GEOCAP

Geothermal Capacity Building Program Indonesia - Netherlands

GEOCAP Handbook

GEOCAP contribution to the Geothermal development in Indonesia

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FOREWORD

Dear Reader,

In front of you lies the GEOCAP Handbook for Geothermal Development. GEOCAP is a bilateral program between Indonesia and the Netherlands that has been running since 2013 as a public-private partnership involving universities, knowledge institutes and companies from both countries. The prime objective of GEOCAP was to contribute to the development and uptake of geothermal resources in Indonesia particularly in the new to be developed areas outside of Java. For this purpose an elaborate and advanced state-of-the-art training and research program has been developed focusing on issues related to exploration, production, governance, legislation and environmental issues involving the full chain from exploration through project development to exploitation. This focused not only on energy generation but also on direct use applications of geothermal resources. Within the 8 targeted training work packages, training materials were developed and subsequently train-the-trainer workshops were given to empower the next generation of geothermal tutors with state-of-the-art education materials. These were used to assist universities, technical and vocational education and training centres to develop their curricula in geothermal. Research has been focused on real-world problem solving in the context of uptake of geothermal resources in Indonesia. This Handbook is a preliminary version of an education package that will be provided in fall of 2018 for geothermal training institutes to be used to develop and enhance their curricula.

This results of the project is presented in this handbook based on their themes. There are seven themes included in this book (see the figure 1).

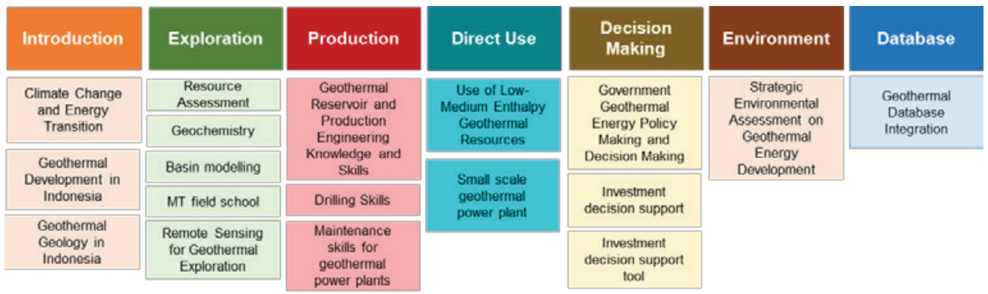

Figure 1 GEOCAP Handbook Structure

The bigger picture of all this effort is combating climate change in response to agreements made in Paris in COP21. Our climate is changing, global temperatures are rising, more frequent and severe hydro-meteorological disasters occur as a result of atmospheric CO2 emissions in large related to fossil fuel burning. Energy transition to renewables is one way to mitigate this and reverse the trend. Besides hydro, solar and wind energy, geothermal energy generated from the natural heat of the earth is an potential source of renewable energy. This is largely confined to areas with high heat flows which are typically areas in geologically active zones such as the subduction zone of Indonesia is.

Indonesia is in the world's top ten of geothermal energy producers and in the top ten of countries in terms of geothermal resources. Only a fraction of the resource is currently being exploited but the government has a strong policy in place to boost that development. This training Handbook could serve as a catalyser for curriculum development in geothermal, it also may serve as a resource providing a state of the art overview of our collective Indonesian-Netherlands knowledge on geothermal development, it may serve as a means of informing policy makers on the do's and don'ts' of geothermal exploration and it may serve as a means to promote geothermal energy development to the broader public.

Figure 2 The GEOCAP community

Freek van der Meer (University of Twente) – GEOCAP project leader

Sanusi Satar (INAGA) – GEOCAP project leader

Tia den Hartog (University of Twente) – GEOCAP project manager and coordinator

GEOTHERMAL CAPACITY BUILDING PROGRAMME INDONESIA-NETHERLANDS (GEOCAP)

Indonesia is with 220 million people and a GDP estimated around US$800 billion in 2010 one of the largest economies in Southeast Asia. The economy has been steady growing over the past decade, mostly in the range of 5 to 6 percent per year. Although the economy in 2013 has seen a slight set back in its growth, the forecasted developments are very positive. The population growth rate along with the economic growth impacts on the countries need for infrastructure (e.g., schools, hospitals, housing, roads), resources (e.g., food, water, electricity), and jobs. This economic growth has also led to increasing demand for electricity that has averaged around 8 percent growth per year. It is envisaged that Indonesia's energy demand is planned to grow 30-fold in 2050. PLN, the national power company, has struggled to mobilize investments to sustain the demand in energy. In 2006, the Government of Indonesia the adopted the Fast-Track Program designed to rapidly develop 10,000 MW of generation capacity utilizing the relatively inexpensive coal resources that is abundant in the country. This resource is cheap but the downside is that it is results in massive CO2 and dust emissions, which are hazardous to the people, and environment and negative contribute to climate change. Indonesia however is also committed to international agreements on greenhouse gas emission. The government launched the INISIATIF ENERGI BERSIH (More Energy, less Carbon), the Indonesian effort to limit the impact of climate change caused by greenhouse gas emissions. This initiative proposes a 9,500 MW of Geothermal electricity generation to be commissioned by 2025 that will reduce 69.5 million ton CO2 annually and over 2,085 million calculated over a 30 year. Indonesia, being located in the ring of fire, a large magmatic arc of active volcanoes, has among the world's largest resources of geothermal energy or energy generated from natural heat produced by the Earth through volcanic processes. There are presently two main hurdles to overcome that limit the development of geothermal energy: lack of skilled and trained personnel to explore, produce and exploit the resource and the competition between exploration and protection of forest areas as most of the suitable locations for geothermal energy are located in protected forest areas. To achieve the ambition of the Government of Indonesia to increase energy production from geothermal resources to 3556 MW in 2014 and 12.332 MW and to support the 20 new geothermal working areas, geothermal companies will need earth scientists (geophysicist, geologists, geochemist) but also engineers, economists, land conservation experts and legal experts. In part, university-level personnel will be required but also a range of technician-level personnel will be needed. At present there is not enough skilled personnel to fill the existing gaps hence a nation-wide capacity building program is needed. It is difficult to assess the capacity needed both in volume as well as in level of education. The Netherlands Embassy, through Agenschap.NL started to assist BAPPENAS in 2009, to accelerate investments in geothermal areas. On 14 October 2011, the National Development Planning Agency of Indonesia (BAPPENAS) by its Directorate for Energy, Mineral Resources, and

Mining issued a program for 'proposed technical assistance' aimed at establishing a National Geothermal Capacity Building Program (NGCBP). The Geothermal Capacity Building Program – Indonesia-Netherlands (GEOCAP) specifically refers to the Indonesian-Netherlands capacity-building program that is seen as a contribution to NGCBP.

The objective of the NGCBP program issued by BAPPENAS was to increase the capacity of Indonesia's Ministries, Local Government Agencies, public and private companies and knowledge institutions in developing, exploring and utilization of geothermal energy sources, and to assess and monitor its impact on the economy and environment. BAPPENAS formally asked to Netherlands to support Indonesia in its quest to develop geothermal resources. A broad Indonesian-Netherlands partnership between the Consortium and relevant and interested Indonesian partners that jointly hold all required knowledge and expertise to support the request was formed. Because of the nature of its members, both in Indonesia and in the Netherlands, the partnership took the form of a Public-Private Partnership (PPP). The main goals of the BAPPENAS capacity building program to which the IND-NL PPP developed its program were:

- Support and strengthen with technical assistance the proposed Project Management Unit (in BAPPENAS) and two Project Implementation Units (one in MEMR and one in ITB/PGE, research and master's program in geothermal).
- over a three year period, strengthen, ITB, Universitas Gadjah Mada and Universitas Indonesia to develop and teach high level specialized geothermal program for senior geothermal experts
- over a three year period, provide capacity for up to 17 Universities (see table below) with planning and assisting relevant government authorities and institutions with the development and supervision of implementation of geothermal projects (both through direct and indirect utilization of steam) including but not limited to i) social, environmental and forestry management plans, ii) geothermal business development, iii) geothermal disaster risk management.
- Train local University lecturers and staff in remote heat sensing methodologies and building on the training put together a resource map for developing Engineered Geothermal Sites.
- Train local university staff to identify, develop and appraise small and medium scale business, which will utilize geothermal energy other than electricity.
- Train university staff and staff from Badan geologi MEMR and district energy bureaus of local governments to utilize a publicly accessible geothermal database, which will also be developed by the universities under this project.
- to upscale the activities Geothermal Energy addressing the need for trained personnel (e.g., scientific staff in Universities, National and local Government staff, Management and technical staff in Companies). For each MW of installed geothermal energy, 1.7 FTE additional personnel is required. At the current ambitions of the Indonesian government, the sector should grow to around 12000 employed in 2025 and 30000 employed in 2050.

The Geothermal capacity building programme Indonesia-Netherlands (GEOCAP) is a public-private partnership (coordinated by INAGA and the University of Twente) of Indonesian and Dutch Universities (Institut Teknologi Bandung, Universitas Gadjah Mada, Universitas Indonesia, University of Twente, Delft Technical University, Utrecht University), knowledge institutes (TNO - Netherlands organisation for applied scientific research), companies (IF Technology, DNV-GL). GEOCAP reports to an advisory board chaired by BAPPENAS with INAGA forming the secretariat. Members are the Rectors of the participating Indonesian universities, the Embassy of the Kingdom of the Netherlands, Directorate General of the New and Renewable Energy (MEMR), Directorate General of Human Resources, Science, Technology and Higher Education (RISTEK-DIKTI), president of INAGA, Head of BPSDM (MEMR).

GEOCAP is funded by the Ministry of Foreign affairs of the Netherlands and received co-funding from BPSDM and in-kind funding and data from several Indonesian geothermal companies.

GEOCAP contributes to build capacity of Indonesian Ministries, Local Government, Agencies, Public and Private Companies, and Knowledge Institutions in developing, exploring and utilization of geothermal energy resources and to assess and monitor its impact on the economy and the environment. The programs aims to lay the foundations of a long-term sustainable relationship between the Netherlands and Indonesia in form of Knowledge-to-Knowledge cooperation, Business-to-Business cooperation and Government-to-Government cooperation. The present GEOCAP has a number of intimately linked components:

- A Education and Training program; focusing on developing capacity at university and technician level in support of the development of the geothermal sector
- A Research program; addressing the real needs of the sector and solving real life problems related to exploration, exploitation of geothermal resources as well as environmental and legislation issues.
- A database program; to collect, standardize, digitize, store surface and disseminate subsurface information relevant to geothermal development.
- A program focusing on the use of-low and medium enthalpy resources.

GEOCAP started in January 2014 and runs until end 2018 although several research projects will outlive the lifetime of the program and there are modest facilities in place for outreach and sustaining training activities.

GEOCAP: GOVERNMENT-TO-GOVERNMENT COOPERATION

In terms of government-to-government cooperation, GEOCAP hosted as part of the annual year plan discussion held in Delft where representatives from the Ministry of Energy of Indonesia, the Ministry of Foreign Affairs of the Netherlands and INAGA (the branch organization of geothermal in Indonesia) presented the current policies on renewable energy uptake. It is clear that our countries foster the uptake of renewable energy. For the Netherlands, this is a direct result of the COP21 agreement. In September 2013, a society-wide Energy Agreement for Sustainable Growth was signed between industries, non-governmental organizations and governments leading to a low CO_2 energy economy and an increased share of renewable energy (14% by 2020 and 16% by 2023). Recently the Energy Report was issued focusing on 2023 and beyond again fostering a CO_2 neutral energy supply system by 2050 taking on board three main principles: 1) focus on CO_2 reduction; 2) make the most of the economic opportunities that the energy transition offers and 3) integrate energy in spatial planning policy. Geothermal plays a key role in this energy transition. The Indonesian the economy grew by 5-6% per year with population growth of 1.2% per year and a growth of the energy supply by 7-8% per year. The country is still highly dependent on fossil fuels and the utilization of renewable energy and implementation of Energy Conservation has not been optimized yet. The government of Indonesia has set itself the ambition to reach 23% and 31% renewable energy usage in 2025 respectively 2050. To speed up the uptake of geothermal a number of legislations have been put in place to simplify the licensing process, to provide incentives for geothermal development (tax holiday, import duties, value-added tax, etc.), with attractive

tariffs and a national banking policy support. There is also harmonization of regulations among sectors ongoing (MEMR, Forestry, MoF, Local Government, etc.). Now there are 51 projects in the pipeline. For further acceleration, the Government is implementing a Feed-in Tariff mechanism. Based on the Government Regulation no. 79/2014, new renewable energy in Indonesia must contribute 23 % of the energy mix and 12-13% will be from Geothermal. It has been determined that by 2025, the geothermal development must reach 7200 MW or in other word, it will require additional of approximately 5700 MW. Currently installed capacity is 1493 MW by the end of 2016, additional capacity will come from Lahendong 20 MW, Karaha Bodas 30 MW and Sarulla 110 MW. Next, other geothermal working areas will be developed such as Hululais, Lumut Balai of PGE, Sarulla another 110 MW, Supreme Energy etc. EBTKE also planned to tender 30 GWA during 2016 - 2026. In 2016, the first successful tender was Gunung Lawu, (165 MW) won by Pertamina, then Wai Ratai (55MW) won by Enel from Italy.

GEOCAP also participated in the Netherlands Trade Mission to Indonesia headed by Prime Minister Mark Rutte accompanied by Ministers Schultz, Ploumen and Dijksma. During the Mission we organized a seminar on renewable energy transition bringing together stake holders from Indonesia and the Netherlands to share best practices on energy transition toward a CO2 neutral society (government-to-government cases), best practices in business cases for easing the uptake of renewable energy (business-to-business cases), best practices in capacity building and the labour market for geothermal personnel (knowledge-to-knowledge cases) and to align forest conservation and geothermal exploration seeking best practices (government-to-government cases). This through a discussion between Vice Minister of Energy and Mineral Resources Indonesia Mr. Archandra Tahar, president of the Confederation of Netherlands Industry and Employers VNO NCW Mr. Hans de Boer, Director General of New and Renewable Energy Mr. Ir. Ridha Mulyana, MSc, Head of the Human Resources Development Agency, MEMR Mr. Dr. Ir. Djajang Sukarna and several GEOCAP experts.

GEOCAP collaborates directly with BAPPENAS and MEMR and maintains a liaison with the Ministry of Environment and Forestry.

GEOCAP: KNOWLEDGE-TO-KNOWLEDGE COOPERATION

In terms of Knowledge-to-Knowledge cooperation, GEOCAP has been active in establishing long-term sustainable means of collaboration in education and in research. In education, we see the need of assisting universities outside of Java in fast track developing their university curricula in geothermal. The three main Indonesian University partners have a sustainable master program in geothermal, however such programs are in large lacking in the islands outside Java. Despite that many of the proposed (e.g., 51) working areas for geothermal are outside Java and on the other main islands. For these working areas to be developed, local skilled personnel is needed. Thus, GEOCAP is opening up its training workshops to trainers of these universities in particular. GEOCAP has an agreement with BADIKLAT now BPSDM (the training centre of the Ministry of Energy) to enable to support more colleagues from outside Java to join its trainings. The long-term aim is to select a number of these universities and as a follow up to GEOCAP assist them in curriculum development possibly in form of joint education programs. GEOCAP has also been pioneering in setting up so called joint (or double) degree PhD programs between the three university partners in Netherlands and Indonesia (co funded by LPDP). Possibly this could be channelled as part of the cooperation under an MoU signed on 22 April 2016 in the Hague by Dutch minister Bussemaker and Indonesian Minister of Foreign Affairs Retno L.P.

Marsudi. In 2016, GEOCAP established the first joint supervision-sandwich PhD program to which six PhD candidates enrolled. These candidates will obtain their PhD through joint supervision from two (one Netherlands and one Indonesian) universities and they will spent half of their research time in the Netherlands and in Indonesia. Initially it was our ambition to develop this program as either a double degree (two degrees, two certificates) or a joint degree (one joint degree and one certificate) to honour the bilateral equal partnership of GEOCAP. However, this was found impossible, as RISTEK DIKTI (e.g., Ministry of Education in Indonesia) back then has no regulation in place to support joint/double programs at PhD level. We had meetings with LPDP and BAPPENAS had meetings with RISTEK DIKTI, which resulted in a legislation from DIKTI that put the responsibility and mandate for joint supervision programs with the Indonesian universities. GEOCAP has also contributed to the development of a joint research agenda for bilateral collaboration fostered by the KNAW and AIPI (e.g., the Netherlands and Indonesian science foundation respectively). With the end of the Scientific Program Indonesia the Netherlands (SPIN) on the horizon, and taking into account significant changes in both our countries concerning institutions, scientific and societal agendas, the KNAW took the initiative for a process of stocktaking. Together with scientists and stakeholder institutions, we wanted to find out what the strengths of our cooperation and networks is at this moment, which scientific ambitions and goals are on our radar and how those scientific ambitions could contribute to answering national and international challenges and problems. We have used the knowledge and strength of the Dutch and Indonesian members of our networks, who all contributed to the identification of themes, defining the scientific and societal importance, and indicating the connections and synergies within the resulting circle of themes. GEOCAP also was part of the scientific organizing committee of the eighth KNAW Open Science Meeting 2017. These Open Science Meetings have become a modern tradition in the scientific cooperation between Indonesia and The Netherlands.

GEOCAP: BUSINESS-TO-BUSINESS COOPERATION

An area of key expertise in the Netherlands is in direct use of geothermal resources for heating and cooling, process heat for companies, drying of crops and small-scale electricity on remote locations. In Indonesia, there is lot of expertise on energy generation from high enthalpy volcanic geothermal systems. Direct use in GEOCAP focuses on the use of low and medium enthalpy geothermal energy (up to 200°C). One important application is direct use: geothermal heat is used directly for heating purposes. The main advantage is that the energy efficiency is very high. Next to direct use, the geothermal heat can also be used for cooling (by using sorption-cooling machines) or electricity production (by using ORC-like technology). The focus of the study is on West-Java. Lessons learned can be used in other areas of Indonesia as well. Direct use has very high-energy efficiencies, but important (technical) boundary conditions are that the source temperature must be high enough to supply the required heat demand and that the source must be close to the demand. Both sources and demands were identified in West Java. Identified sources are five geothermal power plants, 27 locations with surface manifestations (e.g. hot springs and fumaroles) and the West Java sedimentary basin. A lot of heat is needed in (food) industry and agriculture. Detailed production data is not accessible, but using expert knowledge of universities in Indonesia, it was possible to identify important areas and applications. The next figure gives an overview of the identified sources and demand. The figure below gives an overview of the identified sources and demand. Because detailed production data is missing (due to confidentiality), literature and knowledge on agricultural and industrial processes were used to identify opportunities. In addition, input of the workshop with a variety of stakeholders was used to identify opportunities. Based on a temperature match and distance, 26 matches of small/medium enterprises were identified. In addition, three important industrial areas were identified within the West-Java Basin. Promising applications are in milk, tea-, textile- and vetiver oil industry. Promising locations are Wayang Windu, Cisolok/Cisukarame, Jababeka Industrial Estate, Karawang International Industry City, Southern part of Bogor and Awibengkok. Besides direct use, GEOCAP also assists the government of Indonesia and its private sector on the development and streamlining of geothermal databases. During 2016, a lot of discussion has been focused on the role of geothermal databases and repositories in GEOCAP. Several institutes in Indonesia maintain a geothermal or related database in Indonesia including various companies (on their working areas), the Ministry of Energy and the geological survey on Indonesia. In the Netherlands, TNO is maintaining the subsurface data for the Netherlands. GEOCAP will provide assistance in building the Data and Information of the Indonesian underground, building from state of the art technologies and extensive experience in subsurface database development, digital workflows and web information systems, developed in the Netherlands. In 2016, a GEOCAP workshop on the geothermal database has resulted in the scoping of cooperation between MEMR, Indonesian university partners and TNO for a geothermal database work plan, which is focused towards e-reporting.

GEOCAP: TRILATERAL SOUTH-SOUTH COLLABORATION

GEOCAP has collaborated through the World Bank ESMAP program to support capacity building within the Tanzania Geothermal Development Company (TGDC). The objective was to create a forum for knowledge sharing among the key stakeholders in the energy and extractive resource sectors on the status of geothermal development in Tanzania and to prepare Tanzania for exploration drilling. For this purpose, a study visit to Indonesia was executed in 2016 as a follow up of meetings in Tanzania led by staff from ITB (Indonesia) and TNO (The Netherlands).

CONTACT

Prof. Dr. F.D. van der Meer (University of Twente) f.d.vandermeer@utwente.nl

Sanusi Satar (Indonesian Geothermal Association) s.satar08@gmail.com

Tia den Hartog (University of Twente) tia.denhartog@utwente.nl

CLIMATE CHANGE AND ENERGY TRANSITION

Our climate is changing! This in itself is not shocking nor surprising. Over geologic history, the global climate has always changed with warmer and cooler periods than the present period. The past 600.000 years we have had four glacial periods with large parts of Europe covered by ice and three interglacial warmer periods. Technically, at present we are at one such warmer interglacial periods. Carbon dioxide, CO_2 concentration in the atmosphere and temperature have tracked closely over the last over the past 300.000 years as concluded from ice core analysis of the Antarctic. However, since industrialization this correlation has been lost due to the human-induced excess of CO_2 emission to the atmosphere. The most optimistic climate scenario predicts a 4-degrees temperature increase relative to present day while the most pessimistic climate scenario results in 12 degrees of warming in 2100. If we do not act now (https://www.ipcc.ch/report/ar5/).

In Paris in 2015 politicians signed the so-called Paris Agreement during the COP21 meeting (http://www.undp.org/content/undp/en/home/presscenter/events/2015/december/COP21-paris-climate-conference.html). In the Paris agreement, for the first time in over 20 years of UN negotiations, countries ratified an agreement 'to achieve a legally binding and universal agreement on climate, with the aim of keeping global warming below 2°C.' This 2°C is about the level of warming reached after the start of industrialization.

COP21 is an agreement to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. In summary:

- Global temperature rise this century well below 2°C above pre-industrial levels;
- Pursue efforts to limit the temperature increase even further to 1.5 °C;
- Increase the ability of countries to deal with the impacts of climate change;
- Making finance flows consistent with a low GHG emissions and climate-resilient pathway

Over 90% of CO_2 emission to the atmosphere is from fossil fuel burning. A back of the envelope calculation learns that if we continue emissions at the present pace we will have reached this maximum CO_2 concentration by 2050. Thus we have 30 years to make our energy production CO_2 neutral which requires a massive transition from fossil fuels to renewables; the energy transition. This is a wicked problem, as it does not only imply energy transition towards renewables but this in the context of an ever-increasing demand of energy with the increase of global population. It is predicted that the energy demand in 2035 will be double that in 1990. Energy transition is one solution, however CO_2 capture and storage is an option that the Dutch government is seriously considering. CO_2 is captured at the source, compressed and transported through pipelines and stored in geological (former oil and gas) reservoirs. This may have some environmental issues associated with it such as the risk of fault (re-)activation and potentially causing both leakage and induced seismicity and the fact that CO_2 partially dissolves in time thereby potentially increasing the acidity of the water.

Global warming has resulted in additional challenges our planet is facing. The ESA Cryosat satellite mission[1] has shown that the Arctic sea-ice extent has shrunk by 12% per decade since 1978. Satellite missions such as NASA's OMI and ESA's Tropomi[2] allow to measure atmospheric constituents related to air pollution at detail and link them directly to potential sources of the pollution showing increases in various greenhouse gases in the atmosphere. A global network of tide gauges has revealed the increase of sea-level height throughout the 20th century because of thermal expansion of the upper layer of the ocean was in the order of 1,5 to 2 mm/year. Systematic monitoring of the sea level with altimeters started with the NASA TOPEX/Poseidon mission[3] in 1992 and continued with the Jason-1 and Jason-2 missions which confirm sea level rise producing global mean sea level maps every 10 days. Sea level rise not only causes inundation and shoreline erosion, but may also have an effect on various water-borne diseases. Extreme weather events have been attributed to global warming and many scientific studies predict that more extreme weather events will occur with increasing global temperatures. More floods, more heat waves, more droughts, more tropical cyclones. In addition, our vulnerability to such events changes as the world population is growing, urbanization takes place in coastal zones, floodplains and through the occupation of marginal lands.

