geothermal Development Policy in Indonesia*. The project assisted the Indonesian government to formulate proper pricing policy for electricity sales from geothermal power plants. In addition, the project supported revitalizing the geothermal fund, which was funded by Indonesia's Ministry of Finance to provide developers with risk money for exploration. In 2020, JICA and the Indonesian government started a second phase of the project, *The Project to Develop Medium and Long Term Geothermal Development Policy in Indonesia (Phase 2)*. The objective of the Phase 2 project is to formulate specific geothermal development projects by supporting operation of the MoF's geothermal fund. Furthermore, in late 2020 JICA has started a survey to support Indonesian national geothermal developer, PT. Geo Dipa Energi, to conduct exploration activities in two cites in Java by utilizing geothermal funds. As the Indonesia government advances its policy reforms, JICA continues to support its counterparts to overcome the above issues through the project.

iii) Human resources

As already explained, improving geothermal human resource capacity is crucial, especially to reduce exploration risk. JICA conducted a technical cooperation project from 2014 to 2019 to transfer the knowledge to the engineers in the Geological Agency of the Ministry of Energy and Mineral Resources who are responsible for conducting resource surveys before providing the geothermal working area with public and private entities.

A joint research cooperation is ongoing between Bandung Institutes of Technology and Kyoto University under the the Science and Technology Research Partnership for Sustainable Development (SATREPS) scheme (2014-2019). The project aims to improve resources identification success rate by integrating non-drilling survey methods such as satellite remote sensing and geomorphological analysis.

4.3 East Africa

The following section highlights JICA's assistance in Kenya,Ethiopia, and Djibouti following a region-wide survey that JICA conducted in 2010. A brief overview is as follows.

In 2010, JICA conducted a comprehensive survey spanning five countries; Kenya, Ethiopia, Djibouti, Tanzania, and Uganda to understand the region's geothermal potential, geothermal development policy and roadmaps, and the state of human resources and equipment in the sector. The survey provided important information for JICA to ramp up its efforts in the region. Since then, master plan studies and reviews were conducted in Ethiopia (2015), Rwanda (2016), and Kenya (2017).

In Kenya, JICA has implemented a technical cooperation project to assist GDC to develop its capacity in resource exploration. In 2020, JICA and United Nations Industrial Development Organization (UNIDO) started a project to assist KenGen to upgrade its operation and maintenance of Olkaria geothermal field using Internet of Things (IoT) technology.

In Ethiopia, JICA is conducting a feasibility study for an ODA Loan project to construct a geothermal power plant in Aluto Langano. It is also providing grant aid to construct a wellhead geothermal power plant in the area using steam from the two test wells drilled with assistance from the Japanese government and the World Bank. JICA is also taking upstream risks and preparing to drill exploratory wells in Tendaho, Ethiopia.

In Djibouti, JICA conducted a nation-wide survey to understand geothermal development potential there and to prioritize prospective sites based on economic and technical analysis. After three years of surface surveys, JICA and the Djiboutian government began a technical cooperation project focused on exploratory drilling in Hanle, Djibouti.

4.3.1 Region-wide survey

In 2010, JICA conducted a comprehensive survey spanning five countries; Kenya, Ethiopia, Djibouti, Tanzania, and Uganda to understand the region's geothermal potential, geothermal development policy and roadmaps, and the state of human resources and equipment in the sector. The survey, *Situation Analysis Study on Geothermal Development in Africa* (2010), concluded with several recommendations for how JICA can assist its partner countries. Following the survey, JICA conducted similar studies in 2013 in Rwanda and Southern African countries (Malawi, Mozambique, and Zambia). The main findings of the 2010 survey were as follows.

(a) Governments should take a leading role in upstream development, since private companies are unlikely to participate in the development of areas where there are no exploration wells. The Kenyan government is currently playing a leading role in the country's geothermal development in precisely this manner. Therefore, the Kenyan model is recommended as a successful model for the rest of East African countries.

(b) The number of equipment and geothermal professionals (engineers and geo-scientists) in each country are seriously lacking. Local universities are not sufficiently equipped in terms of the capacity of lecturers to train geothermal engineers. Therefore, a regional training institution is necessary. Moreover, equipment for geo-scientific analysis, drilling, vehicles, weather stations, GIS, etc. is lacking.