SUSTAINABLE DEVELOPMENT GOALS AND ENERGY TRANSITION

On September 25th 2015, the UN associated countries adopted a set of 17 Sustainable Development Goals (SDG's) to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda[4]. Each goal has specific targets to be achieved over the next 15 years. For each of these targets in total 232 Indicators were identified to measure progress made in achieving the 17 goals. Monitoring of the indicators is the responsibility of the national governments of the countries that have adopted the UN SDG's. These indicators were in turn grouped into three levels of scientific understanding on how to assess them as:

- Tier 1: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.
- Tier 2: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.
- Tier 3: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested.

There is no explicit SDG goal that relates to Energy Transition. However in the goals 7 (affordable and clean energy), goal 9 (Industry, Innovation and Infrastructure) and Goal 13 (Climate action) there are elements that link to the theme of Energy Transition. SDG Goal 7 defines that we should ensure access to affordable, reliable, sustainable and modern energy for all by increasing the share of renewable energy in the global energy mix. SDG Goal 9 aims to build resilient infrastructure, promote inclusive and

[1] (https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/cryosat)
[2] (http://www.tropomi.nl/)
[3] (https://sealevel.jpl.nasa.gov/missions/topex/)
[4] (https://www.un.org/sustainabledevelopment/sustainable-development-goals/)

sustainable industrialization and foster innovation with the aim to reduce CO_2 emission while goal 13 is the so-called climate action strengthening the resilience and adaptive capacity to climate related hazards and natural disasters in all countries.

GEOTHERMAL ENERGY IN THE ENERGY MIX

Radioactively generated heat in the core of the Earth is the driver of the Earth's internal heat engine. Heat moves to the surface through conductive and convective processes. In addition, the top layer of the Earth surface is heated by solar radiation. Typical temperature gradients in the Earth crust are in the order of 25 to 30 °C per kilometre depth (equivalent to a conductive heat flux of 0.1 MW/km2). However near tectonic plate boundaries specifically near diverging plate boundaries (like in active rift systems such as the mid-Atlantic rift and the East African rift), converging plate boundaries (subduction zones; Indonesia, Philippines, Chili), and along recent volcanic in intraplate settings (Hawaii, Yellowstone/US) volcanic activity results in gradients as high as 150°C per kilometre depth. These high gradients through magma conduits trigger fluid circulation from fresh water from precipitation, ground water, lake water intrusion (meteoric water) which results in hot springs, steam vents. The amount of heat flow (heat flowing by conduction through a unit area in mW/m2) is dependent on the temperature gradient and the thermal conductivity (in W/m°C) of the medium (rock, water). Heat from geothermal reservoirs can be used to generate energy (electrical power) by using the steam to drive turbines in case of high temperature (>200°C) reservoirs. Sometimes water is injected into the geothermal system to enhance the process. In case of normal geothermal gradients (30°C /km) and low (<150°C) temperature reservoirs, heat can be used for direct use (Lund et al., 2005) involving heating of buildings, drying of agricultural products etc.

Geothermal generated energy has a number of benefits: it is renewable, it provides a stable base-load power for several decades and it is environmentally friendly with low carbon dioxide emissions compared to alternatives like fossil fuels. The downside maybe the emission of volcanic gases notably SO_2, CO_2 and H_2S which may be enhanced due to geothermal exploration and which are associated with respiratory mortality. In low enthalpy systems, there is the competition between aquifers used for shallow geothermal energy and for the production of drinking water. Geothermal activity gives rise to temperature variations beyond natural conditions, which adversely affects groundwater quality. Groundwater potentially can be polluted from reservoir fluids but also corrosion in the pipeline system used for exploration can adversely affect groundwater quality. Lastly, geothermal energy production can result in surface deformation. Lastly, geothermal energy production can result in surface deformation. Geothermal energy provides approximately 0.4% of the world global power generation with a growth rate of 5%. At present, the largest providers are in USA, Philippines, Indonesia, Mexico and Italy. To put this in perspective, solar energy plays a very limited role in global power generation (<0.2%), but it has a very high growth rate of 25-30%, especially in USA, Spain, China, Australia and India.

A recent survey[5] shows that a total of 24 countries now generate electricity from geothermal resources with a total installed capacity worldwide of 10,898 MW (corresponding to about 67,246 GWh of electricity). Germany, Papua – New Guinea, Australia, Turkey, Iceland, Portugal, New Zealand, Guatemala, Kenya, and Indonesia have increased the capacity of their power plant installations by more

[5] (https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01001.pdf)

than 50% with respect to the year 2005. The top five countries for electricity from geothermal resources are USA, Philippines, Indonesia, Mexico and Italy and the top five countries that realized an increase above 100 MW with respect to 2005 are USA, Indonesia, Iceland, New Zealand and Kenya. In addition, nearly 40 countries worldwide possess sufficient geothermal potential that could be exploited to satisfy the energy demand of the country; the largest are Indonesia, Philippines, Peru, Ecuador, Iceland, Mozambique, Costa Rica and Guatemala. In terms of installed capacity as a factor of inhabitants Iceland (>1900 MWe/mill.people) and New Zealand (150 MWe/mill.people) are world leader (USA reaches 10 MWe/mill.people).

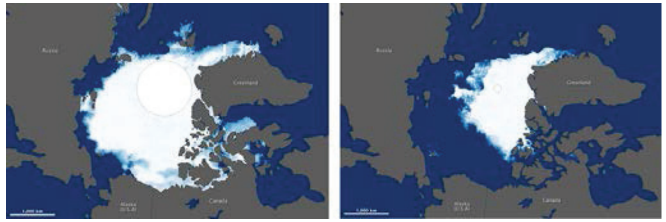

Figure 3 Sea ice coverage of the North Pole (Left: September 1984, Right: September 2012) showing a steady loss of ice cover.

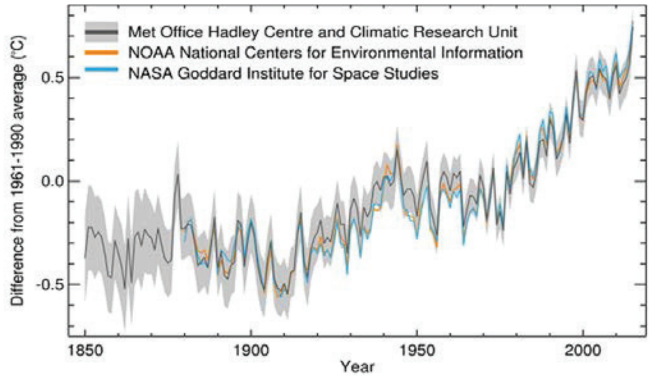

Figure 4 Global temperature rise from three independent sources showing a steady increase in temperature.

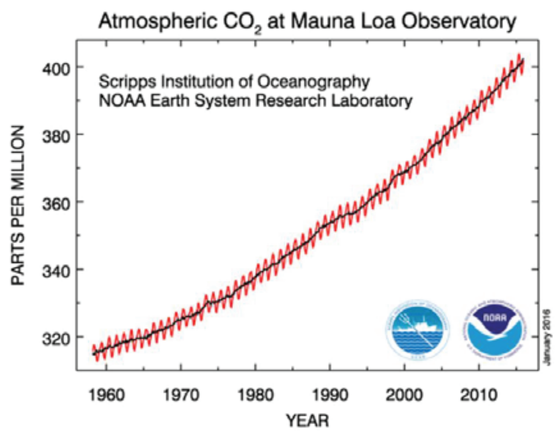

Figure 5 CO_2 in the atmosphere measured by NOAA at the Mouna Loa (Hawaii) observatory showing a steady increase.

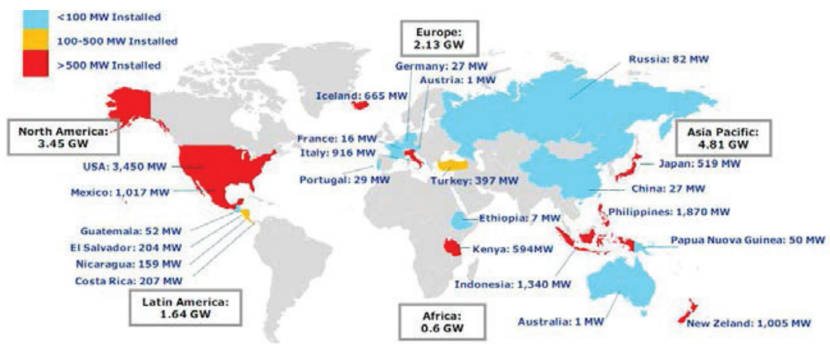

Figure 6 Installed capacity of geothermal energy systems worldwide (source: Bertani report).

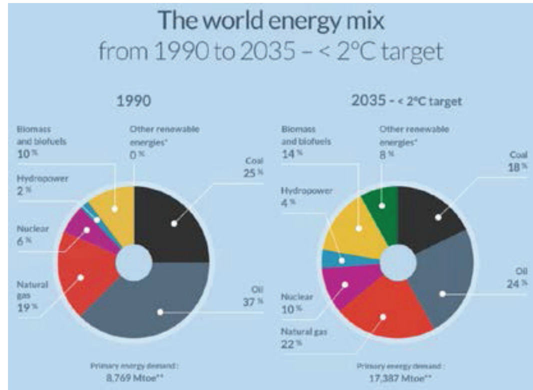

Figure 7 Energy mix in 1990 and a scenario energy mix for 2035 to meet the COP21 target.[6]

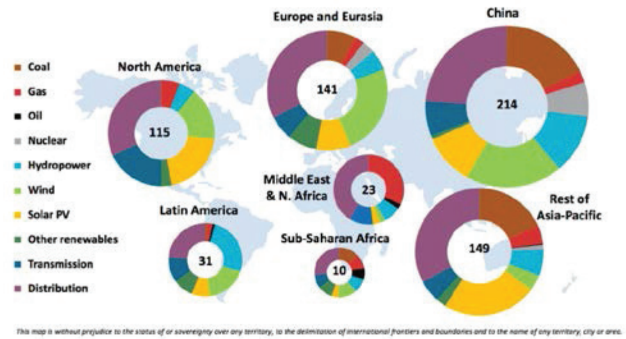

Figure 8 Investment in electricity generation and networks by region and type in 2015 after the World Energy Investment (2016) by the IEA[7]

CONTACT

Prof. Dr. F.D. van der Meer (University of Twente) f.d.vandermeer@utwente.nl

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[6] https://www.planete-energies.com/en/medias/infographics/world-energy-mix-1990-2035-2degc-target

[7] https://www.carbonbrief.org/seven-charts-show-new-renewables-outpacing-rising-demand-for-first-time.

GEOTHERMAL DEVELOPMENT IN INDONESIA

Historically, the survey and exploration of geothermal energy in Indonesia started in 1918, and the exploration drilling started in 1926 by the Dutch government in the Kamojang area of West Java. There were 5 wells drilled, and 4 wells were then abandoned and there is only one well KMJ-3 still exists and flows until today as shown on the Figure 9. In other word, it has been more than 90 years the renewable energy activity took place in Indonesia.

Figure 9 KMJ-3 Well Drilled by the Dutch 1926 (source: courtesy of PGE)

This is the beauty of the renewable energy that sustains for many years and it is obvious that the geothermal energy is one of the best source of renewable energy to provide power in the current condition and for the future. The geothermal energy can also be utilized as a direct use in providing the heat steam or source for many applications such for drying agricultural produce.

As one of the renewable energy sources, geothermal energy is also known as the clean energy that produce almost zero CO_2 and environmentally friendly that will support the world program for CO_2 emission reduction as agreed in the COP21 Paris back in 2016.

The first geothermal power plant which was for only 0.25 MW as a pilot project in the Kamojang field, installed and inaugurated by the government of Indonesia in 1978. See Figure 10

Figure 10 Monoblock 0.25 MW Power Plant (1978) source: courtesy of PGE

However, the real development of indirect use geothermal energy or steam to produce the electricity commercially in Indonesia has begun in early 1980 by Pertamina (State Owned Oil & Gas Company) with the assistant from New Zealand government, where finally the first geothermal power plant with the capacity of 30 MW installed in 1983 Kamojang, operated by Indonesia Power (IP), a subsidiary of PLN as the State Owned Electricity company. In this case, Pertamina just sold the steam to IP, whereas the power plant was owned by IP including its operation. During 1983 until 2015, Pertamina Geothermal Energy (PGE) has successfully developed the Kamojang geothermal field with installed capacity now reached 235 MW.

The development of geothermal energy in Indonesia was based on the Presidential Decree N0. 16 year 1974 by giving authority to Pertamina to carry out the survey and exploration on the Geothermal Energy. The decree was then replaced by the Presidential Decree no. 22 year 1981, which authorized Pertamina to carry out exploration and exploitation and to sell the electricity from geothermal including authorization to form a Join Operating Contract (JOC) with other private developer. Since then geothermal development moved with the development of Drajat field with installed capacity off 270 MW in early 1990 through 2007 and Salak field with installed capacity of 377 MW also in early 1990 through 1997 by Chevron.

Through survey in more than 300 locations around Indonesia's islands by Badan Geologi (Geological Agency of Ministry Energy and Mineral Resources (MEMR), it was predicted that the geothermal potential is about 29 GW see Table 1.

No	Island	Number of Location	Potential for Energy (MWe)					Installed
			Resources		Reserves			
			Speculative	Hypothetical	Predicted	Probable	Proven	
1	Sumatra	98	2.817	1.917	5.065	930	917	538
2	Jawa	73	1.410	1.689	3949	1.373	1.865	1.254
3	Bali	6	70	22	122	110	30	0
4	Nusa Tenggara	28	225	395	901	0	15	12,5
5	Kalimantan	14	152	17	13	0	0	0
6	Sulawesi	87	1.308	325	1.248	80	140	120
7	Maluku	33	560	91	677	0	0	0
8	Papua	3	75	0	0	0	0	0
	Total	342	6.617	4.456	11.975	2.493	2.967	1.924,5 *)
			11.073		17.435			

Table 1 Geothermal Potential by Islands (source: Badan Geologi ESDM, December 2017)

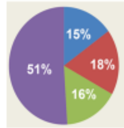
After the world crisis in 1998, the geothermal development then start progressing again and the Law No. 27 on geothermal was then issued in 2003, by giving the authority to the Local Government to Carry out the tendering process for indirect utilization of geothermal energy. Nevertheless, due to the lack of experience of the local government and due to geothermal is classified as mining activity, the problems occurred in developing geothermal energy and that the geothermal activity may not be carried out in the forest particularly in the conservation forest. It has caused the government to revoke the Law No. 27 year 2003 on Geothermal and then replaced with the Law No. 21 year 2014 on Geothermal where the word mining is omitted and gave permission for geothermal energy to be developed in conservation forest and the Geothermal business for indirect use was returned back to the Central Government.

However, please note since the Law no. 27 / 2003 was issued only few blocks were in progress to be developed, among others Muara Laboh, Rantau Dedap and Sorik Merapi. Therefore, the current total installed capacity was mostly from the Geothermal Working Area (GWA) that was assigned to Pertamina.

Pertamina Geothermal Energy such as Kamojang, Lahendong, Ulubelu, and Karaha Bodas developed some of the Pertamina Geothermal Working Area. A few GWA were then developed by the private sectors in the term of Joint Operating Contract (JOC) among others Drajat and Salak by Chevron (which was taken over by Star Energy in 2017), Wayang Windu by MNL (Magma Nusantara Limited) which was taken over by Star Energy in 2003, Dieng and Patuha by Geodipa, Sarulla by Sarulla Operation Limited etc.

When the introduction was being prepared, the Lumut Balai of PGE is scheduled for COD for 55 MW in the 4th Quarter of 2018, the Muara Laboh development is in progress, that is scheduled to be COD in Mid 2019 for 80 MW, and the Sorik Marapi Modular Unit 1, will be COD for 20 MW in Mid-2018, and will be followed with Modular Unit 2 for 30 MW at later date.

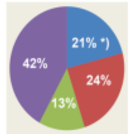
Distribution of potential Geothermal site in forestry area



- Conservation Forest
- Protected Forest
- Production Forest

Number of potentital geothermal site: 330

Geothermal potential in forestry area



- Conservation Forest
- Protected Forest
- Production Forest

Geothermal potential: 29GW

Figure 11 Geothermal potential in the forestry area (source: INAGA)

The current installed capacity through June 2018 was 1948.5 MW as shown in Table 2. Which made Indonesia is now as second largest geothermal producer in the world.

No.	WKP, Location	Power Plant	Developers/Operators	Turbine Capacity	Total Capacity (MW)
1	Sibayak – Sinabung, SUMUT	Sibayak	PT. Pertamina Geothermal Energy	1 x 10 MW; 2 MW(monoblok)	12
2	Cibeureum – Parabakti, JABAR	Salak	Star Energy Geothermal Salak, Ltd	3 x 60 MW; 3 x 65,6 MW	377
3	Pangalengan, JABAR	Wayang Windu	Star Energy Geothermal Wayang Windu	1 x 110 MW; 1 x 117 MW	227
		Patuha	PT Geo Dipa Energi	1 x 55 MW	55
4	Kamojang – Darajat, JABAR	Kamojang	PT. Pertamina Geothermal Energy	1 x30 MW; 2 x 55 MW; 1 x 60 MW; 1 x 35 MW	235
		Darajat	Star Energy Geothermal Darajat, Ltd	1 x 55 MW; 1 x 94 MW; 1 x 121 MW	270
5	Dataran Tinggi Dieng, JATENG	Dieng	PT. Geo Dipa Energi	1 x 60 MW	60
6	Lahendong – Tompaso, SULUT	Lahendong	PT. Pertamina Geothermal Energy	6 x 20 MW	120
7	Waypanas – LAMPUNG	Ulubelu	PT. Pertamina Geothermal Energy	4 x 55 MW	220
8	Ulumbu - NTT	Ulumbu	PT. PLN (Persero)	4 x 2,5 MW	10
9	Mataloko - NTT	Mataloko	PT. PLN (Persero)	1 x 2,5 MW	2,5
10	Sibual-Buali - SUMUT	Sarulla	Sarulla Operation Ltd.	2 x 110 MW 1 x 86 MW 1 x 24 MW	330
11	Karaha Bodas - JABAR	Karaha	PT. Pertamina Geothermal Energy	1 x 30 MW	30
		TOTAL			1.948,5

Table 2 Geothermal power plant installed capacity by 2018 (source Ditjen EBTKE ESDM)

Through the Government Regulation No. 79 year 2014, on the Energy Mix Policy, it was determined that 23% of the energy mix must come from renewable energy by 2025. Out of 23 %, geothermal is dedicated to about 12%, which is approximately equal to 7000 MW to be developed by 2025. In other word, approximately 5000 MW need to be developed up to 2025. It has attracted attention on the need for Human Resources to support such huge development. In the past, geothermal development was moving fast and resulted shortage on expertise and enough experience human resources to support the target development by 2025. It is therefore, the program on capacity building became necessary, which lead to GEOCAP (Geothermal Capacity Building Programme Netherlands – Indonesia) which is part of the Human Resources Capacity Building in the Geothermal Sector in Indonesia.

Table 3 showed the requirements of the Human Resources through 2025 as the result of the study by a consultant from New Zealand for BPSDM (Badan Pengembangan Sumber Daya Manusia/The Agency for Human Resources Development) of Ministry of Energy and Mineral Resources.

Category	By 2017	By 2019	By 2020	By 2025
Additional engineers and scientists	1,600	2,400	2,400	3,250
Technicians/trades requiring training	4,900	8,400	7,300	7,800
Staff turnover requiring training	8%/year	8%/year	8%/year	8%/year
Cumulative additional engineers/scientists for training	2,000	3,500	3,800	6,300
Trainers required - lecturers	50	25	25	28
Trainers required – research assistants	53	27	27	30

Table 3 The manpower requirements for geothermal development up to 2025 (source: BPSDM - ESDM)

GEOCAP focuses on the capacity building with three major programs: (1) Training, (2) Research and (3) Database, which will be described in detail in section 4. This is a bilateral cooperation between two countries, the Republic of Indonesia through Bappenas and The Kingdom of the Netherlands through the Netherland Embassy in Jakarta for 5 years that was started in the beginning of 2014 and will end in December 2018 (the project was initially 3.5 years and it was extended to give ample time for the training implementation, Database development and also the research program).

The handbook contains the summary of the Geocap Projects for the past 5 years to be presented to the geothermal community for their references and information should they need to know more detail on the capacity building that have been accomplished by the Geocap team.

GEOCAP team wishes that this book would be helpful and useful for the Indonesian Geothermal Community to look for or to get the information on the training programs, result of the research, and the Database for the successful of Indonesia Geothermal Development toward 2025.

CONTACT

Sanusi Satar (Indonesian Geothermal Association) s.satar08@gmail.com

GEOTHERMAL GEOLOGY OF INDONESIA

Indonesia Geothermal System distribution is strongly controlled by the geology and tectonic setting of the region. This causes, each geothermal system found in this country is unique and vary from place to place. Currently 331 geothermal occurrences and prospects have been mapped by Geological Agency, Ministry of Energy of Mineral Resources Republic of Indonesia (see Figure 12).

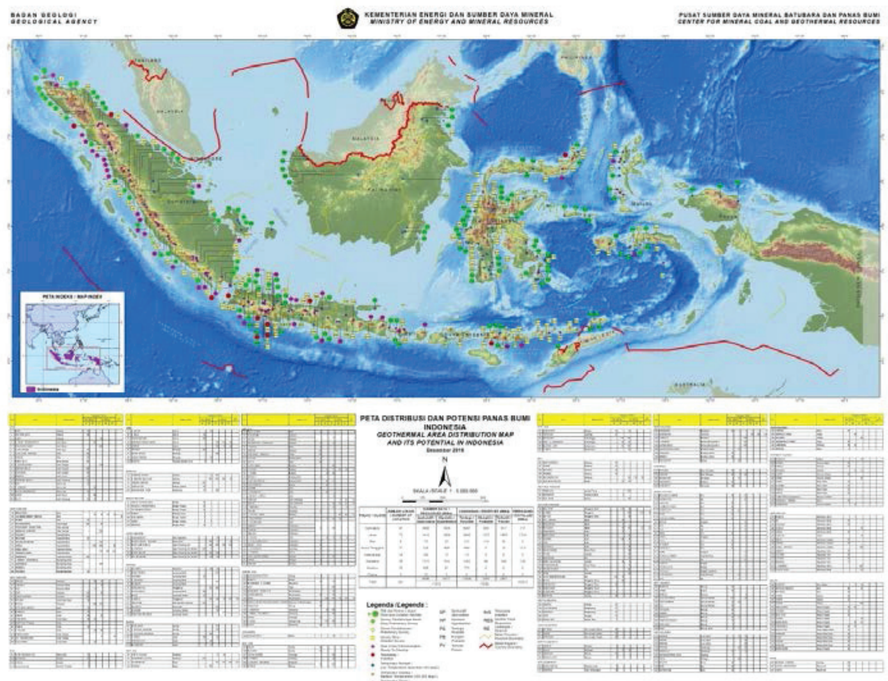


Figure 12 Geothermal Area Distribution Map (KESDM, 2017)

The geology and tectonic setting that form Indonesian Archipelago start as early as Cretaceous age as part of geology and plate tectonic evolution of SE Asia and the SW Pacific (Hall, 2002). The Present day major geology and tectonic framework is shown in Figure 13. It is the result of evolution of subduction zone and its associated magmatic arc since Cretaceous until now, as shown in Figure 14 (Katilli, 1994). It is an extremely complex collection of continental blocks, active and extinct volcanic arcs and associated subduction complexes and old and young ocean basins that form the major tectonic framework of Indonesia. Now, the region is at the convergence of three major tectonic plates: Eurasia, Pacific and Indo-Australia.

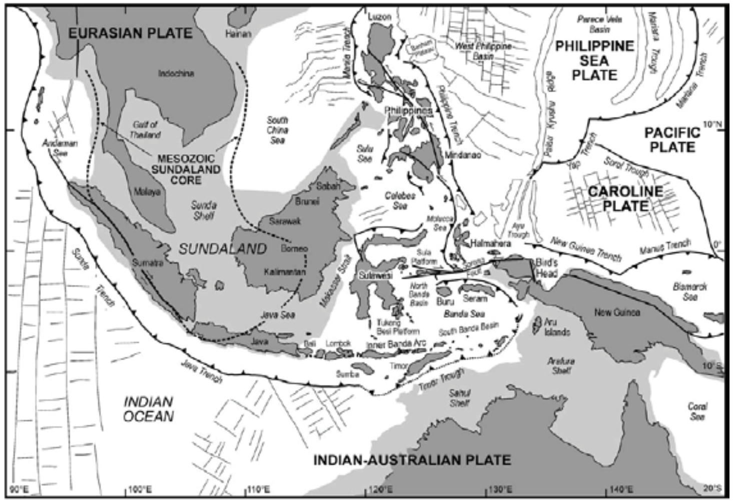
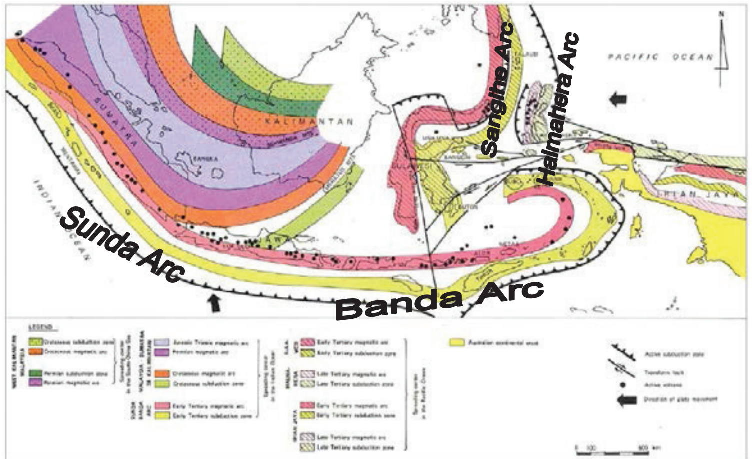


Figure 13 Present day tectonic framework of Indonesian Archipelago (Hall, 2001)



Cretaceous- recent magmatic arcs/ subduction zones Indonesian Archipelago (Katili 1974)

Figure 14 Evolution of Magmatic arc / Subduction Zones of Indonesian Archipelago from Cretaceous-Recent (Katili, 1975)

In general, the present day geology of the archipelago is underlined by two geological basement: continental crust of Eurasian Plate and Australian Plate, and oceanic crust of Pacific Plate Figure 13. The continental crust located at the western region, also known as Sundaland that underlie the three big islands i.e. Sumatera, Java and Kalimantan. Whereas the continental crust at the eastern region,

form the basement of New Guinea. The oceanic crust is found in between of both region and covers Sulawesi and smaller islands nearby.

The present day subduction zones, as the result of the movement of three plates, give rise to four active volcanic arc segments. Those are Sunda Arc, Banda Arc, Sangihe Arc and Halmahera Arc. The Sunda and Banda Arc are related to the same subducting Indian Ocean plate (part of Indo-Australian Plate). About 128 active or dormant and many additional extinct volcanoes have been identified along these arcs. The chemical and physical characteristic of the volcanoes at the western and eastern Indonesia are often different that affect the characteristics of volcanic or magmatic associated geothermal system in these areas. Currently, geothermal system associated with volcanism or magmatism are the most exploited resources in this country.

Old subduction zones form tectonic suture that aged from Cretaceous or older. These sutures mostly found in Kalimantan. In this island, also known as Borneo, uplift, crustal thickening, thrusting and folding occur in many areas. Several major sedimentary basins that produce oil and gas, as well as coal have been found in this island. Several geothermal occurrences, which are indicated by the appearance of warm to hot spring, have been identified. Nevertheless, the association of geothermal heat source with geology of the area has not been well understand. These geothermal occurrences are potential for development of medium to low enthalpy geothermal energy.

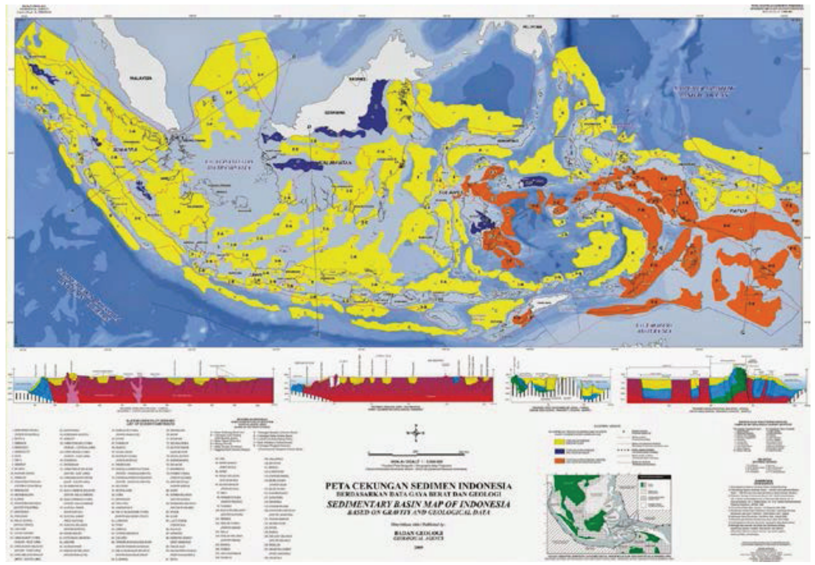


Figure 15 Sedimentary Basin Map of Indonesia (Geological Agency, 2009)

Sedimentary basins can form conduction dominated geothermal system. Total of 128 basins inland and offshore, have been identified by Geological Agency (2009) (Figure 15). Some of them are major oil and gas producers. Geothermal occurrences in the sedimentary basin can be identified as hot water tap from oil well, where many of them are found all over the basins in Indonesia. Although the potential of geothermal energy from sedimentary hot aquifer in Indonesia is significant as shown by many sedimentary basins in the country, but they are poorly understood and lack of investigated.

Geothermal system can be associated with extensional tectonic regime. The occurrence of segmented strike slip faults controls the geometry and permeability of geothermal systems. Several major Young active strike slip faults have been mapped in this country and some of them have been proved to be associated with geothermal system such as Great Sumatran Fault, in Sumatra Island, Palu Koro Fault and its splay to the SE, in Sulawesi, and Cimandiri Fault in West Java. Other possibilities such as Sorong Fault in West Papua and other major fault system has not been investigate yet.

Conduction dominated geothermal type can also occur as in association with old or young orogeny tectonic. Four Orogenic Belt Type have been identified in Indonesia (Simandjuntak and Barber, 1996) shown in Figure 16. They are (1) Sunda Orogeny located at Java Southern Mountain Ranges – Sumatera Barisan Mountain Ranges, (2) Banda Orogeny, located in Sulawesi Mountain Ranges, (3) Melanesia Orogeny in West Papua – Papua New Guinea Mountain Ranges and (4) Talaud Orogeny which is spread at Talaud – Tifore ridge. Nevertheless, the geothermal potential associated with this system has not been investigated yet.

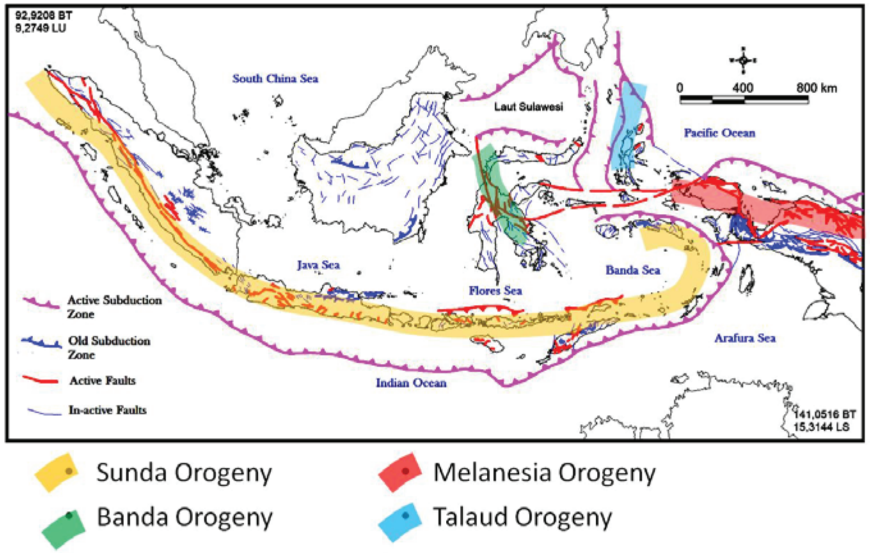


Figure 16 Location of Orogeny Belts in Indonesia with respect to faults distribution and Active and old Subduction Zone

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CONTACT

"Dr.Eng. Suryantini S.T., Dipl Geothermal EnTech., M.Sc. (ITB) suryantini@gl.itb.ac.id ; ninik_suryantini@yahoo.com

EXPLORATION

A geothermal project has a number of development phases: preliminary survey/site selection, exploration, test drilling, geothermal field development, power plant design, commissioning and operation. Alongside baseline environmental studies and environmental impact analysis studies are conducted. Various geological, geochemical and geophysical surveys are conducted in the exploration to develop a 3D subsurface model of the reservoir based on conductivity/resistivity imaging, magneto-telluric methods and drill whole geophysics.

Traditional exploration methods are directed to finding the best suitable target locations for steam or fluid production. An initial reconnaissance survey often using airborne or space borne remote sensing in combination with literature study at regional scale results in a selection of a prospective area. This pre-feasibility study explores both the likelihood of the presence of a commercial geothermal reservoir, but also investigates the regional power demand, the regulatory framework, and infrastructure, access to the power grid as well as environmental conditions and legislation.

A hydrogeological survey aims to reconstruct the water circulation system trying to relate surface manifestations of geothermal activity (e.g., hot springs, steam vents, fumaroles, etc) to fault/fracture systems, variation in lithology etc. Depending on the terrain condition and the geology, detailed surface mineralogic mapping may be conducted to get a better understanding of the alteration in relation to the temperature, pressure and chemical conditions. Fluid inclusions in minerals may provide more detailed information on the temperature of geothermal fluids as well as their chemical composition.

Geochemical surveys typically sample water from hot springs, gas from hot pools and steam from fumaroles where the fluid chemistry can be used to develop geothermometers that provide an estimate of the temperature of deep reservoirs.

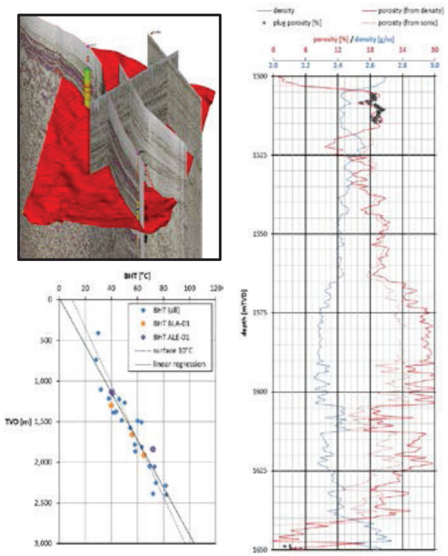
Multitudes of geophysical techniques are deployed in exploration surveys for geothermal characterization. Gravity and magnetic surveys provide information about subsurface lithology and active seismic surveys as well as (passive) seismic tomography provide information about subsurface structure and identification of warmer and cooler regions. Electrical methods measure resistivity of the shallow subsurface, which is related to the conductivity of the rocks, which in turn is dependent on the composition, the porosity, the fill of pore spaces, and the temperature and salinity of the fluids. Electromagnetic methods in particular magnetotelluric (MT) sounding and the more recently introduced time-lapse MT uses natural variations of the Earth's electrical and magnetic fields to determine the depth, geometry and geologic characteristics of electrically conductive features including (clay) reservoir caps, fluid-filled reservoirs, melt accumulation in the core, fluid pathways and geothermal reservoir temperatures at depths ranging from 300m down to several kilometres.

Reservoir modelling integrates elements from geological, geochemical and geophysical surveying to refine the geologic model through numerical simulation in order to understand the behaviour of a geothermal reservoir, to find the most suitable and productive reservoir, to estimate reservoir volume and recoverable heat, to identify zones of high permeability, to locate drilling locations, and to forecast future well and reservoir behaviour.

RESOURCE ASSESSMENT FOR LOW ENTHALPY GEOTHERMAL EXPLORATION IN SEDIMENTARY BASINS

INTRODUCTION

Sedimentary basins offer a huge geothermal potential for direct heating and even power generation. In order to quantitatively estimate the resource potential, a solid understanding of the subsurface is key. This includes the depth, thickness and structure of the geothermal reservoir, tectonic history, temperature, and flow capacity of the reservoir. The resource assessment course explains what data are typically required, how to calculate the geothermal potential from a variety of possibly available sources of data using state of the art techniques and freely available software, and how to assess the uncertainty of the estimate.



(top left) Borehole data, preferably in combination with seismic, provide a first estimate of depth and thickness of the geothermal reservoir

(bottom left) Bottom hole temperatures are routinely collected in exploration wells. Usually a linear trend exists in sedimentary basins, but considerable deviations from this trend may occur. A 5 °C difference at 2500 meters results in 10% difference in energy yield for a dT of 50 °C

(Right) Reservoir properties can be estimated from core plugs or geophysical wireline logs. Core plugs provide very local information that may not fully represent the whole reservoir accurately.

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Large sedimentary basins exist in Indonesia like on Sumatra and Java. Their geothermal potential has until now largely been overlooked because of the exploration focus on volcanic areas for power generation, and the relatively low enthalpy. A study conducted within GEOCAP shows that also in Indonesia a low enthalpy direct use demand exists. Heat produced from sedimentary basins could fill this demand. Lessons learned from the course on Basin Modelling show that sedimentary basins might be favourable exploration targets.

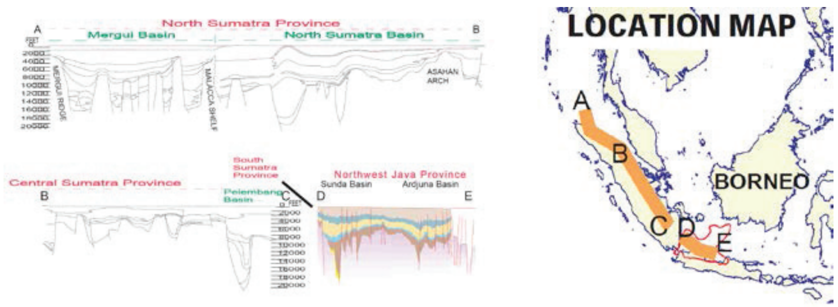


Figure 17 Figure showing generalized sedimentary basins in Sumatera and Java (after Bishop, 2000, based on Pertamina 1996 and others

GEOCAP ACTIVITY IN THIS TOPIC

A one-week course on geothermal resource estimation for low and medium enthalpy sedimentary basins was developed. To goal of the course is to enhance the participants knowledge and skills on assessing the geothermal potential in sedimentary basins for low and medium enthalpy resources using seismic interpretation techniques, petrophysical analysis and doublet performance software tools. Given a variety of possible subsurface data types, the audience is guided through the entire workflow from modelling the architecture of the reservoir, selecting the most favourable layer, assigning the relevant properties and finally calculating the potential geothermal power, including the uncertainty. The target groups of this course are practitioners (industry) and trainers / lecturers (academia). Those wishing to enrol should hold at least a BSc in geology, geophysics, geochemistry or comparable.

The course evolves around the following topics:

- Log interpretation
- Geophysics:
- Geothermal model building
- Geothermal production

Each topic is introduced by morning lectures, followed by hands-on exercises using real field data in the afternoon.

Log interpretation:

The objective of this module is to learn how to calculate the reservoir properties that are relevant for geothermal flow. To this end, coreplug data and geophysical wireline logs are used, including gamma ray, sonic velocity and density logs. Porosity and permeability are calculated. Various techniques are used in order to understand the uncertainty of the calculated porosity and permeability. The concept of bottom hole temperature acquisition will be explained, and the correction and use of those data for estimating the temperature gradient. The influence of different choices on the geothermal power prediction will be discussed.

Geophysics:

The objective of this module is to explain how borehole and seismic data can be used to model the depth, thickness and faults of the geothermal reservoir in 2.5 or 3D. The basics of seismic data acquisition will be explained, reflection and refraction, passive and active seismic, and time-depth conversion. The use of seismic attributes for deriving properties will be explained, and advanced filtering techniques for improving the quality of the data.

Geothermal model building

A geothermal model is required for predicting the potential flow, temperature and power of a doublet, prior to drilling for determining if an economic doublet is possible. After drilling, the model needs to be adjusted to the newly acquired data.

Using field data (seismic, well data, logs, temperature and permeability measurement), a simple geothermal model architecture is built which will be populated with the relevant properties (Net-to-Gross, temperature, permeability, or possibly dual permeability when relevant). Since the data is sparse, interpolation algorithms (IDW, Kriging, Simulation, ..) need to be used in order to derive property estimates for the whole reservoir. This introduces uncertainty, the role of which will be discussed.

Geothermal production

For optimal and sustainable doublet performance, the geothermal field needs to be modelled in order to be able to study the effects of pressure change and cooling, including thermal breakthrough. Various scenarios can be modelled to study the potential lifetime of the doublet, for instance including sealing or open faults or high permeability streaks.

During the course, the open source model software DoubletCalc (1D and 2D) will be used. DoubletCalc 1D is a pre-drill geothermal flow modelling too. It calculates flow rate, geothermal power and COP based on a 1D estimate of reservoir properties and well architecture. Hence, it can be used to determine whether a doublet could in principle be economical. The influence of uncertainty on the geothermal power can be studied in an interactive manner. DoubletCalc 2D is an easy-to-use reservoir simulator that calculates changes in the pressure and temperature fields due to geothermal production. Different scenarios can be modelled, including the influence of flow barriers and heterogeneity, well planning, and assessment of uncertainties.

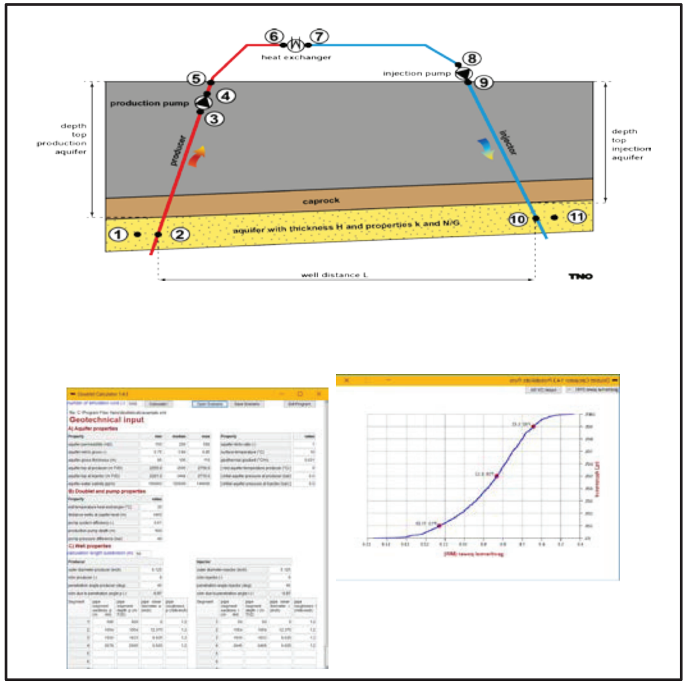


Figure 18 Generalized doublet architecture, doublet performance calculation input from DoubletCalc1D, and geothermal power expectation curve

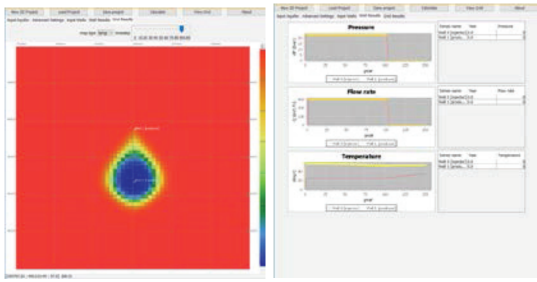


Figure 19 Reservoir cooling and pressure and temperature development modelled with the DoubletCalc2D software, showing cooling and reheating after production stop

CONTACT

Hans Veldkamp (TNO) hans.veldkamp@tno.nl

Stefan Carpentier (TNO) stefan.carpentier@tno.nl

Vincent Vandeweijer (TNO) vincent.vandeweijer@tno.nl

GEOCHEMISTRY FOR GEOTHERMAL DEVELOPMENT

INTRODUCTION

High-temperature geothermal systems, such as typical geothermal systems in Indonesia, are mostly volcanic hosted geothermal system where they are associated to tectonic plate boundaries where magmatic activities provide heat source for the geothermal systems. The type of geothermal system that is considered economically most feasible is where magmatic intrusions or shallow magma chamber are emplaced shallow enough in the crust that they induce convective circulation of groundwater. Such circulation is essential to carry the heat to the surface. Therefore, hydrological structure of a geothermal system has to be well understood. Hydrology of convective geothermal systems is determined by topography. Surface manifestations and chemical composition of the fluids can be used as guides to understand hydrological structure of the systems in both low relief and high-relief terrain.

The types and occurrences of the manifestation, and the total heat discharged at the surface are controlled by: heat input at the bottom of the reservoir; reservoir parameters (e.g., permeability); fluid parameters (e.g., density, viscosity, and temperature); hydrological framework of the system; and other factors controlling the outflow path of the hot fluids. Meanwhile, the chemical composition of the fluid is governed by the physico-chemical processes in the subsurface. Understanding the type of geothermal manifestations of a geothermal system, including the chemistry of their fluids, will enable us to identify the characteristics of the geothermal system.

Most geothermal systems in Indonesia is a typical of convective, volcano-hosted geothermal system. The components of the system include heat source, reservoir, recharge fluids, and discharge fluids at the surface (geothermal manifestations). The chemistry of the discharge fluids is resulted from all processes occurred in the system involving other components.

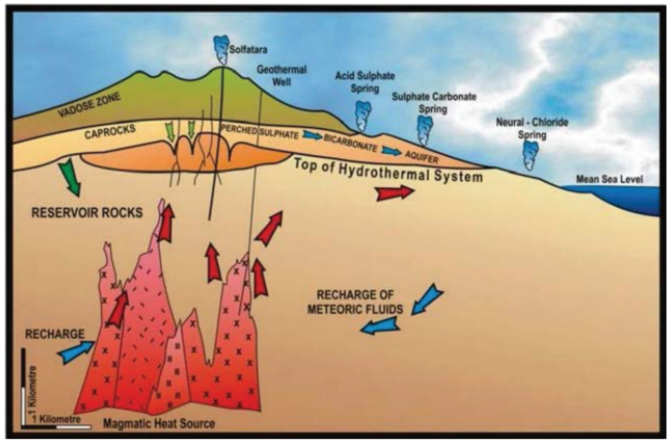


Figure 20 Adapted from Corbett and Leach (1998)

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Indonesia is known to have a great number of geothermal resources as shown in Figure 21 Some of them are still in the preparation and exploration stage, while some other are already in a production and exploitation stage. Geothermal resources in Indonesia are mostly linked to volcanic systems whose magmatic and hydrothermal activities are currently still active. Thus, continuous surveys have to be done to ensure the success of geothermal production. Geochemical survey in geothermal areas is one powerful method to understand the characteristics of geothermal fluids and can be applied in all stages of geothermal development. Training courses such as the 'Geochemistry for Geothermal development' may provide an excellent opportunity to increase knowledge and skills that are required for developing geothermal resources in Indonesia.