The survey then recommended that JICA should take upfront development risks by undertaking initial surveys including the drilling of exploration wells. It also recommended that JICA should closely link its in-Japan training programs with development projects in the trainees' countries so that the trainees can directly utilize their skills on-the job after returning to their country.

4.3.2 Kenya

The Government of Kenya has prioritized geothermal development in the country's long-term development plan-*Vision 2030*-with the anticipation of generating 5,000 MW of electricity from geothermal resources. JICA has supported this goal since the late 2000s by signing three ODA Loan projects for constructing geothermal power plants in the Olkaria, providing three technical cooperation projects alongside the GDC and KenGen, and dispatching Public-Private Partnership (PPP) experts to the Ministry of Energy and Petroleum. So far, 280 MW of JICA supported geothermal power plants are in operation. An additional 70 MW is currently under construction and 51 MW is under rehabilitation.

Finance

JICA has so far signed three ODA loans agreements with the Kenyan government for geothermal development. In total, these loans amount to JPY 84.5 billion (around 768 million USD) and will support construction of geothermal power plants with 401 MW of electricity generation capacity.

(a) In 2010, JICA signed the first Japanese ODA loan agreement to construct Olkaria I Units 4 and 5, with 140 MW (2 x 70 MW) of capacity. The plant was commissioned in 2015. Utilizing the remaining loan balance, a contract for the construction of an additional Unit 6 with 70 MW of capacity is currently being constructed.

(b) In 2016, a second Japanese ODA loan agreement was signed to construct Olkaria V Geothermal Power Plant Units 1 and 2, as well as for the installation of a steam gathering system, substation, and transmission line. The total capacity of this Plant is 140 MW, and construction completed and came into operation in 2019.

(c) In 2018, JICA signed the third loan agreement to rehabilitate the oldest geothermal power plant-Olkaria I Units 1, 2, and 3. The first unit of Olkaria I started operations in the 1980s, so the plant has reached the end of its life-span. The plant's total current capacity is 45 MW (15 MW per unit). After rehabilitation, the plant's output will be upgraded to a total net capacity of 51 MW (17 MW per unit), and it is expected to provide power for another 30 years.

JICA is also currently supporting the construction of a double circuit 400kV transmission line from Olkaria to Lessos (230km), a 220kV transmission line from Lessos to Kisumu (70km), and three substations. The loan agreement for these transmission lines was signed in 2010 and construction is ongoing. The project will contribute to strengthening the grid in order to allow for additional generation capacity and to transmit power to the poorly connected western region of the country. The project will also act as gateway to the East African Power Pool connectivity, as AfDB is financing another transmission line from Lessos to Uganda.

Strengthening GDC's capacity

In 2009, the Kenyan government established GDC to further accelerate geothermal development in Kenya. GDC's role is to take upfront risks associated with resource exploration and steam development. It is tasked with conducting surface surveys, exploratory drilling, resource evaluation, appraisal and production drilling and supplying steam to Independent Power Producers (IPPs).

In 2013, four years after GDC's establishment, JICA and GDC started a technical cooperation project, *The Project for Capacity Strengthening for Geothermal Development* in Kenya. The project aims to improve GDC's capacity to manage technical risks, so that it will be able to supply geothermal plant operators with sufficient steam. This project was completed in December 2019.

Through this technical cooperation project, JICA experts trained GDC staff on-the-job in geothermal fields, mainly in Menengai. Training was provided for the full spectrum of geothermal development, from surface surveys, exploration, and plant design. GDC staff were trained in geosciences, reservoir engineering, drilling, environmental and social considerations, direct use, plant engineering, and economic and financial analysis of projects. Each course was tailor-designed based on interviews with staff from each GDC department. The project will jointly produce training modules for GDC staff. At project completion, GDC is expected to conduct its own course, as well as to continuously improve its contents.