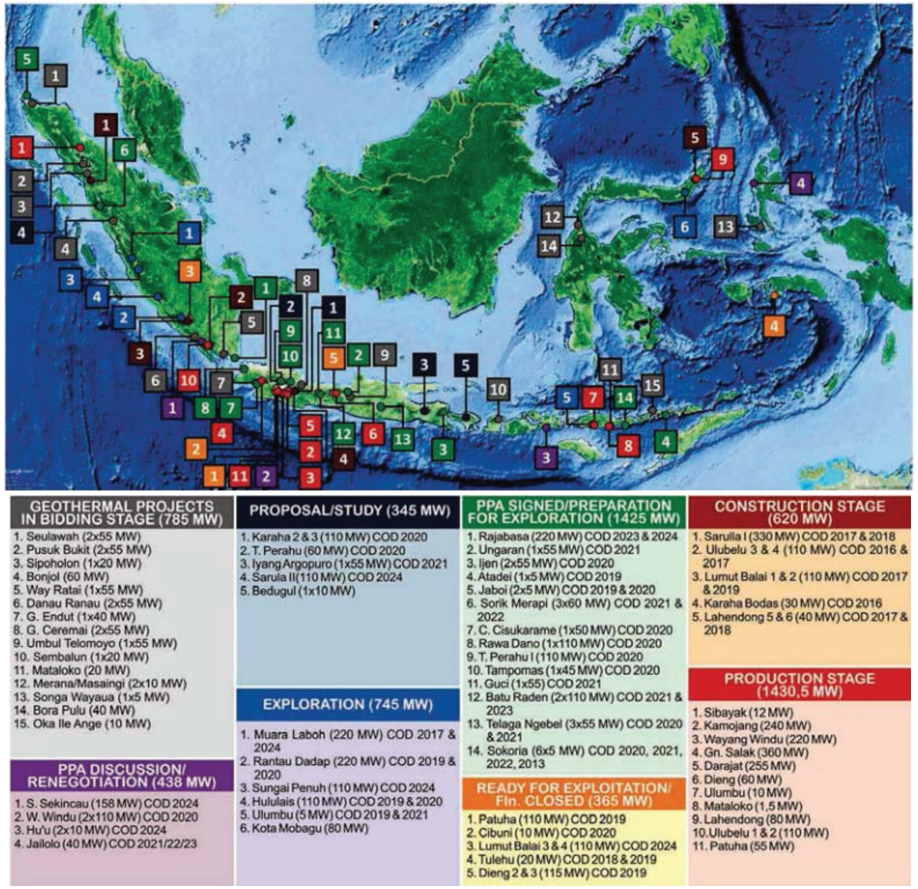


Figure 21 Geothermal resources in Indonesia

GEOCAP ACTIVITY IN THIS TOPIC

The project has developed a 1-week course on "Geochemistry for Geothermal Development" presenting the roles of geochemistry analyses on different stages of geothermal development from exploration, exploitation to monitoring. This course allows the participants to understand the application of geochemical analyses methods on investigating geothermal systems. The participants are academics and industrials with wide range of specialities (geology, geophysics, and engineering). The course is developed and given by geological and geophysical experts from The Netherlands and Indonesia.

The course includes three main topics of discussion:

1. The chemistry of geothermal fluids
2. Sampling techniques
3. Environmental impact of geothermal activity and production

At the end of the course, the participants were taken into a field trip to Dieng Geothermal Field. Through this activity, participants can observe directly how surface geochemical activities reflect hydrothermal processes occurred in a geothermal system.

<u>The chemistry of geothermal fluids</u>

This topic of discussion aims to understand the impacts of hydrothermal processes occurred in geothermal systems to the chemistry of geothermal fluids resulted at the surface. Thus, we can trace the origin of the geothermal fluids as well as infer what hydrothermal processes may have occurred by analysing their chemistry. Types of geochemical analyses and interpretation, both on water and gas, as well as geothermomether analyses to estimate the reservoir temperature were introduced and explained.

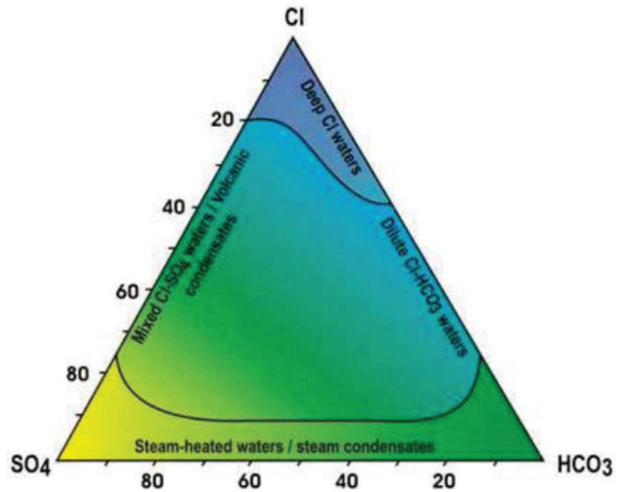


Figure 22 A ternary diagram of three main anion of Cl-, HCO3-, and SO42- to classify geothermal waters proposed by Giggenbach (1998)

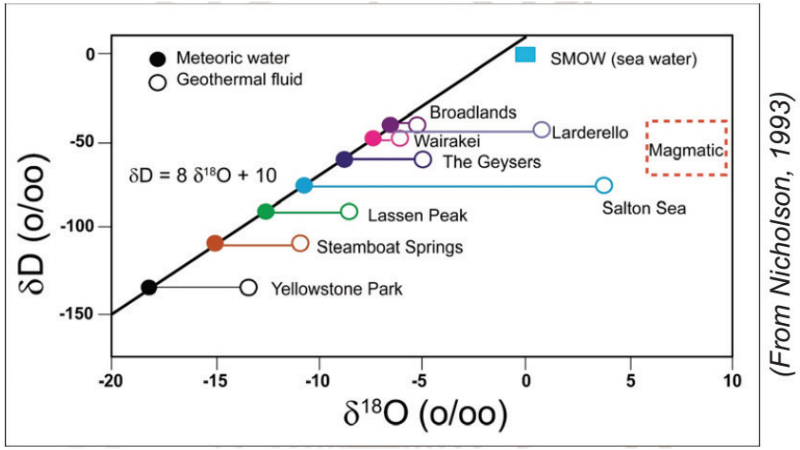


Figure 23 A diagram D vs 18O stable isotopes to trace the prominent source of geothermal fluids

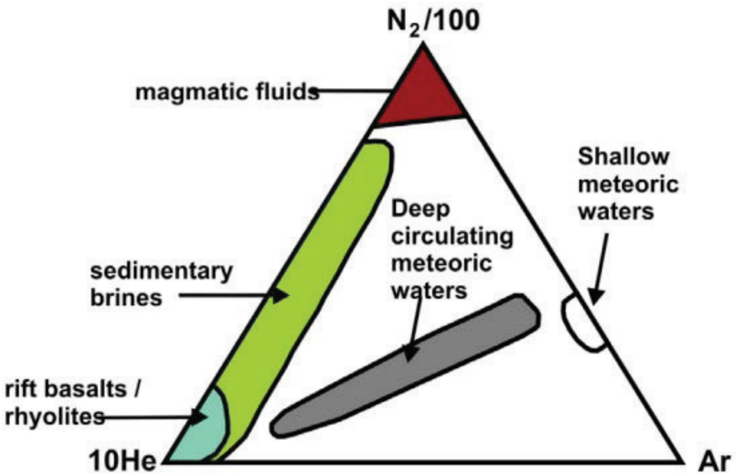


Figure 24 A ternary diagram of N2-Ar-He to classify geothermal gas proposed by Giggenbach (1986).

Sampling techniques

This topic of discussion aims to increase knowledge on how geochemistry sampling should be carried on considering geothermal areas can be hazardous. Knowledge on the possible hazards in geothermal area and safety requirements were explained at the first place. Techniques and procedures on sampling so that the results are accurate are also explained

Environmental impact of geothermal activity and production

This topic of discussion aims to understand potential environmental impacts from geothermal development. The impacts include gaseous emissions, water pollution, solids emissions, noise and thermal pollution, disturbance of natural hydrothermal manifestations, subsidence, induced seismicity, catastrophic events, land and water use problems, and disturbance of wildlife habitat, vegetation, and scenic vistas. Environmental issues occurred in the surrounding of Kawah Ijen is chosen to represent the common environmental issues in geothermal areas. Such knowledge are essential to determine solution and actions to overcome environmental issues in geothermal areas, such as technical solution, monitoring and early warning programme, increasing public awareness, and maintaining communication between stakeholders.

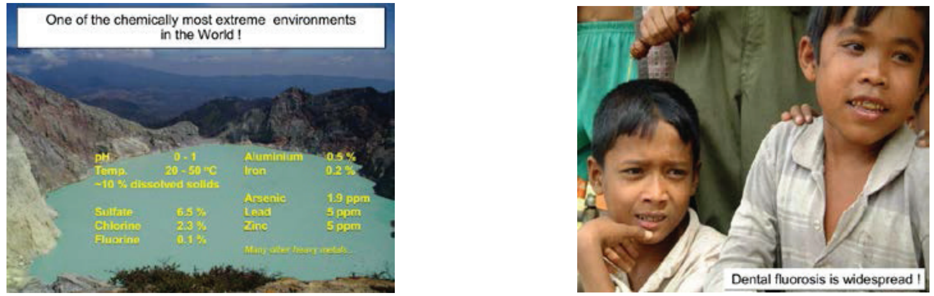


Figure 25

Left : The geothermal fluid discharged at Ijen crater lake is very acid. Even though damned the lake still loses water

Right One of the health issues epidemic at the surrounding of Ijen crater is dental fluorosis as the drinking water is contaminated by the lake water

CONTACT

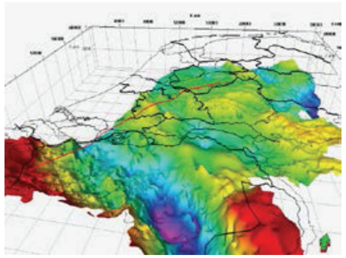
Pri Utami (Universitas Gadjah Mada): p.utami@ugm.ac.id

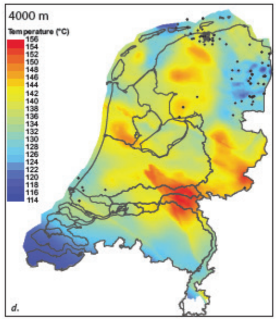
Agung Harijoko (Universitas Gadjah Mada): aharijoko@ugm.ac.id

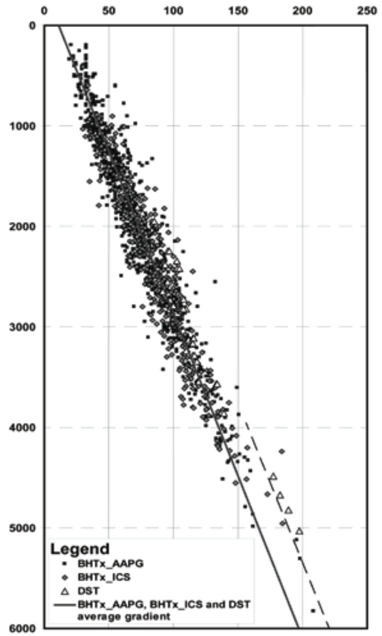
BASIN MODELLING FOR GEOTHERMAL EXPLORATION

INTRODUCTION

The transfer of in-depth knowledge and skills to conduct a quantitative analysis of the thermo-tectonic structure, composition and evolution of sedimentary basins is critical for acquiring a solid understanding of the potential geothermal energy resources in basins. This quantitative basin modelling course uses advance knowledge and state-of-the-art technics from geological characterisation and modelling using selected case studies of low- to medium-enthalpy geothermal systems.







(top left) *Perspective view of the geometry of the Mesozoic sedimentary basins of the Netherlands, which formed as extensional rift basins in a passive margin setting. Variations in subsidence (aka compaction) and uplift causes lateral heterogeneity in permeability of sedimentary layers, which affects the geothermal resource potential of the basins.*

(top right) *The average geothermal in the Netherlands is based 1293 temperature data points from 454 wells across the Netherlands. 52 from DST measurements, 412 from corrected BHT with the ICS method, and 829 from corrected BHT with the AAPG method*

(bottom left) *The borehole data were used to constrain a 3D temperature model of the Dutch subsurface. The isodepth map displays the modelled temperature distribution at 4000 m depth. The lateral variations in temperature are linked closely to the structure of the Dutch sedimentary basins. (after Bonté et al., 2012).*

RELEVANCE FOR AND APPLICIBILITY TO INDONESIA

The current geothermal prospects in Indonesia are linked directly to the distribution of volcanic systems, as shown in the figure below. The development of geothermal energy in the non or less volcanic active parts of Indonesia, such as Kalimantan, eastern Sumatra, western Sulawesi and Irian Jaya, will therefore have to focus on geothermal prospects that potentially are present in sedimentary basins systems in those areas.

Training courses such as the Geothermal Basin modelling course may provide an excellent opportunity to increase in an efficient way the knowledge and skills that are required for a solid quantitative assessment of the geothermal power from sedimentary basins across Indonesia.

GEOCAP ACTIVITY IN THIS TOPIC

The project has developed a 1-week basin modelling course presents a precise overview on the characterisation at regional scale of basin structure, evolution, and composition to allow the participant to understand the overall complexity of sedimentary basins: from their geodynamical context to basin structuration and composition. Given the target audience (academics, industrials, and governmental) and the wide range of specialities (geology, geophysics, and engineering) the course first covers basic knowledge before going into more details regarding geothermal characterisation. The course is developed and given by geological and geophysical experts from The Netherlands and Indonesia.

The course is articulated around three main modules:

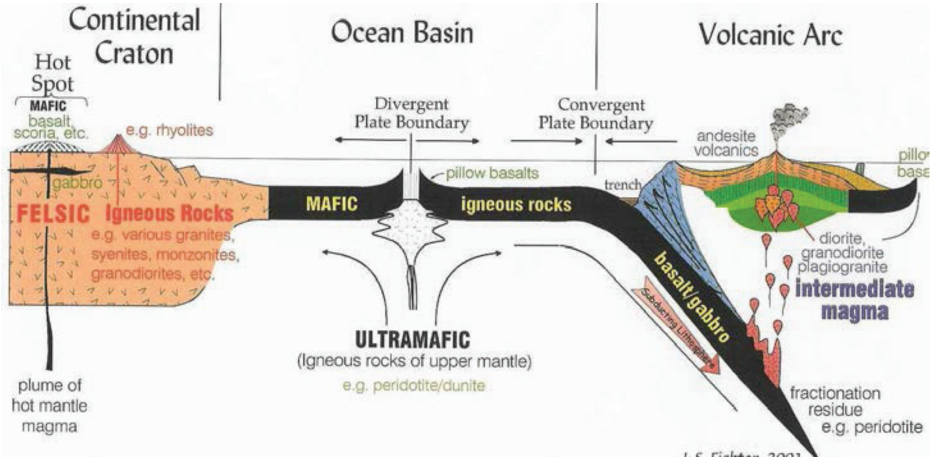
1. Geodynamics and thermal structure of the lithosphere
2. Characterisation and formation of sedimentary basins
3. Thermal evolution of sedimentary basin

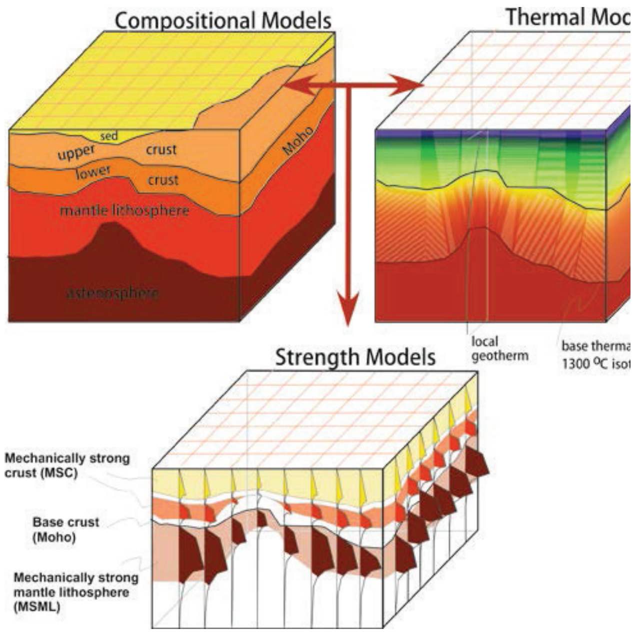
A special topical session on enhanced geothermal systems (EGS) in extensional sedimentary basins is also included in the course.

Each module starts with a lecture that aims to provide the participant a solid foundation of the fundamental aspects. The lecture is followed by exercise(s) designed to provide a thorough understanding of the different aspects introduced during the lecture.

1- Geodynamics and thermal structure of the lithosphere

The objective of this module is to understand the impact of the plate tectonic and lithosphere movements at very large scale on the development of sedimentary basins and geothermal occurrences in various basin environments. Building on the knowledge of geodynamic, the characteristic of anomalous thermal condition that provides geothermal interest are introduced and explained.





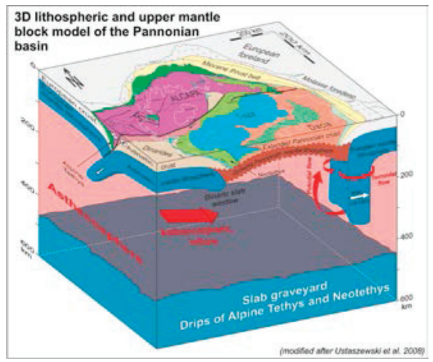
*(**top**) The key geodynamic and plate tectonic processes that control the structural and temperature evolution of the Netherlands (situated at a continental passive margin) and Indonesia (situated in an active subduction zone with volcanic arc). Source:*

https://watchers.news/2011/03/13/the-failure-of-plate-tectonics/

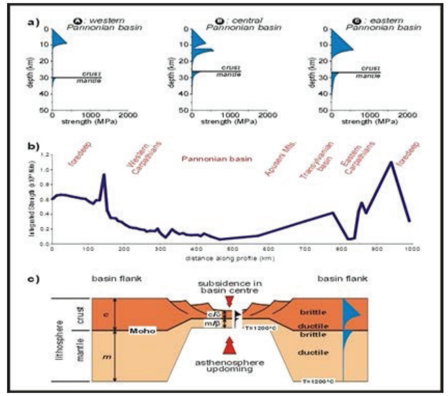
*(**left**) Variations in lithosphere and crustal thickness created by geodynamic processes strongly affect the temperature distribution, and consequently the 3D thermo-mechanical strength distribution. This in turn controls the formation and evolution of sedimentary basin systems. (after Cloetingh et al., 2005)*

2- Characterisation and formation of sedimentary basins

This module aims to develop the understanding of the impact of large-scale processes on the development of sedimentary basins in different geodynamic and tectonic settings, like for instance extensional basins formed at passive margins and back-arc basins formed in subduction systems. Also addressed is the impact of the large-scale processes on the thermal structure of the lithosphere, crust, and sedimentary basin systems.



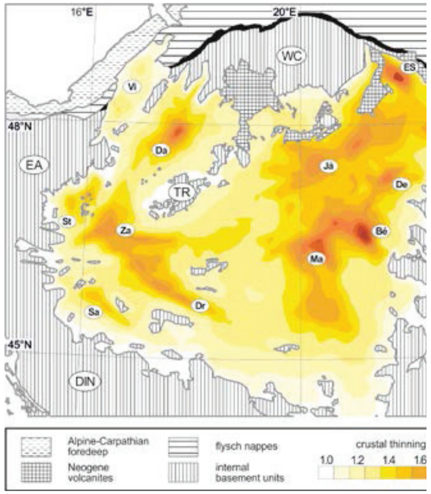
The Pannonian Basin in Europe is a complex back-arc basin that has undergone various phases of extension and compression. (after Horvath et al., 2015)



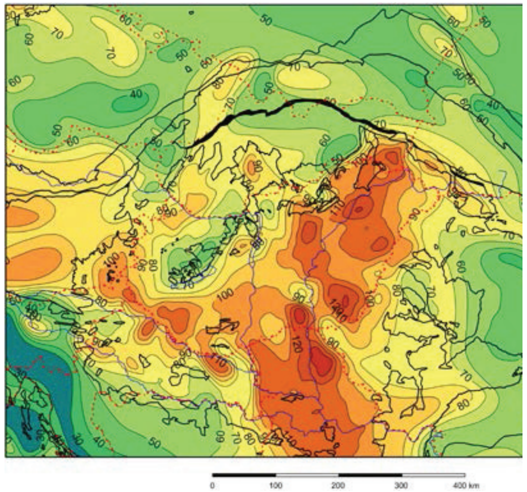
The variations in crustal thinning across the Pannonian Basin and the associated variations in crustal heat flow strongly affect the rheological strength of the lithosphere. (after Cloetingh et al., 2006)

3- Thermal evolution of a sedimentary basin

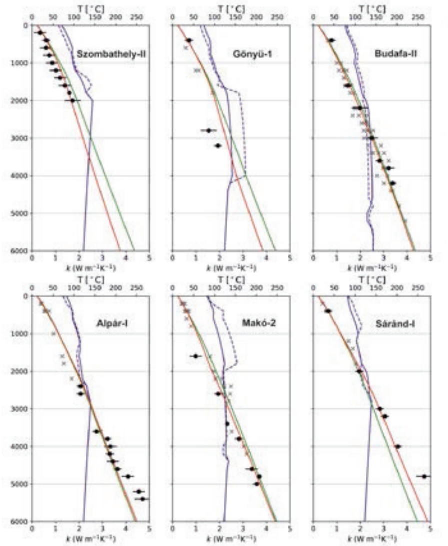
Building on the understanding of the geological context that allow the formation of sedimentary basin and the way they develop, we then develop the understanding on the geothermal specific aspect of this structure and development. Based on the case studies situated in the Netherlands and the Pannonian Basin (*figure below*) the knowledge of building the thermal structure has been first presented and then used for a practical case scenario, incorporating all regional scale geological complexity.



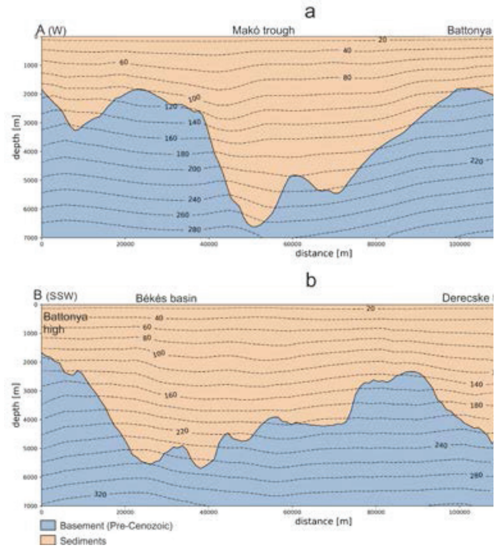
The complex evolution of the Pannonian Basin resulted in considerable variations in crustal thinning across the basin (after Cloetingh et al., 2006)



Heat flow map of the Pannonian Basin. (after Lenkey et al., 2002)



Depth curves of temperature (top panels) and thermal conductivity (bottom panels) at different well locations across Hungary. Due to the elevated geothermal gradient and high heat flows, Hungary has considerable potential for geothermal development. (after Bekesi et al., 2017)



Modelled isotherms across the Hungarian part of the Pannonian Basin. The results suggest that the hottest areas below 3 km are linked to the basement highs surrounded by deep sub-basins of the Great Hungarian Plain. (after Bekesi et al., 2017).

CONTACT

Damien Bonté (University of Utrecht): d.d.p.bonte@uu.nl

Fred Beekman (University of Utrecht): w.w.w.beekman@uu.nl

MAGNETOTELLURIC (MT) FIELD SCHOOL: MT TECHNOLOGY FOR GEOTHERMAL EXPLORATION

The magnetotelluric (MT) method is a frequency domain electromagnetic tool that utilizes natural variation in the earth's magnetic field as a source. The changes of Earth's magnetic field disturbed by solar wind and lightning activities induces electric currents beneath the earth's surface, called telluric currents (Figure 29).

Variations in the Earth's natural magnetic field supply frequencies ranging from nearly DC (0.001 Hz) to ten Hertz. The wide frequency range MT gives us the ability to study the electric substructure of the Earth from near surface to greater depth. The large frequency range also means that the method can handle conductive overburden and has large penetration depth. The MT method measures simultaneously the electric and magnetic fields in two perpendicular directions. The ratio of the horizontal electric field to the orthogonal horizontal magnetic field (termed the EM impedance, Z), measured at a number of frequencies, gives Earth resistivity as a function of frequency or period, resulting in a form of depth sounding (Figure 29).

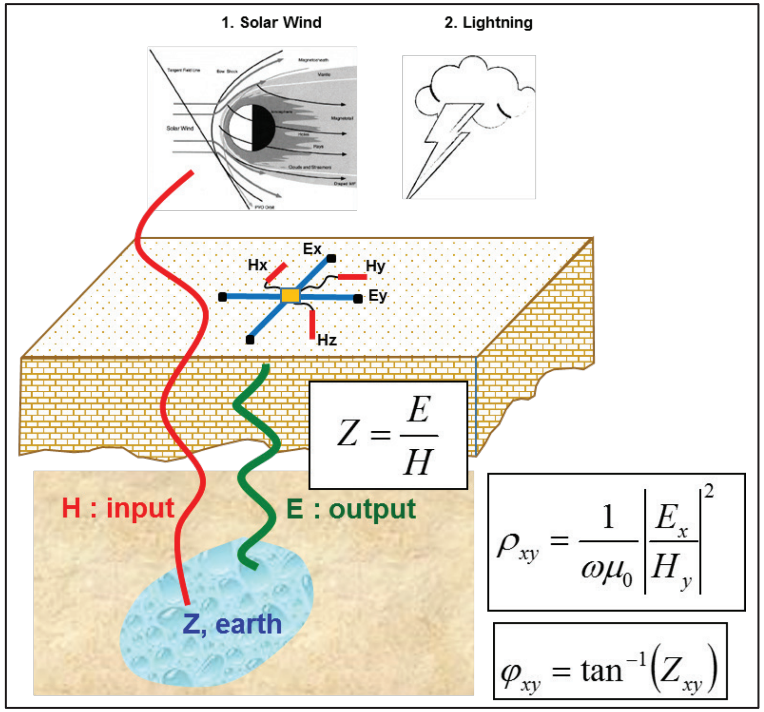


Figure 26 Basic principle of MT for imaging subsurface resistivity structure

reservoir and determine well target zones. The subsurface information derived from the MT data is then confirmed through drilling.

To provide better accuracy of resistivity distribution as well as further analysis using MT data, proper acquisition, processing, and modelling of the data should be applied (Figure 30).

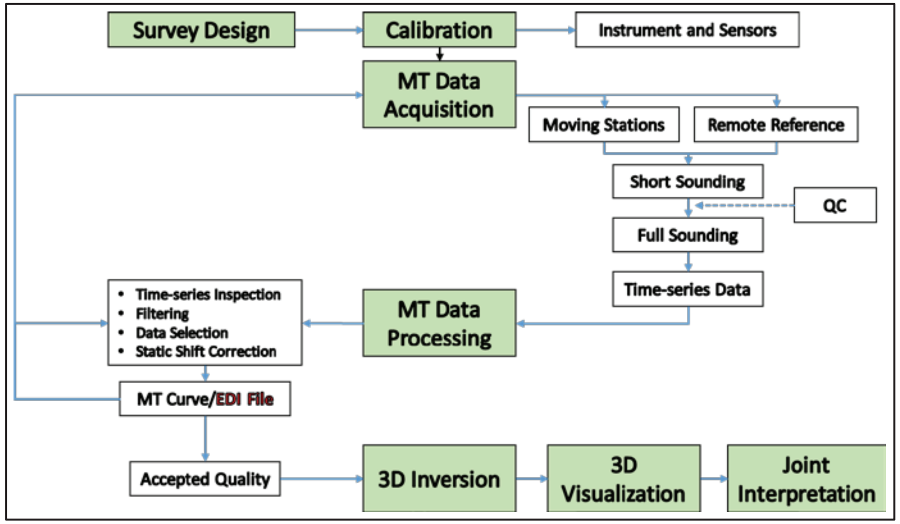


Figure 27 Flow chart of data acquisition through modelling/inversion (Daud et al., 2017)

Survey Design

MT survey design should be made by considering the geological condition of investigation area. We use remote sensing data to get initial important information related to boundary of lithology, indication of alteration as well as geological structure. Accordingly, the hypothesis of prospect area including its possible extension and boundary could be developed. Moreover, noise analysis is also needed as a consideration for locating MT equipment. The other important thing, finding suitable place for remote reference, because it plays important role in reducing electromagnetic noises, which contaminate MT data in local site.

Field Data Acquisition

A proper way of data acquisition with following standard operational procedure is important to carry out in order to get high quality data. Understanding the objective of the survey is also needed for planning efficient survey strategy.

Figure 28 MT field data acquisition

Processing of MT Data

Data processing is the most important and influential stage in applying MT technology. As a passive geophysical method (depending on the natural source), MT is very sensitive to electromagnetic noises. Szarka (1988) and Chave & Jones (2012) have been discussed regarding influences of electromagnetic noises to MT data. Accordingly, for the first step in applying suitable processing is conducting time-series inspection and applying noise filter (Ismail et al., 2015). Figure 32 shows the result of before and after applying noise filter.

After applying several filters and data conversion, the MT result is represented by both apparent resistivity vs. frequency curve and phase vs. frequency curve. However, the curves have not directly a good result. Accordingly, data selection (sometimes called cross power selection) should be performed. Different method of data selection may produce different curve trend (Figure 33). Manual selection, which is done carefully with expert-judgement, is more recommended rather than auto-processing (automatically processed by software).

Before conducting data inversion, final data correction related to static shift effect should be overcome properly (Arnason, 2015). Otherwise, it will cause misinterpretation of subsurface resistivity data, increase drilling risk, and consequently increase financial risk. Static shift correction is mostly performed by conducting TDEM survey. However, several geothermal fields in Indonesia have no TDEM data. An alternative solution is applying geostatistical method using StaticShifter-X software (Daud, 2011). Based on several MT data, the results of static-shift corrections by using geostatistical data are comparable with those corrected by TDEM data. In addition, the inversion results of the both corrected MT data are comparable Figure 34).

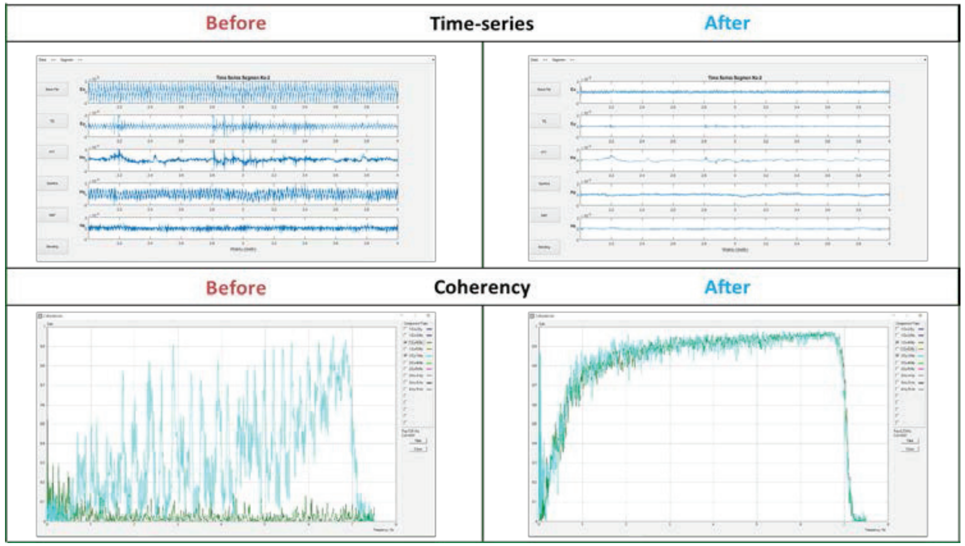


Figure 29 Condition of time-series and coherency before and after applying noise filters (Daud et al., 2017).

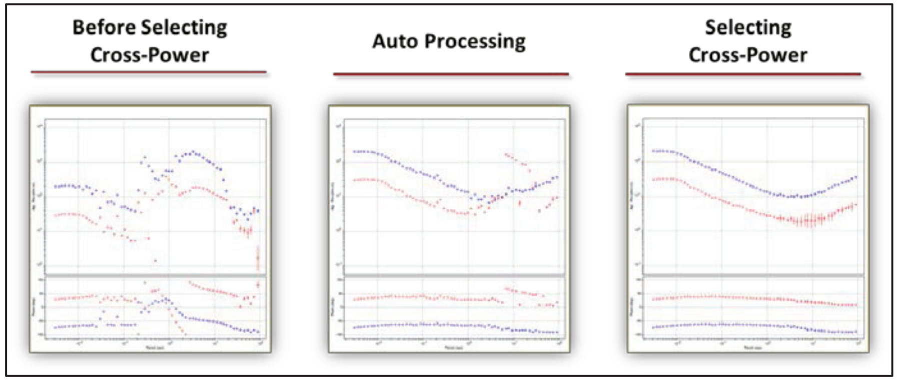


Figure 30 Comparison between before selecting cross power, auto-processing and "manual" selection (Daud et al., 2017).

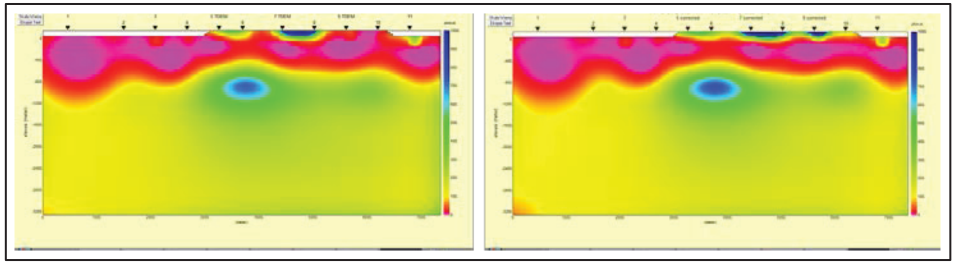


Figure 31 Comparison of inversion result of MT data after applying TDEM (left) and Geostatistic (right) (Daud et al., 2017).

MT Modelling Schemes

Choosing the most appropriate inversion scheme is also important. The real geological condition where geothermal area is located should be considered when selecting the proper modelling criteria for MT data. 1-D inversion method can be used in 1-D subsurface structure or stratified layer such as in sedimentary formation. 2-D inversion method can be used in 2-D subsurface structure or single geoelectric strike direction. Meanwhile, geothermal system in Indonesia is mostly related to volcanic activity, which is located in mountainous terrain with complex geological structure. Accordingly, the most reliable approach is 3D inversion.

Before conducting 3-D inversion, the most important to be considered is data input. EDI file as a SEG standard format for MT data should be produced by proper MT data processing. After checking the data input, the workflow of 3-D inversion can be followed (**Error! Reference source not found.**) (Daud et al., 2012), from initial model construction to the most appropriate model selection. Basic principle for selecting the most appropriate model is understanding the geothermal system. A hypothetical model about geothermal system should be in mind of modelling engineers. For giving better visualization of 3-D inversion result, 3-D visualization software such as GeoSlicer-X (Daud & Saputra, 2010) can be utilized. Several features can be optimized in form of resistivity section, resistivity map, 3-D cake model, iso-value, as well as observed vs. calculated data curves.

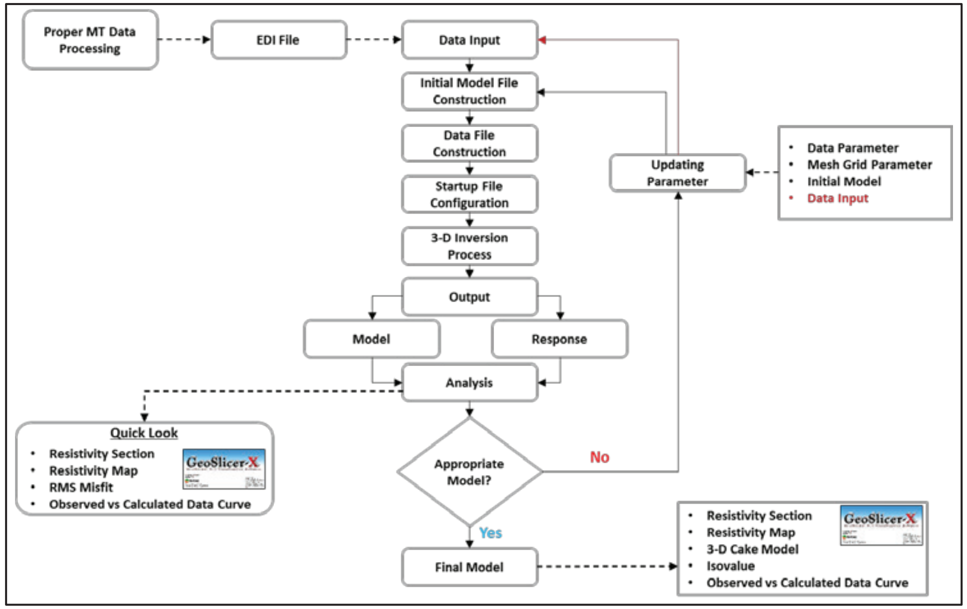


Figure 32 3-D inversion flowchart using MT3DInv-X software (Daud et al., 2017).

MT Data Interpretation

Interpretation is the crucial step of MT application in geothermal exploration. To achieve good interpretation result we need good data acquisition, good pre-processing as well as good inversion. Furthermore, good understanding of earth resources system (such as geothermal resources system) is necessary for achieving the best interpretation results.

Geothermal system, which has high salinity, clay alteration and high temperature, can be characterized by the resistivity value. The conductive zone (< 10 ohm-m) that commonly lies above geothermal systems has been shown to have a strong correlation with temperature between 70 and 200°C. The cause of this has been linked with the type of clay alteration that occurs in this temperature range (Ussher et al, 2000) (Figure 36).

The high temperature reservoir is the main objective of geothermal exploration. It could been seen beneath the conductive zone which has slightly higher resistivity value (>30 ohm-m) than the overlaying conductive zone. Alteration process involving conversion from smectite clays to illite or chlorite becomes the main factor of increasing the resistivity value (Figure 36).

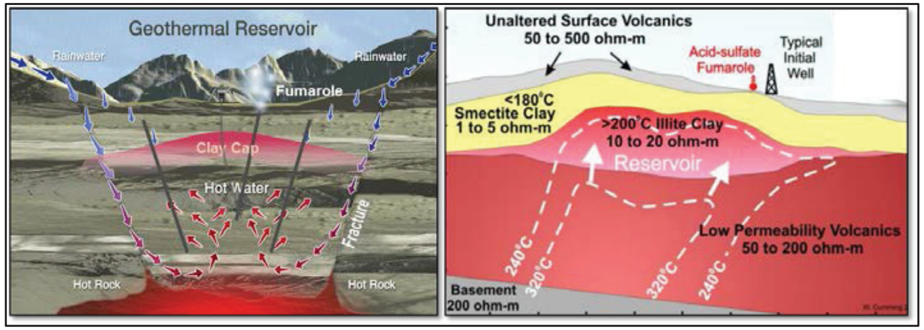


Figure 33 Simplified geothermal system with its resistivity characteristics

MT is a technology, where "the man behind the gun" (engineers) become the most important thing. Special treatment to the MT technology and innovations to the processing and modelling of the MT data should be applied carefully and appropriately. Otherwise, misleading information can be generated leading to unsuccessful recommendations (**Error! Reference source not found.** and **Error! Reference source not found.**). The MT results in Figure 9 (left) and Figure 10 (left) are in disagreements with drilling data. While the MT results in Figure 9 (right) and Figure 10 (right) after applying the innovation of MT technology (including filtering) are in good agreements with drilling data.

It should be a warning for geologist or interpreter wishing to use MT model for describing the geothermal system as well as determining the drilling target. Since MT data is not only a display of MT resistivity data, but also need proper way in the data processing. Accordingly, it is important to make a re-evaluation of the data processing of the existing MT data before continuing to further steps.

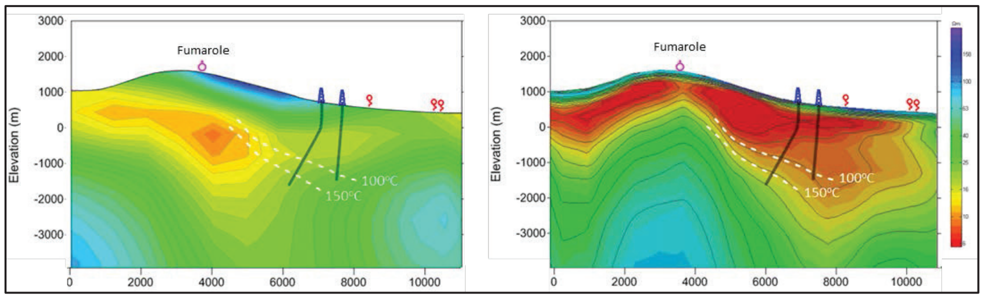


Figure 34 Correlation between MT and drilling result before (left) and after (right) applying the innovation to (Daud et al., 2017).

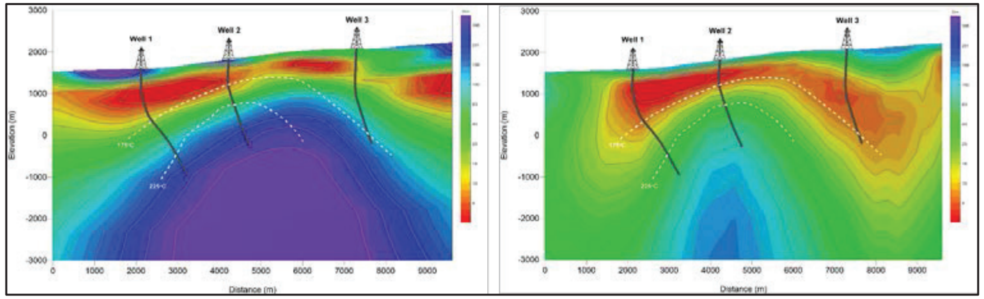


Figure 35 Correlation between MT and drilling result before (left) and after (right) applying the innovation (Daud et al., 2017).

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RELEVANCE FOR AND APPLICABILITY TO INDONESIA

MT technology has been widely used in Indonesia as the main exploration technology for delineating the subsurface low resistivity clay alteration (clay cap), interpreting the top and geometry of reservoir and indicating the subsurface temperature derived from resistivity distribution. By integrating the MT data with geological and geochemical data, a conceptual geothermal model and well targeting could be defined. Since most geothermal area in Indonesia have characteristics: located in high and rugged topography, the reservoir is usually deep and concealed, and in some parts of Indonesia influenced by high electromagnetic noises, therefore, careful and proper application of the MT technology should be done in many geothermal fields in Indonesia to obtain better results of the geothermal reservoir and finally better delineation of drilling targets.

GEOCAP ACTIVITY RELATED TO MT TECHNOLOGY

GEOCAP has a special training related to MT technology namely “MT Field School”. This training was delivered by GEOCAP member from UI (Dr. Yunus Daud) and IF Technology (Dr. Wouter van Leeuwen) for about 25 participants from universities and government agency. The training covered basic concept of MT technology, field data acquisition, processing, modelling and interpretation. Case studies were also delivered during the training.

In addition, deep MT survey, as a part of GEOCAP program, will be conducted in North Sumatera for delineating deep subsurface resistivity distribution related with possible geothermal occurrences associated to the tectonic and volcanic activity along the Great Sumatera Fault Zone. This program is part of the Joint Supervision PhD research program between University of Utrecht and Universitas Indonesia. The student involved is Lukman Sutrisno (from UI), supervised by Prof. Dr. J.D.M. van Wees (UU) and Prof. Widodo W. Purwanto (UI) and co-supervised by DR. Yunus Daud (UI) and Dr. D.D.P. Bonte (UU).

CONTACT:

Yunus Daud (Universitas Indonesia): ydaud@sci.ui.ac.id

REMOTE SENSING FOR GEOTHERMAL EXPLORATION

INTRODUCTION

Remote sensing is a series of techniques that study the Earth’s surface with the help of datasets recorded from various types of sensors. These sensors can either be satellite-based, airborne or mounted on drones, where the former are more suitable for acquiring regional information and the latter for more detailed data on smaller study areas. The sensors can measure in different parts of the electromagnetic spectrum:

- reflective remote sensing uses reflected sunlight in the visible to short-wave infrared region and an indication of the surface composition
- emissive (or thermal) remote sensing measures thermal infrared energy emitted by the ground, and can indicate surface compositions as well as surface temperatures.
- microwave remote sensing uses the reflected portion of the emitted microwave radiation and can give information on elevation, slopes and surface roughness.
- LiDAR remote sensing uses the reflected laser beam from an airplane to calculate very high resolution digital surface and terrain models (several measurement spots per square meter)

The main advantage of remote sensing is that it gives fast, reproducible information for large areas. It gives a synoptic overview that is often lost when the observer is located closer to the object like during field visits. Remote sensing as such does not replace fieldwork, but is most efficiently used in early stages of the exploration process, to get a regional overview (satellite data) followed by more detailed local analysis (airborne data) and efficient fieldwork to the most striking areas (see figure below for examples of platform types). As each remote sensing technique gives information on an important parameter (such as the surface composition). Several techniques are often combined to give the full picture and make the most use of their complementary nature. Remote sensing results are also complementary to several of the geophysical techniques (e.g. resistivity imaging and MT) as remote sensing focuses on the surface information and geophysics can give information about the deeper subsurface.

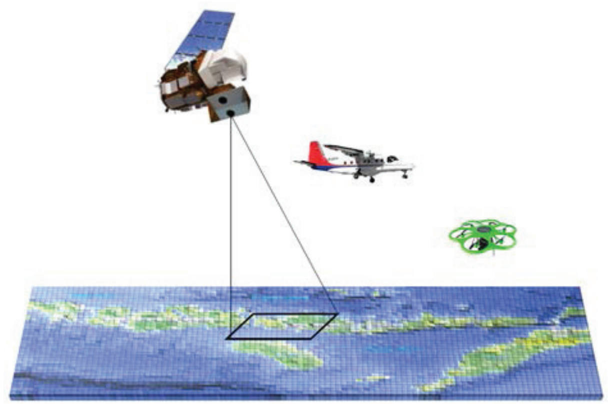


Figure 36 Different platforms that can carry remote sensing devices: spaceborne (satellite), airborne (plane) and drone (from left to right).

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Remote sensing can have a big impact on streamlining efforts in geothermal exploration. Detecting geothermal hotspots from thermal infrared data shows at which areas surface manifestations occur which can be targeted for mineralogic and geochemical sampling during a field campaign. Detecting clay alteration (see figure below) from short-wave infrared data allows to track current or historic areas of hydrothermal alteration that has caused the rocks to change in composition towards more clay rich areas. The type of clay that us detected is an indicator of the alteration conditions (e.g. pH) of the fluids involved and can be used to better understand the areas of hydrothermal upflow versus outflow. However, reflective and emissive remote sensing results are disturbed by vegetation cover which is often quite substantial in Indonesian areas prospective for geothermal resources. Even though steaming grounds and other surface manifestations typically influence and reduce the vegetation density, the surface areas that are free of vegetation and show elevated temperatures and clay altered ground are rather small to be effectively detected in satellite data (pixel size typically in the range of meters to tens of meters). Airborne data, however, does not have this restriction as low flying survey planes can produce datasets with pixel sizes in the range of centimetres to a few meters. They can detect anomalous surface temperatures and altered ground in small gaps of the vegetation canopy.

RADAR and LiDAR data can both create digital terrain models that can show the surface expression of fault lines, crater rims and other geologically interesting structures, such as the outline of different volcanic rock units and lava flows. Both of these techniques are much less restricted by vegetation cover than reflective and emissive remote sensing, and are very suitable datasets for the Indonesian context. High density LiDAR surveys fire hundreds of laser pulses per square meter. While many are reflected by the canopy, some will penetrate through small gaps and reach the understory and the ground surface. As part of the LiDAR data processing, the reflected laser pulses are classified into different reflection classes which allows to filter the data by either the first return (the top of the canopy) or by the last return (the ground underneath the canopy), which allows to study the shape of the actual terrain underlying the forest canopy.

Figure 37 Example of extensive clay alteration in the geothermal area of Wayang Windu, West Java.

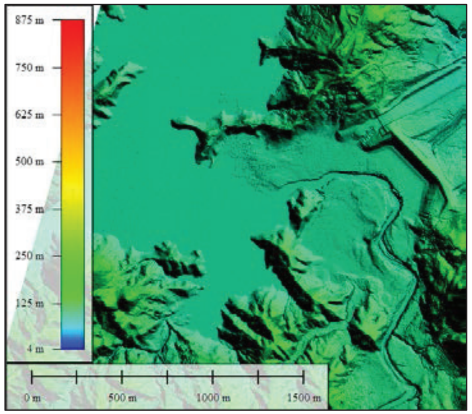


Figure 38 Example of LiDAR-derived DEM with artificial lighting to enhance tompographic expression. (Figure courtesy PT. Asi Pudjiastuti Geosurvey).

GEOCAP ACTIVITY IN THIS TOPIC

As part of GEOCAP workpackage 1.01, two train-the-trainer courses on Advanced Remote Sensing for Geothermal Exploration were given. The first edition given in November 2016 at ITB in Bandung focused on spectral and thermal satellite data processing with ASTER data, on LiDAR processing for geomorphological and structural interpretation, and on Synthetic Aperture RADAR processing for structural feature extraction. In a second course, given in July 2017 iat UGM in Yogyakarta, the material was extended with an interpretation and fieldvisit to the Dieng Plateau. This included satellite data interpretation for preparation of field checks, execution of the field checks and reporting of the results.

Figure 39 A portable infrared spectrometer for remote sensing field checking is demonstrated during the train-the-trainer course at ITB.

Additionally, GEOCAP also developed case applications of remote sensing for the Indonesian geothermal context in several other workpackages. WP 2.04 did a regional satellite remote sensing study on the geothermal Island of Flores (NTT). This study revealed potential areas of interest, one of which (Bajawa, Flores) was investigated in more detail during an campaign combining airborne LiDAR with thermal infrared mapping in June 2018. These data are part of MSc and PhD studies between UT-ITC and UGM.