The project sent 109 international experts to Kenya (mostly from Japan and Philippines) and trained a total of around 500 GDC personnel in seven professional areas; (a) geosciences and reservoir engineering, (b) drilling, (c) environmental and social considerations, (d) plant engineering, (e) direct use, (f) business development, and (g) project management and finance. 71 GDC staffs also received training in Japan. By the end of the project, 21 certificates and 25 technical handbooks were developed and handed over to GDC for them to utilize in their in-house training. The project also assisted GDC to reevaluate the Menengai geothermal reservoir for the 105 MW IPP project. This helped GDC to assure the IPP developers and financiers of the technical feasibility of its steam supply.

In 2014, a year after the GDC capacity development project started, JICA and GDC started another technical cooperation project, the Project for Reviewing GDC's Geothermal Development Strategy in Kenya. This project re-evaluated five prospects: Arus, Baringo, Korosi, Chepchuk, Paka, and Silali. It also revised the estimates of resource potential at 8 sites[9] using the volumetric method, while detailed surveys, conceptual model, and well targets were developed for Paka, Korosi and Chepchuk. The project reviewed GDC's existing strategy and made recommendations. It was completed in 2017.

Following these technical cooperation projects, JICA is currently implementing a survey that will to collect and analyze current status of geothermal development in Baringo, Suswa, Bogoria-Silali and Menengai. The project will also analyze the current geothermal Public Private Partnership (PPP) models in Kenya. The survey results will inform JICA's future assistance to develop Kenya's geothermal resources.

Using Internet of Things (IoT) for operation and management of power plants

JICA is currently implementing a technical cooperation project that aims to improve KenGen's capacity to maintain and operate its Olkaria geothermal field. The project will be an initial step for Olkaria geothermal field to evolve into an Internet of Things (IoT) system.

JICA is collaborating with United Nations Industrial Development Organization (UNIDO) in order to achieve a common goal of improving the efficiency of KenGen's power plant operation and improving its profitability as a result. UNIDO is responsible for installing the IT infrastructure, and JICA is responsible for training KenGen's engineers to improve its O&M.

With the installation of the IT infrastructure in KenGen's geothermal power plants, it will be able to collect and store appropriate information and data related to O&M of its power plants and the geothermal reservoir. In addition, through JICA's O&M project, KenGen will be able to monitor plant operations in real-time, predict problems with analysis based on data storage, plan efficient and economical maintenance and repair schedules based on long-term operational data plus inspection data collected during maintenance, and manage the reservoir via measuring, monitoring, and modeling.

Joint Research project

A joint research project among Kyushu University and West Japan Engineering Consultants on Japanese side and Jomo Kenyatta University of Agriculture and Technology, University of Nairobi, KenGen, Kenya GDC on the Kenyan side is currently being prepared. The project aims to develop a conceptual model of geothermal systems in the Rift Valley Zone using hybrid geophysical survey and data analysis, temperature distribution estimation based on resistivity data, and integrated interpretation using GIS.

The expected model will be higher in resolution than the current one because it will use densely arranged measurement points for gravity surveys and MT surveys, as well as using passive seismic survey. By densely arranging measurement points and using precision measurement tools for gravity survey, a more precise gravity anomaly with higher spatial resolution than before can be detected. Also, by conducting MT surveys with more densely arranged measurement points, more precise resistivity distribution with high spatial resolution can be obtained. Moreover, by using passive seismic survey, 3 dimensional S-wave velocity structure from surface to 5km depth and source locations (i.e., fluid pathway) can be estimated. By densely arranging measurement points of passive seismic survey, spatial resolution can detect more detailed crack distribution (flow-path of geothermal fluid).

The project will also examine Silica scale formation mechanisms and know-how of data interpretation of geothermal fluid as well as develop a model for cascade use of geothermal energy.

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[9] Paka, Korosi, Chepchuk, Arus, Baringo, Barrier, Namarunu and Emuruangogolak

These researches will help develop geothermal resources in East African Rift Valley more sustainably. Strengthening collaboration between academia and industry is expected to contribute to strengthening the research capacity of Jomo Kenyatta University of Agriculture and Technology and University of Nairobi.