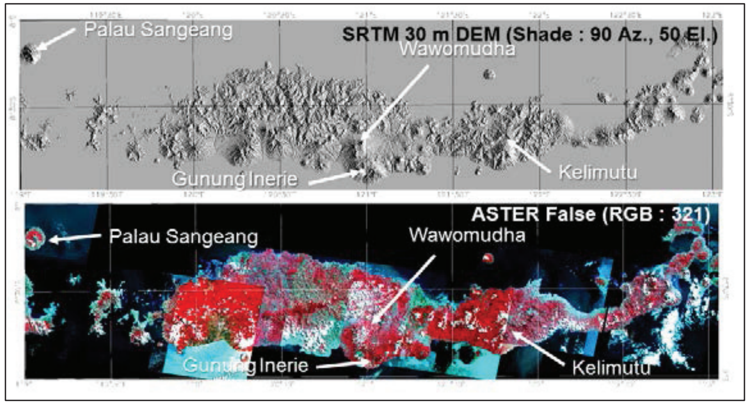


Figure 40 Example of data used in the regional remote sensing study of Flores Island. Above: Digital Terrain model with topographic shading derived from Shuttle RADAR Tomographic Mission data (NASA). Below: false colour composite of the visible and near infrared

As part of WP 2.08 on Governance and Rules & Regulations, GEOCAP partners ITB and UT-ITC did a remote sensing monitoring case study on the Patuha geothermal area of West Java. Land use and landcover changes were investigated with optical remote sensing, and subsidence due to the geothermal fluid extraction in the Patuha geothermal area, as well as ground water extraction in de Bandung region were investigated using interferometric synthetic aperture RADAR satellite data.

CONTACT

Dr. Chris Hecker (UT-ITC): c.a.hecker@utwente.nl

Dr. Agung Setianto (UGM): agung.setianto@gmail.com

Dr. Asep Saepuloh (ITB): saepuloh@gc.itb.ac.id

Dr. Robert Hewson (UT-ITC): r.d.hewson@utwente.nl

PRODUCTION

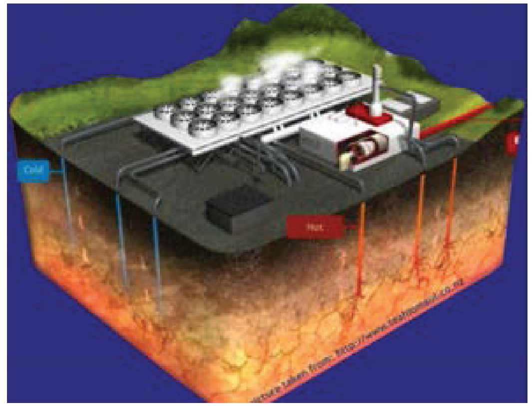
GEOTHERMAL RESERVOIR AND PRODUCTION ENGINEERING KNOWLEDGE AND SKILLS

INTRODUCTION

The geothermal reservoir and production engineering is complex multidisciplinary studies to provide an understanding of the dynamic behaviour of geothermal reservoir and with the application skills to assess those reservoirs. This would be accomplished with the knowledge about basic geothermal system, reservoir engineering, reservoir geomechanics and the working skills with tools to evaluate and model the reservoir. The geothermal reservoir and production engineering course uses advance knowledge and state of the art of geothermal reservoir simulation, like well testing for reservoir characterization, flow measurement and production testing, numerical geothermal reservoir modelling. The course aims at a multidisciplinary approach using concepts from geology, physics, and engineering

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Most of the geothermal system in Indonesia is hydrothermal system and the development of geothermal energy in hydrothermal system high temperature still become a first priority of geothermal development. Therefore, the fundamental of dynamics and reservoir engineering, geomechanics, key reservoir parameters, flow measurement and numerical simulation should be understood well. The training course of "Geothermal Reservoir and Production Engineering Knowledge and Skills" might provide an excellent opportunity to increase in an efficient way the knowledge and skills that are required understanding of the dynamic behaviour of geothermal reservoir and with the application skills to assess those reservoirs.



This 2-week course (10 days) targets at reservoir and production engineering using lectures, exercises, and assignment and background reading material.

The main components of the course are:

- Basics of geothermal systems and reservoir engineering and reservoir geo-mechanics
- Flow measurements and production testing
- Well testing procedures for reservoir characterization

- Numerical geothermal reservoir modelling

The target group of the course are Master Students, PhD Students and Industrial Professionals. The participants should have a basic knowledge about reservoir geology, flow mechanics, and mathematical modelling.

The course is articulated around ten main modules:

1. Main component of hydrothermal systems
   Types of hydrothermal system, rock properties, conceptual model, key questions about reservoir
2. Fundamental of dynamics reservoir engineering
   Simple quantitative models, pressure transient models
3. Reservoir geomechanics
   Fundamental of geomechanics, coupling with flow, applications
4. Identification of reservoir characterization and key parameters from logging, downhole measurement and well completion
   Well logging, downhole measurements, well completions test
5. Production Engineering. Production Test & Well Stimulation
   Fundamental of production engineering, wellbore modelling, stimulation, flow measurement for steam wells & two-phase wells
6. Wellbore testing
   Fundamental of transient test, type of transient testing, dual porosity/dual permeability, testing hydraulic fractured wells, tracer test
7. Geothermal reservoir modelling

   Principle & methodology, lumped model, conceptual development model, computer model, data preparation for modelling, modelling process, natural state modelling, history matching, performance forecasting.

Each module starts with lecture those objectives to deliver the participant a solid foundation of the fundamental aspects. The lecture is followed by exercise that has designed to provide a throughout understanding of the different course introduced during the lecture.

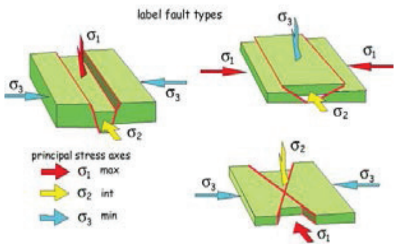


Figure 41 Stress Conditions in the Earth

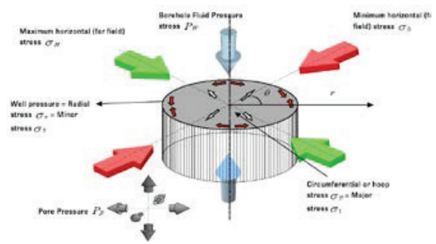


Figure 42 Stress configuration around borehole

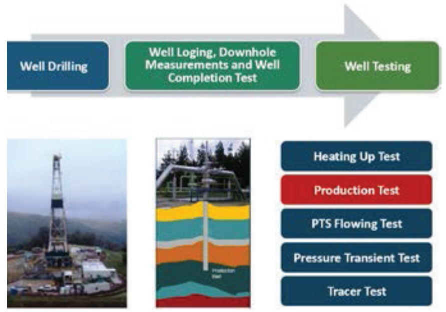


Figure 43 Flow measurement and production testing

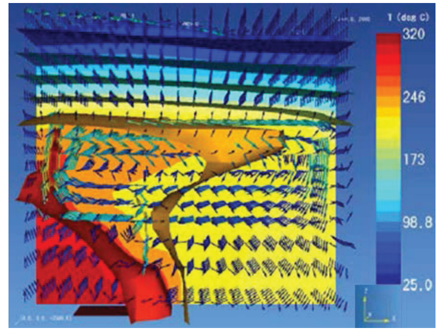


Figure 44 Reservoir modelling in liquid-dominated reservoir

CONTACT

Nenny Miryani Saptadji (Institut Teknologi Bandung): nenny.saptadji@geothermal.itb.ac.id

Sutopo (Institut Teknologi Bandung): sutopo@tm.itb.ac.id

Ali Ashat (Institut Teknologi Bandung): labgeothermal@yahoo.com

Zuher Syihab (Institut Teknologi Bandung): zuher.syihab@tm.itb.ac.id

Nurita Putri Hardiani (Institut Teknologi Bandung): nurita_putri@yahoo.co.uk

Heru Berian Pratama (Institut Teknologi Bandung): heru.berian@geothermal.itb.ac.id

Dimas Taha Maulana (Institut Teknologi Bandung): dimas.taha@geothermal.itb.ac.id

DRILLING SKILLS

INTRODUCTION

Generally about this work package

The GEOCAP work package "Drilling skills" focussed on A) corrosion problems B) a study on gas lift in production wells re-using gas from the reservoir and C) using slim hole drilling techniques. Several items for this work package are worked out by ITB and IF Technology.

A) Corrosion has a major impact on geothermal wells. For many projects, this is one of the main risks with a high impact on the exploitation. Highly corrosive liquids/steam produced do have a big impact on the integrity of the wells and surface installation. ITB worked on this subject and delivered several related articles. These can be found on the GEOCAP website.

B) IF Technology did specific research on a new technique to re-use out coming gases from produced reservoir water for gas lifting geothermal wells using a closed loop system. This specific research can also be found on the GEOCAP website (Artificial Lift in Geothermal Wells: A Study to Binary Cycle Geothermal Power Plants with Gas Lift in the Production well; F.W.J. Niewold, GEOCAP/2017/REP/IF Technology/WP2.03)

C) Furthermore research has been done on the use of slim hole drilling techniques for drilling geothermal wells. ITB worked out some articles on this item (see GEOCAP website). IF Technology looked into the feasibility of using slim hole drilling techniques for small scale and less deep (in sedimentary basins) geothermal projects.

For this handbook, the latter item is worked out more in specific. However, the reader of this handbook-item is advised to have a more detailed look on the GEOCAP website for the other interesting articles and reports that have been made for this work package.

Small-scale direct use of geothermal energy in sedimentary basins using slimhole drilling techniques

The focus of Indonesian geothermal market is exploiting big geothermal fields in high enthalpy volcanic systems. However many remote areas in Indonesia are less populated, less accessible and less developed. Expensive and complicated deep and high enthalpy projects will not easily be developed in these areas.

Therefore, it can be interesting to focus on less deep and smaller geothermal energy systems. Making smaller projects using slim holes (small hole drillings) into shallow sedimentary layers could improve business cases: less investment costs, less environmental impact, less project development time, better match between heat-demand and heat delivery and less drilling risks. Small-scale projects could finally lead to more projects, as these are easier to finance and develop. Many small geothermal projects could lead to a significant contribution of the environmental objectives to reduce CO2 emissions.

In this research, we investigated the direct-use of geothermal heat in industry using slimholes in sedimentary basins as competitive alternative to conventional sources of energy.

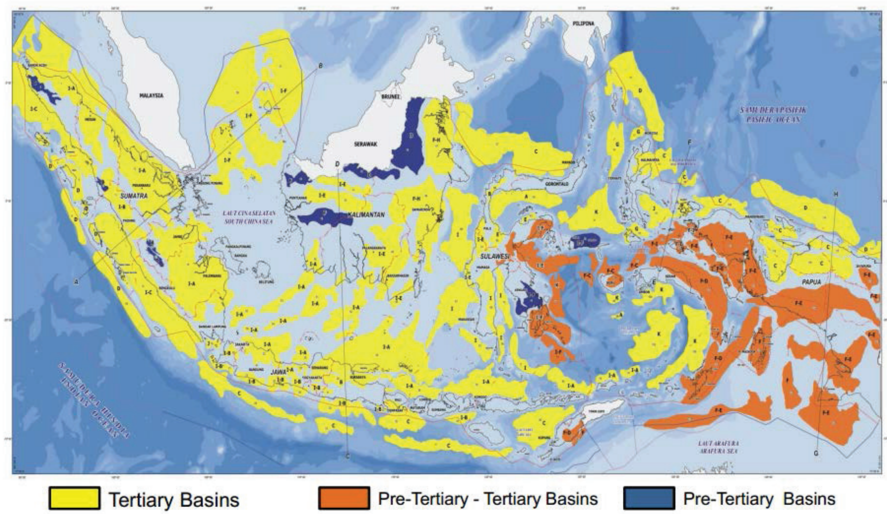


Figure 45 Sedimentary basins in Indonesia (Source: Badan Geologi KESDM)

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Indonesia has one of the largest geothermal potentials of all countries in the world. In Indonesia, geothermal energy is synonymous with power generation from high enthalpy volcanic systems. These volcanic systems are commonly found in mountainous and therefore quite sparsely populated areas, while industrial centres are concentrated in the lowlands where there is lots of people and good transport infrastructure.

This does not mean that the idea is of using geothermal heat for industry in Indonesia is without merit. It does however require a different approach to geothermal than the prevailing notion that geothermal is only viable in high enthalpy volcanic systems. It is here that some of the experiences of using geothermal heat from sedimentary geology could be of use. Using direct geothermal heat from sedimentary basins is developing fast in parts of Europe.

The downside of sedimentary geology compared to volcanic regions is that the geothermal gradient is generally lower. This means that much deeper and therefore more expensive wells are required to achieve the same production temperature. The upside is that the permeability of sedimentary layers is more uniform, reducing the drilling risks and the need for extensive exploration efforts. On top of that, many sedimentary basins have been subjected to oil and gas exploration further reducing the need for additional surveys and exploration wells.

As there is no conversion efficiency in a direct-use application the potential thermal power output of a well is generally significantly higher than the electrical power output. The downside of a direct-use well is that thermal energy is much harder and therefore more expensive to transport than electrical energy. This means that the energy must be used locally putting a restriction on how much offtake you can realize.

As an example, a conventional geothermal well in a sedimentary basin: It could easily produce a flow of 250 m3/hour. If this flow were cooled down by 50°C, the thermal output of the well would be about 20MW. The demand of the local industry however is in almost all cases lower than 20MW. This leaves two options, pooling multiple users together or developing smaller wells (also called slim-hole wells).

The challenge with pooling different users is that it becomes much more complex from an organizational perspective. All parties have to agree on the set-up and operation of the project. It is therefore worthwhile to look at the option of using smaller and cheaper wells to provide a suitable power output for a single user.

Figure 46 Rotary rig drilling slim holes up to 1500m (Source: ISOR)

Slimhole drilling

Making these small-scale geothermal direct-use projects feasible requires the smaller wells to also be cheaper compared to conventional geothermal production wells. Slim hole wells are already applied in oil and gas industry as well as in mining and geothermal exploration. As far as we know slim hole wells have not (or only scarcely) been used as direct heat supply for industry or other applications.

Sedimentary basins

Most of the Indonesian industry is situated nearby the major cities in industrial estates. Most of these Industrial estates are located in the sedimentary basins. Therefore, we focussed on sedimentary basins in this study.

GEOCAP ACTIVITY IN THIS TOPIC

Set-up of the research

First a literature review about the state of art of slim hole drilling worldwide and especially in Indonesia was performed. Market opportunities within the Indonesian Industry have been evaluated. Based on this information a well design for a specific case was made and a business case was developed to verify the economic feasibility.

The most and biggest cities are located at Java, the relative potential can be found there. Besides this, the most information of the geology (temperatures, depths and Aquifer thickness) is available from Java within the GEOCAP project (WP 3.0). This is the main reason this study focussed on two industrial Estates located near Jakarta. These Industrial Estates are situated in the Northwest Java Basin. These industrial Estates are Jababeka and Karawang.

Figure 47 Location of Jababeka and Karawang

Temperatures and depth

In the Jakarta area, in the Northwest Java Basin, two major Aquifers are situated, the Baturaja Aquifer and the Talang Akar Aquifer. The temperatures and depths of several wells in this area have been mapped. From this data, it is found that the most potential aquifers are found at circa 2500m depth and the reservoir temperatures are around 120 degrees Celsius.

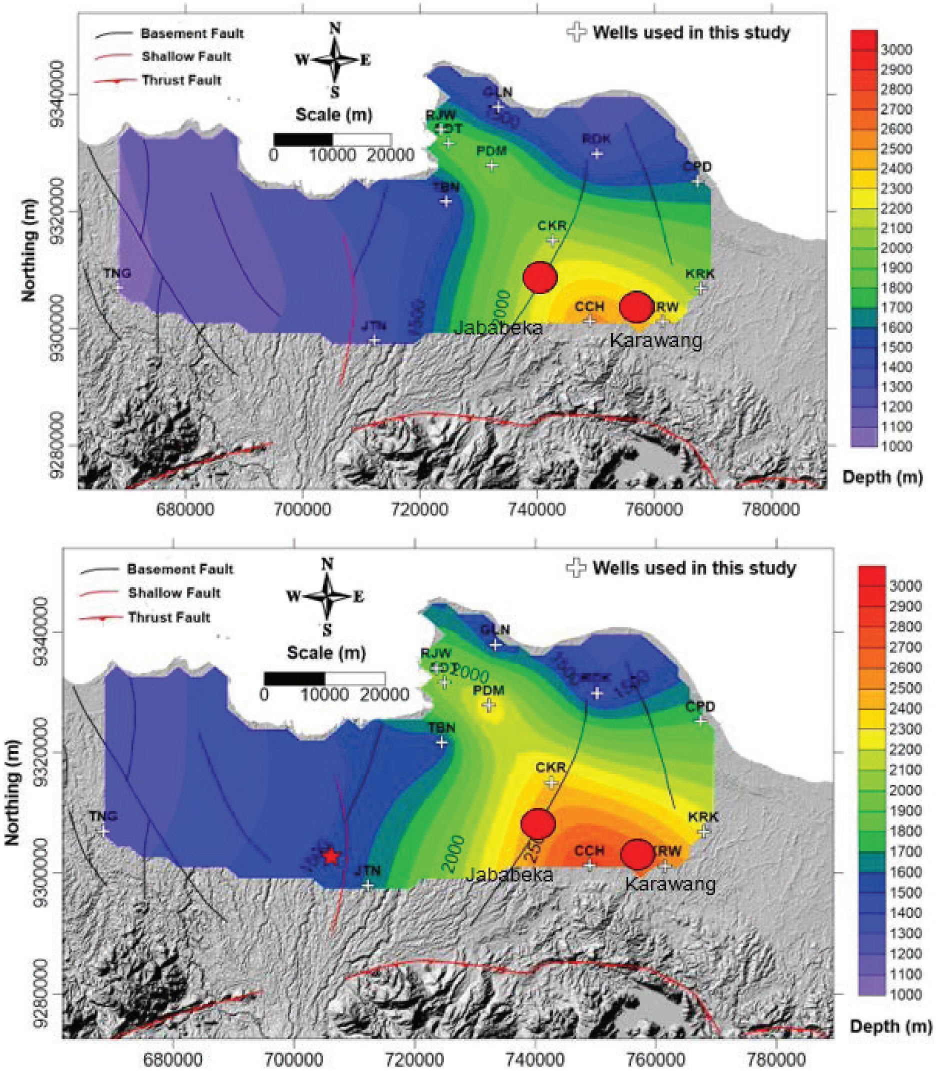


Figure 48 Mapping of the distribution of depth to the centre of Baturaja aquifer (above) and Talang Akar aquifer (below)

Evaluation of market opportunities

This study focused on present Industry in Karawang and Jababeka. The following users in the industrial areas of Karawang and Jababeka are seen as practical potential users of direct use of geothermal energy:

- Paper Industry

- Processing of Palm oil (Indonesia is the biggest supplier of palm oil in the World)
- Milk Industry Food industry
- Consumer goods

The energy demands vary between the several potential users. An estimation of the thermal energy demands has been made and is expected to be between 3 – 10 MW thermal energy. The required temperatures has been determined between 55 – 135°C.

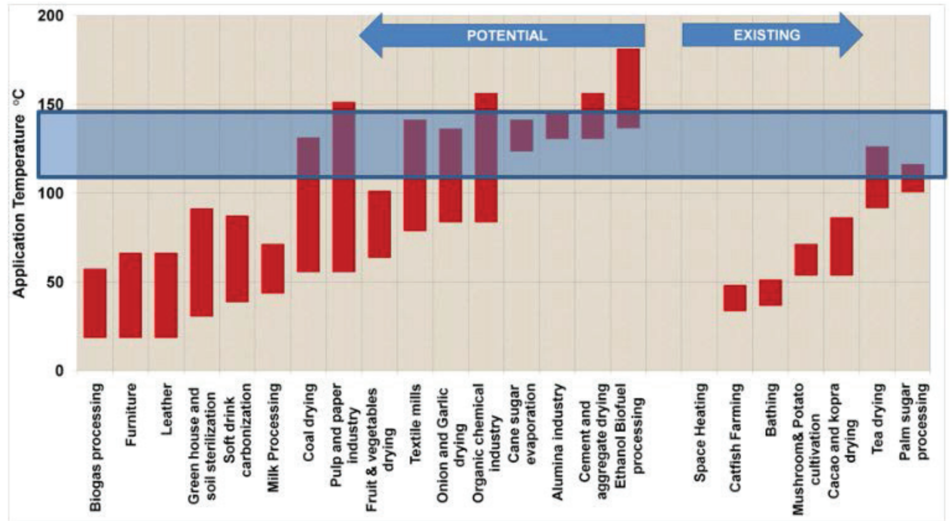


Figure 49 Potential consumers of geothermal direct heat

Business case excel tool

For this specific case a slimhole design was made and the business case was calculated using a new developed excel tool. This tool is available on the GEOCAP website.

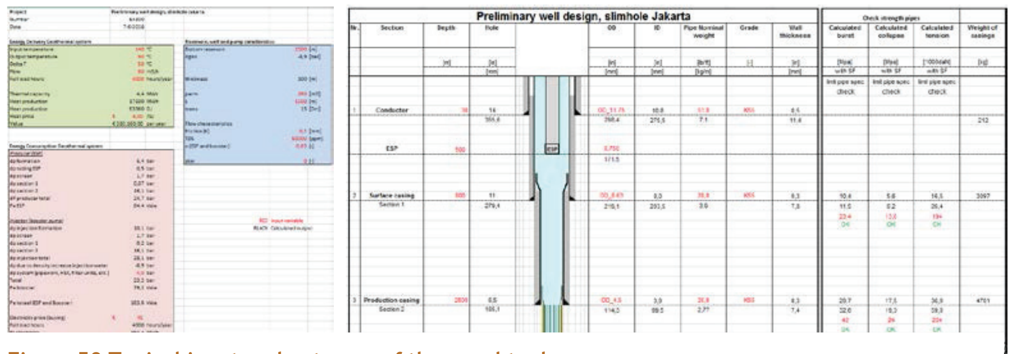


Figure 50 Typical input and outcome of the excel tool

Conclusions

- Slim holes can supply industrial users with sustainable heat.
- In case of hot water production for single industrial users, a payback period is estimated at 9 years. The investment required is estimated at 6 M$.
- Compared to standard (large scale) geothermal wells, small projects using slim holes will be much easier to realize, due to
    - much lower investments
    - small projects are easier to organize (only one user/heat-consumer required)
    - due to a better match with the local demands, it fits for purpose and therefore it can be used more widely.
    - the impact of several risks are limited
    - space requirements are limited

CONTACT

Bas Pittens (IF Technology): b.pittens@iftechnology.nl

MAINTENANCE SKILLS FOR GEOTHERMAL POWER PLANTS FOR INSPECTORS, OPERATORS AND ENGINEERS

INTRODUCTION

In general, the construction and components of a geothermal power plant are similar to those of other power plants such as coal and gas plants except that geothermal power plants do not have boilers. Other specific feature in geothermal power plant is it uses geothermal fluid that has special characteristic that differs from surface fluid. Various components build the function of the geothermal power plant. Related to these typical conditions, there is no available single indicator that is able to present the reliability degree of the geothermal power plant. Therefore, it is important to build composite reliability indicator to present the reliability degree of the geothermal power plant. The composite indicator may be built base on several single indicators, namely: net electricity production, auxiliary load, steam supply, internal problem of scaling, internal problem of corrosion, other internal problems, risk of internal scaling problem, risk of internal corrosion problem, as well as external problem and problem risk. Those several single indicators can be selected so that the composite indicator can represent some typical aspects of the geothermal power plant, which are in line with the objective and context of reliability. A good reliability of the system can be achieved by a proper management of maintenance of the existing system.

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Based on field observation in some fields, maintenance activities of most geothermal power plants in Indonesia have not become the first priority by the operators. For examples, we can find that some important measurement instruments are not installed in the facilities. Other situation is that the instruments have been already installed but most of them are broken, so that they are not in the functional purpose. Some instruments are not calibrated in a proper procedure results in doubt measurement results. From this situation, it is difficult to make analysis such as performance of power plant, simulation of the process in specific equipment, etc. since no or limited available measured data. It is common to assume some parameters for analysis purpose, which is of course decreasing the level of confidence.

In terms of maintenance management implementation, the situation are quite different from one operator to other ones. There are some operators that have already implemented reliability centred maintenance while others still use conventional way. We still find that the critical equipment are not maintained in a proper way, so that they are repaired after they broken since the first installation. Considering this situation, the maintenance issue in Indonesia should be considered as the critical problem. The operators should be aware for the reliability and availability of geothermal power plant equipment. This issue was also addressed to the participants.

Figure 51 Typical problems found in the fields due to the impurity of geothermal fluid; silica scaling in pipes (left) and erosion on turbine blades (right)

GEOCAP ACTIVITY IN THIS TOPIC

This course was held in three different places and times according to the targeted participants, i.e. inspectors, operators or engineers. But in general, the courses contain similar modules that cover basic knowledge of heat transfer, thermodynamics and fluid mechanics, geothermal power plant systems and technology including various types of geothermal power cycles, design and standard of main component of geothermal power plants, maintenance and reliability for geothermal power plants, inspection techniques, sampling and reporting, and geothermal power plant safety.

Most of the participants come from universities, some from governmental staff and few from companies. In order to give better picture of what and how geothermal power plant works including the problems that are common in the development of geothermal resources, the participants had a field trip to one of geothermal fields in Central Java, called as Dieng field. The guest instructors from company and government were invited to give update on the current situation on the geothermal development in Indonesia. At the end of the course, the comprehensive test was conducted to evaluate the understanding of different aspects of knowledge given during the lectures.

The main modules are summarized as follows:

1-Basic knowledge of thermodynamics, fluid mechanics and heat transfer

This module aims to provide the basic concept for designing power plants including their components in terms of important parameters that involve in flow process. The transportation of geothermal fluid from sub-surface (reservoir) up to the turbine involves those three basic sciences. This concept mostly consists of set of governing equations for calculating thermodynamics properties, heat transfer and fluid flow. The analysis allows us to obtain the optimum design of power plant and its components.

Diagrams of geothermal power plant types (Adapted from Dickson and Fanelli, 2004) can be seen in Figure 51, Figure 52, and Figure 53

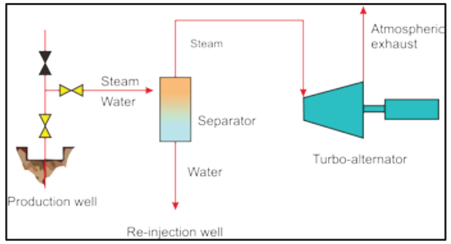


Figure 52 atmospheric (back-pressure) type

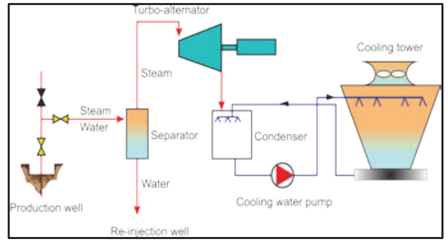


Figure 53 condensing type

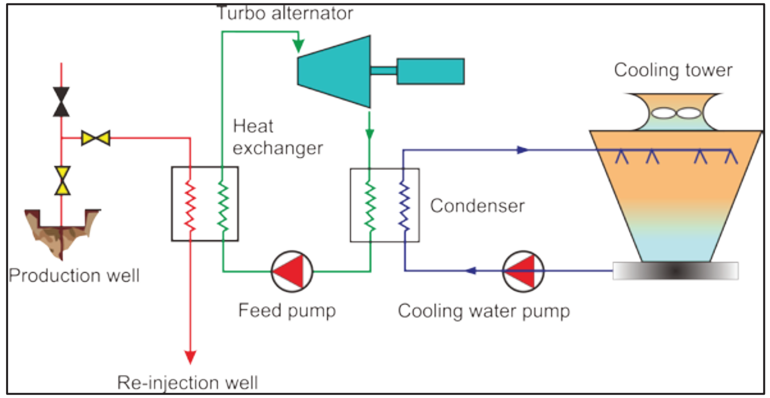


Figure 54 binary type

2-Geothermal power plant systems and technology

The choice of type of geothermal power plant depends on the nature of the geothermal resource. The enthalpy (temperature) of resource is one of parameters that is considered for selecting the power plant type. This module covers the types of geothermal power plant, especially in volcanic setting of geothermal systems. The conventional type requires the fluid temperature at least 150^0C and can utilize atmospheric (back-pressure) or condensing types for turbine outlet. Back-pressure types have simple construction and cheaper. The dry steam directly flows from the well or from the flashing process in the separator for wet well is transferred to the turbine and discharged to the atmosphere. The electricity generation from the geothermal fluid for moderate to low enthalpies or from the hot water from the separator for water, dominated geothermal system can use binary fluid technology. The binary power plant uses secondary working fluid, normally organic fluid such as n-pentane that has low boiling point and high steam pressure at low temperature compared with steam.

3-Design and standard of geothermal power plant

The importance of this module is to provide the participants in understanding that the geothermal power plants consists of main equipment and many auxiliary components. It involves mechanical equipment, electrical devices and instrumentation. The standards that are commonly used in the construction of geothermal power plants include ANSI/API, ISO, ASME, ASTM, AWS, NEMA. All designed equipment must follow the required standard.

4- Maintenance and reliability for geothermal power plants

The reliability of the geothermal power plant can be expressed in terms of continuity and stability of steam supply, which is then used to obtain the continuity and stability of electricity production. Correlation between change of steam demand and change of electricity production can provide early indication as a signal of the reliability level of each geothermal power plant. It shows early signal, which is categorized in three problem cases. Case number 1 is if there is an increase in steam demand, which is higher than an increase in electricity production. Case number 2 is if there is a case of higher decrease level on electricity production than decrease level of steam demand. Further, case number 3 is if there is a decrease in electricity production while steam demand increases. Knowing one of these cases will provide us to make appropriate actions in the maintenance activity.

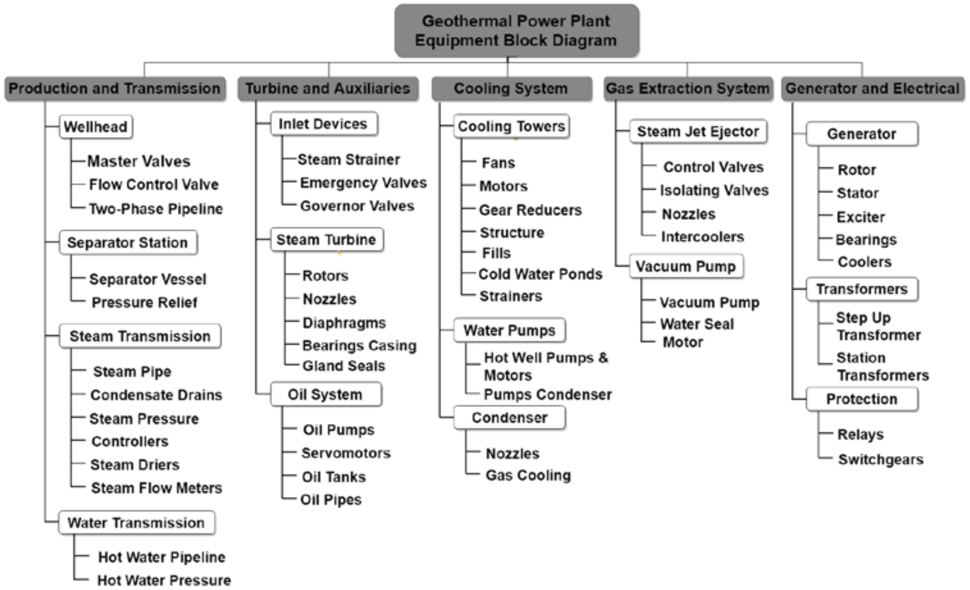


Figure 55 Diagram of basic components of geothermal power plant. (Adapted from Feili et. al., 2013).

In the maintenance activity, it is important to conduct a mapping on various problem risks, problems in the components of the geothermal power plant, their causes and impacts. The geothermal power plant components can be categorized as production well and separator, turbine, condenser and cooling system, gas removal system, piping, pump and valve, electric, instrumentation and control. While the causes of reliability problems can be grouped as scaling, corrosion, erosion, and others (sticking, leakage, debris, fatigue, wash damage, component failures, deformation, burst, lubrication, operational error, calibration, etc.). Reliability Centered Maintenance (RCM) is one of the techniques in the management of maintenance that is widely used in many industrial applications.

5- Inspection techniques in geothermal power plant

In this module, the participants are provided with several knowledge of general inspection and related topics. Inspection activities cannot be separated with the maintenance program. Inspection aims to evaluate one equipment or part of the equipment where possible failure may happen. Failure analysis

is one of the key components in the maintenance activities. In order to perform good and proper inspection, the supporting knowledge play an important role such as material technology (types, structure and behaviour, corrosion, failure), instrumentation and testing (non-destructive testing, ultrasonic testing, magnetic testing, radiographic testing, infrared thermography, acoustic emission testing) and safety (hot surface, chemicals, protection equipment, roles). The inspection standard consists of several activities, namely risk assessment for all parts in the installation, inspection protocol, review document after each inspection and failure.

Figure 56 Sample of inspection activity

CONTACTS

Khasani (Universitas Gadjah Mada): khasani@ugm.ac.id

Nasruddin (Universitas Indonesia): nasruddin@eng.ui.ac.id

Jooned Hendrarsakti (Bandung Institute of Technology): jooned@ftmd.itb.ac.id

LOW AND MEDIUM ENTHALPY

DIRECT USE OF GEOTHERMAL RESOURCES IN INDONESIA

INTRODUCTION

Geothermal direct use dates back thousands of years, when people began using hot springs for bathing, cooking food, and loosening feathers and skin from game. Today, hot springs are still used as spas. Nevertheless, there are now more sophisticated ways of using this geothermal resource.

In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, and a mechanical system - piping, a heat exchanger, and controls - delivers the heat directly for its intended use. A disposal system then either injects the cooled water underground or disposes of it on the surface.

Geothermal hot water can be used for many applications that require heat. Its current uses include heating buildings (either individually or whole towns), raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes, such as pasteurizing milk[8].

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Worldwide two main types of geothermal use can be found:

1) Electricity production from geothermal heat resources. Geothermal heat is transformed into electricity using turbines (Carnot cycle).
2) Direct use of geothermal heat for heating of all kinds of processes and/or space heating. The heat can be used directly and/or by applying a heat pump to transform it into higher temperatures that may be required in the application of the heat.

Currently most geothermal applications in Indonesia are found in electricity production from high enthalpy resources. Until now, the direct use of geothermal resources in Indonesia is limited. Considering the large geothermal potential in Indonesia, and considering the large demand for heat for processing in agriculture and industry, a large market for direct use is anticipated, especially considering the Paris agreements that will limit the use of fossil fuels for heating in future.

GEOCAP ACTIVITY IN THIS TOPIC

Within the GeoCap program, the potential for direct use was studied in more detail, especially for process heating, both from the resources side and from the point of view of the market. Considering the relatively high outdoor temperatures in Indonesia, it is anticipated that most heat demand is for process heat in agriculture and industry. Space heating is not a market. We focussed on western Java, because a) we had access to data for this area, and b) because most of the heat demand in industry is located in this area.

[8] https://www.renewableenergyworld.com/geothermal-energy/tech/geodirectuse.html

Resources

Three types of resources have been studied: surface manifestations, waste heat from geothermal power plants and sedimentary basins.

Surface manifestations like hot springs

These resources are found all over western Java, depending on the local volcanic activity. The known resources have been listed. A summary can be found below.

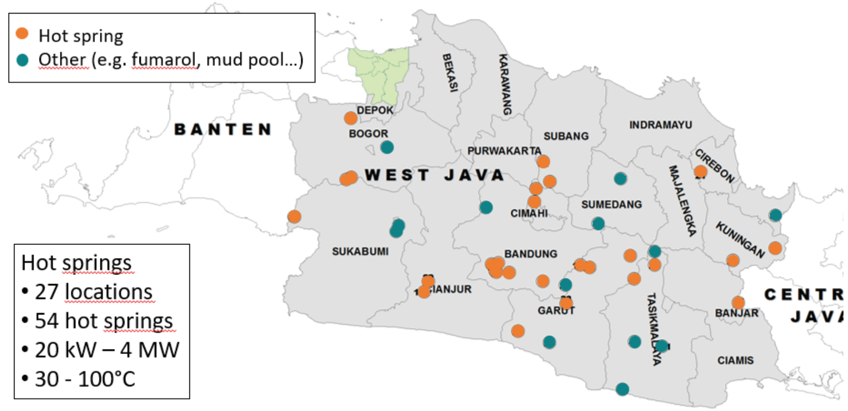


Figure 57 Locations of geothermal manifestations in West Java

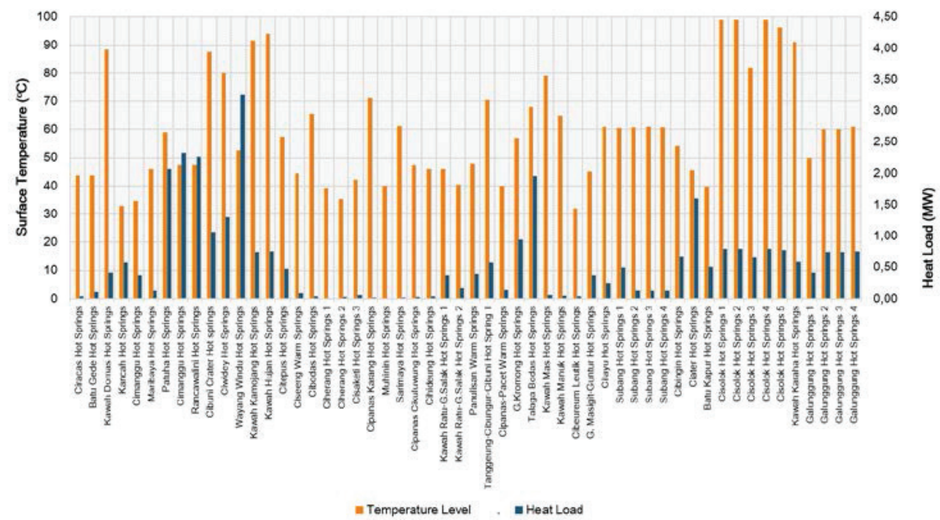


Figure 58 Surface temperatures and heat load of surface manifestations in West Java

The data show that most resources have a thermal power between 100 kW and 3 MW, and a temperature level between 30 and 100°C.

Waste streams from geothermal power plants

Geothermal power plants do not use all the heat for electricity production. There is still (waste) heat in the brine and condensate. The existing power plants on Western Java are shown below, and the characteristics of the waste heat available are depicted in the figure below that. Available temperature levels are between 45 to 175°C at a thermal power of 20 to 185 MW.

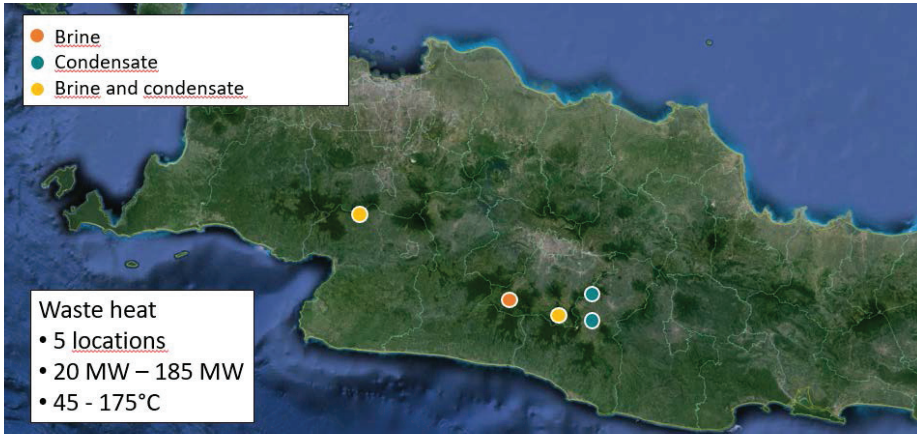


Figure 59 Locations of geothermal power plants with geothermal waste heat in West Java

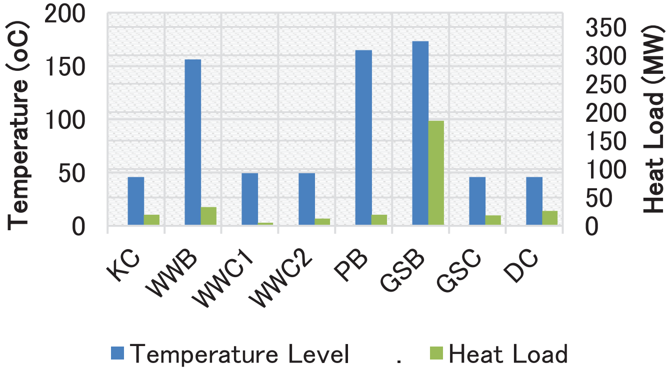


Figure 60 The potential geothermal waste heat in existing geothermal power plant in West Java

KC = Kamojang Condensate, WWB = Wayang Windu Brine, WWC1= Wayang Windu Condensate 1,

WWC2 = Wayang Windu Condensate 2, PB = Patuha Brine, GSB = Gunung Salak Brine, GSC = Gunung Salak

Condensate, DC = Darajat Condensate

Sedimentary basins

Both types of direct use resources mentioned above are related to volcanic activities. The locations of these resources are strongly dependent on certain geological conditions. The location of the resource will determine the possible locations of the heat demand. For sedimentary basins, this is (at least partly) reversed: the location of the demand determines where we look for a resource. The largest heat demand for process heat is found around Jakarta, Bandung and Surabaya. For the Jakarta area, the sedimentary basin that is in the subsurface has been drilled extensively for oil and gas. From these data, we know that there are several reservoirs that have significant potential for low/medium enthalpy geothermal heat production. These reservoirs have been mapped, and some of these mapping results are shown below.

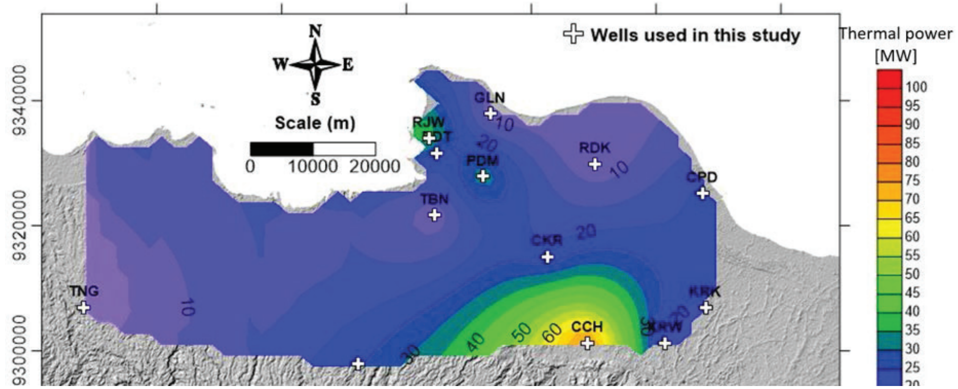


Figure 61 Map showing the distribution of calculated well thermal power of the Baturaja aquifer (from Suryantini et al, 2016)

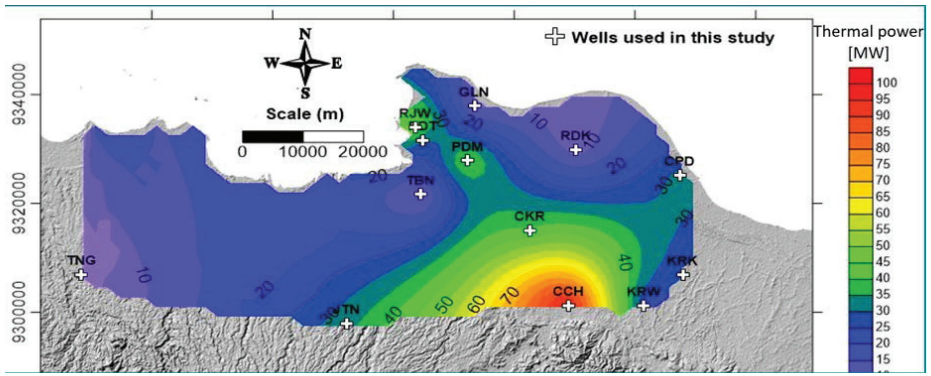


Figure 62 Map showing the distribution of calculated well thermal power of the Talang Akar aquifer (from Suryantini et al, 2016)

Market

The market can be split up in existing projects, and potential new projects.

Existing direct use

Existing projects are listed in the table below. All projects are based on surface manifestations or waste heat resources.

Table 4 Existing geothermal direct use projects in Indonesia

Market	Temperature	Type	Location
Catfish farming	40°C	Commercial	Lampung
Warm bathing	43-45°C	Commercial	West/Central/East Java, Bengkulu
Mushroom & potato cultivation	60-65°C	Pilot	Pangalengan
Mushroom cultivation	60-65°C	Pilot	Kamojang
Cacao & coconut drying	60-80°C	Pilot	Way Ratai
Tea drying	98-120°C	Pilot	Pangalengan
Palm sugar processing	107-110°C	Commerical	Lahendong

Potential direct use

Below a map is given of West Java with some potential direct use that can be found in this area.

Figure 63 Potential direct use markets and locations in West Java

Almost 60% of processing industries in Indonesia are located in West Java province. Nearly all of them need heat for product processing. The majority of industrial energy demand is for heat. Heat is integral to many industrial processes including melting, drying, frying, pasteurising, and distilling. Each of these processes uses heat at a temperature specific to the materials involved and the product being manufactured. Current situation in West Java province, almost all heat demand is supplied by coal combustion, oil, solar, gas, and electricity. Very few of of them use geothermal as heat supply for their industrial processes. The northern area of West Java has become a major industrial area. Areas such as Bekasi, Cikarang, and Karawang are sprawling with factories and industries, such as textiles, processed food, wood carvings and furniture, paper, chemicals, etc.

Match of market and resources

Surface manifestations

Most surface manifestations are relatively small in geothermal power. Only heat demand that is located very close to the source can be matched. Most interesting market for use of surface manifestations is for bathing, hotels and spas. The impact of this kind of direct use on the local economy may be very positive, but the impact on the energy picture of Indonesia will not be significant due to cheap of domestic energy prices.

Waste heat

All geothermal power plants have waste heat to some extent, just like fossil fuel thermal power plants do. Reuse of waste heat from power plants is common in many countries, especially in moderate climates, where waste heat is being used for space heating. For Indonesia, the main market is for industrial processes. Widodo et al (2018) studied one potential example of direct use: tea drying using waste heat from Wayang Windu power plant. The economies are shown in the figure below:

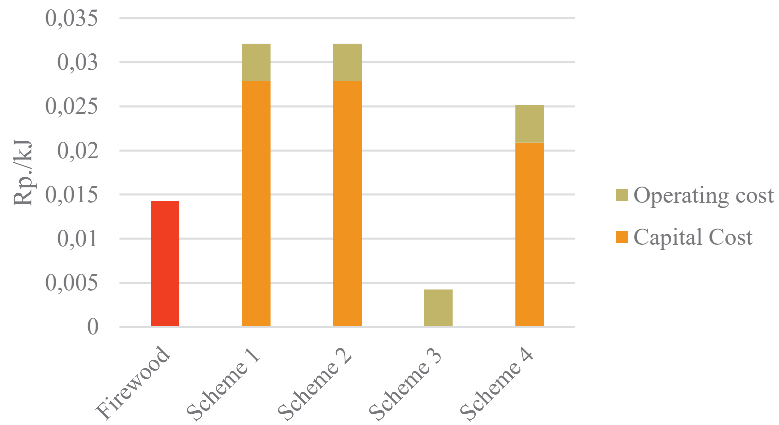


Figure 64 Energy cost comparison of each scheme with firewood.

Scheme 1: Capital (investment) is 100% funded by a bank loan at 10%. Income tax of 25%.

Scheme 2: Capital (investment) is 100% funded by a bank loan at 10%. Tax component adjusted to the regulation of Finance Ministry (PMK No. 21/PMK.011/2010). Government provides an income tax facility for activities exploiting renewable energy sources in the form of net income reduction by as much as 30% of the amount of investment, which is charged for 6 years at 5% per year.

Scheme 3: 100% CSR funding without interest rate by producer (waste heat provider). Income tax of 25%.

Scheme 4: Green funding by International Finance Corporation (IFC). The loans obtained from IFC are limited to 25% of the total "greenfield" project cost up to maximum of $100 million. The interest rate on the loan is 0.75% (LIBOR). Income tax of 25%.