4.3.3 Ethiopia

Master Plan

From 2013 to 2015, JICA conducted *The Project for Formulating Master Plan on Development of Geothermal Energy in Ethiopia*. The main purpose of the project was to enhance the capacity of Geological Survey of Ethiopia (GSE) by supporting the formulation of a master plan for geothermal energy development and through training programs in both Japan and Ethiopia.

The Project Team jointly composed of JICA consultants and GSE assessed geothermal resources of 22 sites in Ethiopia based on existing information, remote sensing analysis, field geological and geochemical survey followed by its laboratory analysis, and environmental-social impact assessment. The Team then prioritized the sites based on geothermal potential, social and environmental consideration, economic viability and generation cost.

The financial analysis revealed that the generation cost could be lower than the present exporting tariff level if the sites that ranked the highest in both financial and technical viability are developed with concessional financing programs such as World Bank loans. It could even be lower than the export and domestic tariff level if the same sites are developed with very concessional financing programs such as Japan's ODA loans. However, if the same sites were developed by private funds, the generation cost will exceed both exporting and domestic tariff levels.

The team recommended that if private investments are to be promoted, financial and/or institutional supporting policies will have to be established. It also recommended that a public entity that can handle projects with public financing schemes with low interest rates should implement geothermal development whenever possible, especially when geothermal development is in the early stages.

The Team also conducted geophysical surveys in Tendaho-Ayrobera and Boseti. Based on the geophysical survey conducted, the outer limits of geothermal reservoir were preliminarily inferred for each site, and targets of test wells were proposed. Training programs were conducted both in Japan and in Ethiopia in the following areas: remote sensing, geophysics, reservoir evaluation, geochemistry, database with 3D modeling, fluid analysis, simulation, drilling technology, advanced technology, and geothermal development.

Aluto Langano

At Aluto Langano, in Ethiopia, Japan has been supporting several projects including test well drilling, installation of wellhead generator, and feasibility study for construction of a power plant.

From 2010 to 2016, the Japanese government and the World Bank supported the drilling of two exploratory wells, reservoir evaluation, drilling training, and rig maintenance. In December 2017, JICA signed an agreement with Ethiopia to provide up to approximately 1.8 billion yen in grant aid for the *Project for Installation of Geothermal Wellhead Power System* (installed capacity of 5 MWe). The wellhead power system will utilize the steam from the two exploratory wells. The installation of a power system is now ongoing.

Since 2017, JICA also has been implementing a preparatory survey an ODA loan project, *Aluto Langano Geothermal Power Generation Project*. The main components of this project will be the construction of a geothermal power plant (expected capacity of 35 MWe) and its related facilities. The survey will propose the design of the power plant and related facilities (such as transmission lines) based on resource evaluations of 22 well drillings in the Aluto area, including in Langano and Bobessa, (which the World Bank is supporting).

Test well drilling project in Tendaho-Ayrobera

From 2015 to 2017, JICA implemented a surface survey at both Tendaho-Ayrobera and Boseti under the *Data Collection Survey for Geothermal Development in Ethiopia*. After calculation of geothermal potential of both sites, Tendaho-Ayrobera, with estimated geothermal potential of around 100 MW, was proposed as a hopeful site for test well drilling. The survey also formulated a conceptual reservoir model and drilling plan for the site.

Based on these data, JICA is now planning to support test well drilling at Tendaho-Ayrobera and detailed surface survey at Butajira. Capacity building of counterparts is planned to be conducted simultaneously.

Policy advice

In 2016, Japan's Agency for Natural Resources and Energy of the Ministry of Economy, Trade, and Industry (METI) organized a joint workshop with the Ethiopian government to stimulate discussions and deliver suggestions on options for establishing an integrated institution for geothermal development. During the workshop, various ideas were proposed to the Ethiopian government regarding different roles the government and private sector can play to accelerate geothermal development. Different ideas and point of views were exchanged through the workshop. The dialogue covered the pros and cons of i) possible institutional structures to expedite geothermal development and ii) geothermal development by private companies and State-Own-Enterprises. The discussions were based on JICA's analysis of different country models, characteristics of geothermal development such as development investment cost, and comparisons of practical experiences in other countries.

4.3.4 Djibouti

The Government of Djibouti's Vision 2035 aims to transform from a power importing to a self-sufficient country. It aims to harness the rich geothermal resources that have remained untapped until now.

In 2013, when Prime Minister Shinzo Abe visited Djibouti, H.E. President Mr. Ismaïl Omar Guelleh requested the Prime Minister to assist Djibouti to develop its geothermal resources. Following the request, JICA and Djiboutian Geothermal Energy Development Office (ODDEG) conducted a country wide survey and identified 13 potential sites to be developed. Out of these sites, Hanle-Garrabayis was selected as a site to be further explored. After nearly two years of surface survey, a conceptual model and a drilling plan for exploratory drilling in Hanle was developed. The test well drilling project aims to drill up to three exploratory wells, and at the same time, aims to develop ODDEC's capacity to supervise and manage geothermal drilling. So far, 40 ODDEG staff have received training in Japan.

4.4 Training course and researches in Geothermal Development

In 2016, responding to requests from client countries, JICA started three new training courses for geothermal development in Japan. The course is intended for JICA's partner countries worldwide with geothermal potential. More than 35 organizations from the public sector, private sector, and universities are collaborating for these courses. JICA also has programs that offer Masters and Ph.D. courses to engineers and scholars from client countries. JICA is aiming to host 480 African participants in these courses over 10 years as a commitment made at the Fifth Tokyo International Conference for African Development (TICAD V) in Yokohama, Japan in 2013.

(a) **Geothermal Resource Engineer Training Course**: a 6-month course with an emphasis on practical training for engineers in geology, geochemistry geophysics, and reservoir engineering that has been implemented since 2016 by Kyushu University in collaboration with Tohoku University, National Institute of Advanced Industrial Science and Technology (AIST), developers, and consultants.

(b) **Drilling Manager Training Course**: 6-week course implemented since 2016 together with developers and drilling contractors that aims to enhance drilling managers' capacity to supervise drilling contractors. A unique textbook including failure case analysis based on practical geothermal development experiences in Japan was prepared for this course.

(c) **Geothermal Executive Program**: One and a half week program for directors in geothermal development planning implemented since 2016 together with ministry officials, consultants, developers, and manufactures.

(d) **Masters and Ph.D Program**: Master's and Ph. D courses for engineers in geology, geochemistry, geophysics, and reservoir engineering, implemented since 2014 as Kizuna Program (a program targeted for countries with natural resources) and African Business Education (ABE) Program.

4.5 Securing funds for development

JICA can provide Japanese ODA loans for governments to take upfront risks for exploratory surveys, development of production and reinjection wells, and plant construction. Japanese ODA loans are available with low interest rates and long repayment periods.

Since 2010, JICA has financed approximately 85.3 billion Japanese Yen (approx. 77.5 million USD) for geothermal development projects in Kenya, with an expected installed power capacity of 401 MW.

5. CONCLUSION

This paper discussed the important roles governments can play to diversify risk, take up-front risks, and accumulate data on geothermal resources. It argued that if governments can take the lead in improving the accuracy of geological surveys, developing supervising capacity for drilling operations, and evaluating geothermal reservoirs, then the achievements in each of these areas can positively impact all geothermal development stakeholders.

It also argued the effectiveness of developing technical capacity of government institutions in charge of geothermal development. Capacity development can contribute to improving economic viability of individual projects. Training drillers and drilling managers can reduce accidents and drilling time, thereby cutting overall project cost. Improving accuracy of geoscientific surveys and geothermal reservoir evaluation can also contribute to reducing cost by improving the success rate of drilling.

Geothermal development requires diverse and highly qualified human resources that need to be trained in theory and in practice over a long period of time. Therefore, geothermal development organizations must have long-term plans for developing their staffs' capacities. Overseas training is effective, but in order to develop a wide range of qualified personnel, regional and national training institutions are also necessary, as well as internal training systems in each geothermal development organization.

Financial assistance and capacity development are both indispensable. Concessional financing for geothermal power plants is effective because more than half of the geothermal power's generation cost is composed of capital cost.

Based on these ideas, the paper introduced various ways in which JICA is combining financial assistance with improvement of government capacity to support its partner countries to develop their rich geothermal resources potential.

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