This shows that the investment costs are too high to get a positive business case wrt to the reference case of burning wood for the heat. The main cause is the very low price of heat from wood burning. A price of 0,015 Rp/kJ is about equal to 1 euro/GJ. The wholesale market price for gas is above 3 euro/GJ. So compared to gas, direct use in this case is feasible, but not compared to wood burning. The only realistic way forward under current market conditions would be that the investment in the installation is done entirely by the geothermal power company as a CSR project to involve the local citizens in a positive way. In addition, the use of geothermal heat for the production of vertiver oil was studied, with similar results: the project will only be feasible when the project is realized as a CSR project, with full coverage of the CAPEX by the geothermal power company.

In general, direct use of waste heat from geothermal power plants may be a significant source of renewable heat for all kinds of industries in Indonesia. It is anticipated that there will be more geothermal power projects in Indonesia in the near future. As geothermal power plants export most of the electricity out of the area, the investment of the concession holder in local direct use may be a good way to involve people in a positive way. In addition, for new industries with a high heat demand, locating a new factory close to a geothermal power plant may be a good investment, especially for those investors that are looking for renewable energy to keep their CO_2 footprint low.

Sedimentary basins

As mentioned above, the largest industrial heat demand in Indonesia is located in the area of the Jakarta basin. Here geothermal reservoirs can be found that have the potential to produce a large amount of geothermal heat. For the production of hot water of temperatures of up to 90 °C, this can be done economically under current market conditions (approx. payback time = 7 years) For the production of steam, the payback time is longer, due to the fact that steam heat pumps have to be incorporated in the process. The price of heat made using natural gas is relatively low in Indonesia. This makes it hard for geothermal heat to be competitive.

Future outlook

Currently geothermal direct use is competing against low priced heating fuels like wood and natural gas. As long as the prices of the reference are low, the penetration of geothermal direct use will be limited to a few cases where the heat is (almost) free and where the heat demand is very close to the geothermal resource. In the long run, we anticipate that costs of CO_2 emissions from fossil fuels and scarcity of wood from local forests will have an impact on the business case of direct use. Therefor we anticipate that geothermal direct use will be a very valuable asset for the Indonesian economy in the years to come. To be able to utilize geothermal heat, it is advisable to create a regulatory framework that fits with this market and technology. In addition, to demonstrate the technology/market, it seems appropriate to start full-scale demo projects that would convince investors to apply the technology in the future.

CONTACT

Rob Kleinlugtenbelt (IF Technology): r.kleinlugtenbelt@iftechnology.nl
Nurita Putri H (ITB): nurita_putri@geothermal.itb.ac.id
Suryantini (ITB): suryantini@gc.itb.ac.id
Widodo W Purwanto (UI): widodo@che.ui.ac.id
Dijan Supramono (UI): dsupramo@che.ui.ac.id

SMALL SCALE GEOTHERMAL POWER PLANT

INTRODUCTION

Resources for small scale geothermal power plants can come from hot springs with adequate flow rate, well head generating units of a high enthalpy wells, waste brine from a high enthalpy power plants, low-medium enthalpy wellbores in a volcanic hydrothermal systems and low-medium enthalpy wellbores in a sedimentary basin system. According to Vimmerstedt (1998), small geothermal projects are less than 5 MWe. Small scale geothermal power plants could use a flash system or binary cycle technology. Flash steam power plant in small scale applications are low cost, relatively simple, and require no secondary fluid. However, compared to a binary plant, the flash steam plant operates at higher temperatures. Binary plants operate at lower temperatures and use a second working fluid. Binary geothermal power plants use working fluids or chemical fluids known as a secondary fluid that boils at a lower temperature than water. To encourage geothermal electricity production, small scale also can contribute. This technique can be applied to more remote areas which are currently powered by diesel generators or become an alternative for low-medium enthalpy geothermal resources.

GEOCAP ACTIVITY IN THIS TOPIC

Within the GeoCap programme the potential for small scale geothermal power plants was studied in more detail, especially with the binary system. Technical, financial and social aspects have been studied. Main results of the technical aspect study are the power input and output scheme based on fluid properties and availability. The financial aspect study gives insight in the sensitivity on project cost versus IRR value as a function of parameters that been used. The social aspect study describes key factors to elevate the project. All aspect results will be used for arranging related stakeholder functions and the project time schedule.

Resources

Three types of low-medium enthalpy resources have been studied: surface manifestations, waste heat from geothermal power plants and sedimentary basins. After reviewing geothermal resources especially in West Java region, case studies have been carried out for three preferable resources.

Surface manifestations like hot springs

One potential manifestation for small scale geothermal power plants is located in the Cisolok area in West Java. The geothermal manifestation appears at 106°27'13.4" E and 6°56'0.5" S in the Cisolok River. Currently, the geothermal manifestation of Cisolok is used as a public bathing place. The thermal water discharging into the Cisolok River has high temperatures near boiling temperature, with neutral pH and relatively high discharge rate. Based on data from the survey, the manifestation has a temperature of 95°C and a mass flow rate of 5 kg/s.

Figure 65 Cisolok Hot Spring

Waste heat from geothermal power plants

Geothermal power plants do not use all heat for electricity production. There is still (waste) heat in the brine and condensate. The existing power plants in Western Java have available temperature levels between 45 to 175°C at a thermal power of 20 to 185 MW. Waste heat of the Awibengkok-Salak geothermal power plant has good potential, which is categorized as a two phase geothermal systems.

Sedimentary basins

Small scale grids in remote areas are numerous. At the moment, in many cases power is supplied using diesel generators. These are polluting and expensive. Sedimentary basins nearby existing small scale power grids could be used as an alternative source. Using slim holes, small scale geothermal wells can be realized, matching power demand and minimizing investment costs. Slim holes require much smaller drilling rigs, compared to conventional geothermal wells. Besides electricity production, many secondary outputs are possible, depending on the local needs. Possible secondary outputs are e.g. ice production, drinking water production, food processing modules, waste water treatment, and more.

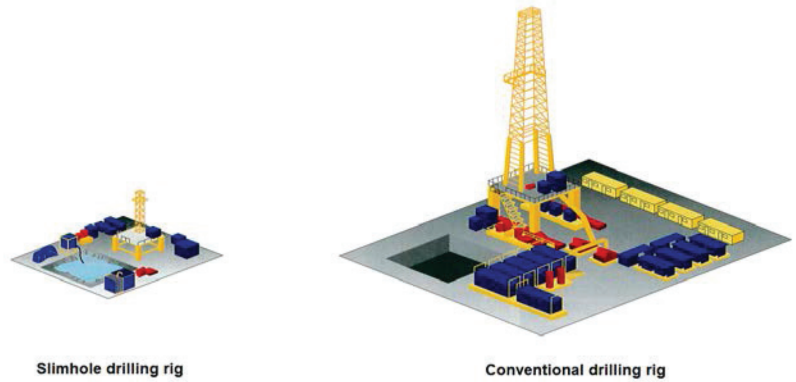


Figure 66 Comparison between the size of a slimhole drilling rig and a convention one (source: Schlumberger)

Assessment Result

The net power that can be generated by the Cisolok hot spring is 23 kWe using n-pentane. The selection of the turbine pressure design that is used in this system is 3 bar. The mass flow of the working fluid is 1.2 kg/s. The power generation in Salak is generated by utilizing the brine after the separator. By simulating the binary cycle output, the total power that can be extracted is approximately 13 MWe. However, by referring to the small-scale project that we discussed, the maximum power generation for this case is adjusted to 5 MWe. Using n-pentane as secondary fluids with mass flow rate 89 kg/s will generate 5042 kWe net power. For the slim holes in sedimentary basins, electricity can be used using standardised low temperature ORC modules. Depending on the potential of the sedimentary basin, the power output is estimated at 300 – 1,500 kWe.

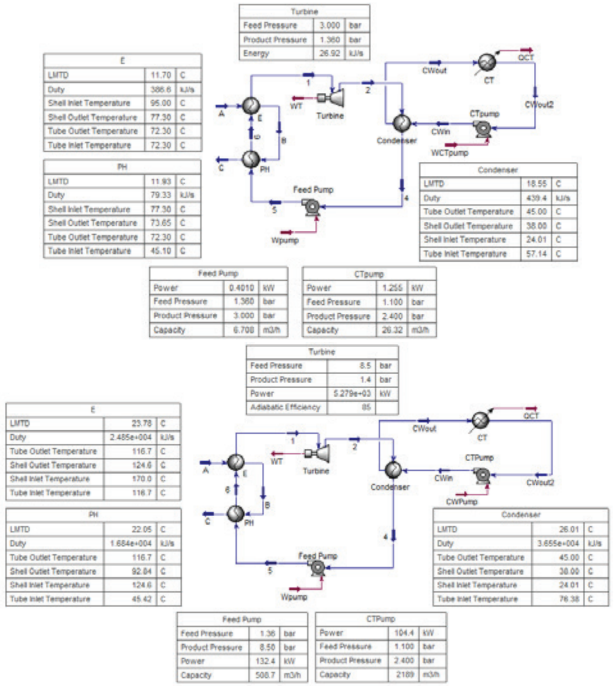


Figure 67 Process flow diagram of Cisolok (left) Salak (right) binary cycle

Required investment for a small scale geothermal power plant at Cisolok is estimated at 1.7 Million USD. This cost includes turbine, generator, heat exchanger, pre-heater, condenser, pumps, piping system, construction and pentane liquid. An electricity price of 102 USD cent/kWh will yield an IRR of 9.7%. For the Awibengkok-Salak case, investments are estimated at 16.6 Million USD. An electricity price of 23.8 USD cent/kWh will yield an IRR of 9.7%. The investments for a slim hole is estimated in the range of 5 M$ and 10 M$. Estimated levelized cost of energy are 0.10 – 0.20 $/kWhe. That is less than half that of pv-battery systems and a third the cost of power made

from diesel generators.

Market and social aspects could contribute to the feasibility of the project. Although power generation is limited, a small scale geothermal power plant at Cisolok and Awibengkok-Salak will replace fossil fuel utilization for the Jawa-Bali Interconnection. Fuel demand and greenhouse effects could also decrease from energy diversification. Social mapping and social engineering programmes should be applied on Cisolok (in-situ) conditions to minimize potential social barriers in a small scale geothermal development and find effective solutions to mutual benefit, enabling successful small scale geothermal development. The estimated time to implement a small scale power plant is 5 years, which consist of a pre-feasibility study, feasibility study, business case, development stage, and commissioning. A project organizational chart has been defined. These tools can be used to eliminate barriers and implement effective management in the project development process.

Future outlook

Currently, geothermal small scale power plant using manifestations and waste heat are less attractive compared to large scale geothermal power plants. At remote areas, small scale geothermal power plants could be attractive, due to high costs for diesel generated electricity. In the long run, we anticipate increased costs of CO_2 emissions and scarcity of fossil fuels. To be able to utilize small scale geothermal power plants, it is advisable to create a regulatory framework that fits with this market and technology. Also, to demonstrate the technology/market, it seems appropriate to start demo projects that would convince investors to apply the technology in the future.

CONTACT

Nurita Putri H (ITB): nurita_putri@geothermal.itb.ac.id

Suryantini (ITB): suryantini@gc.itb.ac.id

Rob Kleinlugtenbelt (IF Technology): r.kleinlugtenbelt@iftechnology.nl

COMPANY AND GOVERNMENT DECISION-MAKING FOR GEOTHERMAL ENERGY PLANTS

In all national economies, even in highly liberalized economies, entrepreneurs develop new economic activities that are subject to the legal framework and controlling mechanisms as implemented by the competent governmental institutions. In liberalized economies, the entrepreneurs are mainly privately capitalized companies, who compete mutually, and who select and mature the investments to be pursued (this is known as 'picking the winners'). To realize these investments, the private entrepreneurs need to apply for the pertinent permits or licenses at the competent authorities, upon which the competent governmental institute studies the application and applies the prevailing criteria for (conditionally) granting or rejecting the application. The criteria must be transparent and tailored to the government's policy of promoting a certain economic activity within the societally accepted constraints. If a license application is deemed to be unduly rejected (or the provisos are deemed excessive), the entrepreneur can escalate this in court, where an independent judicial system will judge the legality of the rejection.

Important distinctions of a truly liberalized economy vis-à-vis a less liberalized economy are, for example, that 1) the government will not compete with private companies in terms of 'picking the winners' (i.e. state companies are an exception and only exist because private companies are not capable of providing some service of national interest, with the required quality and security), and 2) logistical chains will be legally 'unbundled' in order to prevent market power from developing and being concentrated in only one or a few companies. In liberalized economies, monopolies and oligopolies have been broken and the government strives for a competition between private companies that is to be fair, adequate and transparent. For example, in the power sector it is not allowed to combine the functions of transport, trading and generation within one (holding) company. Similarly, in the gas sector: gas production and gas transport must be unbundled. Prices are made by supply and demand on an exchange, which uses anonymous, standardized contracts for pricing transparency. Ultimately, it is believed that liberalized economies provide a better service at a lower price to the general public. However, it is an enormous challenge to bring the governmental institutes to the required level of competence and create and maintain a dynamic and level playing field for private enterprises. In general, this takes many years, gradually evolving from monopolistic (state or private) enterprises to an adequate number of mutually competing private enterprises of which no single company is dominant enough to influence the overall pricing level.

In less liberalized economies, the degree of government control and the government's stake in 'picking the winners' is (much) higher than in liberalized economies. In addition, logistical chains are typically not unbundled legally, thereby perpetuating the incumbent state monopolies or oligopolies and concentrating the market power in only one or a few state enterprises. Indonesia is a relatively young economy in terms of market liberalization. In the power sector, transport and trade are not yet unbundled

and prices or tariffs are negotiated between the power generating company and the state monopolist transport and trading company, rather than 'made' on a power exchange. Therefore, Indonesia's legal framework for the power and geothermal sectors very much determines the overall business climate for private geothermal entrepreneurs, on which the Indonesian government heavily relies to develop its geothermal resources. Hence, if Indonesia's geothermal energy is really to take off, it is crucial to foster the mutual understanding between the private sector and the state institutes, in order to get to know each other's concerns and internal processes. This will be instrumental in expediting Indonesia's geothermal development ambitions.

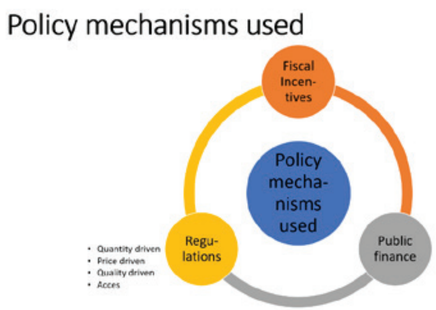
To this end, GEOCAP has developed three activities as part of its overall programme, i.e. 1) Government geothermal energy policy-making and decision-making for geothermal energy projects; 2) Investment decision support for geothermal operators; 3) Investment decision support tool for geothermal operators. The first topic addresses the government's point of view when updating its national policies on geothermal energy and when confronted with a geothermal license application. The second topic addresses the private company's perspective when maturing a rough idea to Final Investment Decision. The third topic discusses a computer tool developed for GEOCAP to investigate the technical and economic feasibility of geothermal field developments. The topics are discussed in the remainder of this chapter.

GOVERNMENT GEOTHERMAL ENERGY POLICY-MAKING AND DECISION-MAKING FOR GEOTHERMAL ENERGY PROJECTS

INTRODUCTION

A three days' workshop was held with lectures, exercises, assignments, knowledge sharing and problem-solving ideas from experts and the stakeholders of geothermal development in Indonesia. The targeted audience of the course constituted of practitioners, government officials from varied ministries, investors and companies. The workshop was held from September 11th - 13th, 2017, at the premises of PPSDM KEBTKE Building, Jakarta.

The goal of the workshop was to provide the participants with a broader perspective of the renewable energy market and understanding the policy framework, thereby giving insight in tools and methodologies to reach the geothermal policy targets. The workshop also included several presentations from geothermal stakeholders in Indonesia regarding regulations, knowledge sharing and problem-solving ideas. While many obstacles remain to expedite geothermal development projects in Indonesia, part of the problems found related to policy making in regulations and tariffs, but also to the collaboration between stakeholders. Therefore, the workshop targeted a deeper understanding and communication between geothermal stakeholders.



The learning objective of the workshop was to provide participants with a deeper insight in government policy and decision-making processes. Methodologies and best practices were discussed that can be applied to developing new and updating existing policies, as well as to expediting the license application and granting process. The current status of the geothermal industry in Indonesia was reviewed, as well as problems concerning its further development.

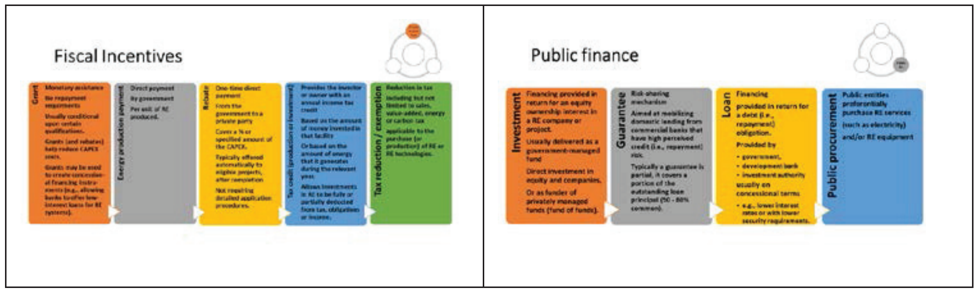
Three days' workshop on government policy and decision-making

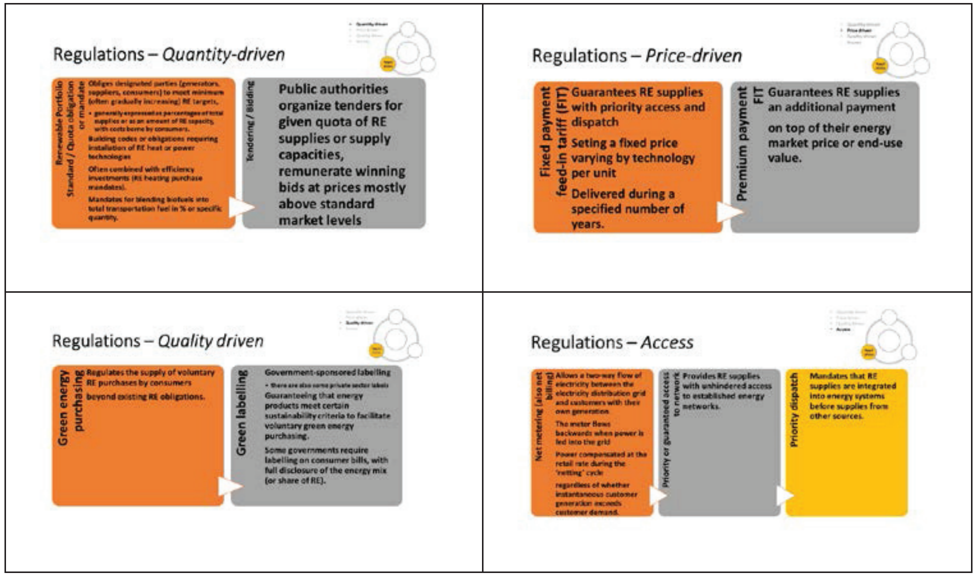
RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Based on its most recent geothermal resource mapping and evaluation, Indonesia has an estimated geothermal energy potential of 29 GW. As of 2014, only 1.44 GW of this potential is being exploited, representing some 5% of its potential. Indonesia has the ambition to realise 7.2 GW in 2025, and 17.5 GW in 2050.

However, major challenges for realizing this geothermal potential are the high initial risks and investment costs, which to a large extent is due to the technical risk of initial wells having a relatively low success rate. With learning, i.e. as the resource is being developed, this drilling success rate on average increases gradually, but how this will reveal itself in a given case is initially very uncertain. The objective of the training was to give methods and tools to manage and control the high initial investment costs and risks. Therefore, this training addressed four key elements supporting the commercial development of geothermal resources, viz.

- Access to a comprehensive range of sufficiently accurate geothermal resource data and other relevant information;
- The development of effective and dedicated governmental institutions;
- The development of supportive policies and regulations;
- Facilitating access to appropriate financing opportunities for the geothermal project developer.





Policy instruments

GEOCAP ACTIVITY IN THIS TOPIC

The workshop gathered a group of Indonesia's geothermal stakeholders from several institutions. Representatives from the government (Ministry of Energy and Mineral Resources/MEMR, Ministry of Environment & Forestry, Jawa Barat government), PLN (State Owned Electricity Enterprise), World Bank, PT Sarana Multi Infrastructure (a state-owned firm under the Ministry of Finance that manage the country's geothermal fund), National Park, as well geothermal developers from PGE (Pertamina Geothermal Energy) and Geodipa joined this workshop as speakers and participants.

Based on feedback by the participants, the workshop has given them a deeper insight into the various geothermal project phases, decision-making processes, policy cycles and instruments, as well as the risks related with geothermal development. The stakeholder gaming exercise has given the participants a broader perspective on and deeper understanding of the geothermal resource development process. Interactive discussions between the participants of a varied background and institutions encouraged them to critically review the current conditions of geothermal development in Indonesia.

Participants also made valuable suggestions for conducting similar events in future, including more local content on Policy Making and Decision Making for geothermal project development. Clearly, there is a strong desire for more knowledge sharing and joint problem solving for Indonesian geothermal development cases.

The workshop was structured along the following topics:

- The energy landscape
- Outlook Indonesian energy mix
- Framing the problem
- Geothermal Policy making
- Policy cycle: Learning & updating
- Geothermal plant project phases
- Decision gates and criteria
- Methodologies and processes
- Risks versus uncertainties
- Types of risks (financial/technical)
- Decision tree analysis
- Creating a good investment climate
- Transparent processing
- Incremental development

CONTACT

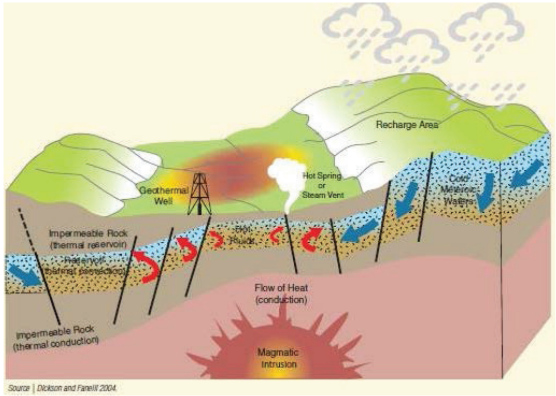
Ali Ashat (ITB) labgeothermal@yahoo.com

Rianne 't Hoen (DNVGL) Rianne.Hoen@dnvgl.com

INVESTMENT DECISION SUPPORT FOR GEOTHERMAL OPERATORS

INTRODUCTION

The second activity on decision-making within the GEOCAP programme centered around the private company's perspective, i.e. the privately financed geothermal operator considering to invest in developing a geothermal resource (although most of the practices will also apply to geothermal state companies). Developing geothermal resources is unlike most other economic activities. This is due mainly to the fact that, at time of spending the major part of the capital expenditure, the productive system (i.e. the subsurface reservoir) is poorly known, resulting in a high technical risk: at time of investing, the forecast project performance will be subject to large uncertainties. There are just too many unknowns in the subsurface reservoir's properties, and these will only be slowly and parsimoniously revealed as the asset is being developed and produced. Moreover, long pay-out times typically apply to such capital-intensive and risky projects, which exacerbate the technical risks. This calls for a prudent approach, as geothermal operators must balance the perceived risks with the expected financial return resulting from the project: the higher the perceived risk, the higher the threshold for profitability must be in order to obtain, at the corporate level, a balanced portfolio of assets where disappointing projects are counterbalanced by projects that perform better than expected.



There are no generally accepted rules for how to assess risk, nor for how to set the required profit margin as a function of the perceived risks. This applies not only to geothermal companies, but also to the analogous oil and gas exploration and production industry. Companies will have their individual practices to decide whether to pursue a business opportunity. However, in all cases governments can contribute a great deal in terms of either de-risking a project, and/or improving the expected return. To understand this better, a two-day workshop was organized in 2016 (adjacent to the IIGW # 5 conference in Bandung, together with the previous topic on government decision-making), followed by a one-week course in October/November 2017 (at PPSDM, Jakarta).

The course's contents discussed mainly the issue of how to 'frame' an investment problem and, subsequently, how to use integrated technical / business models to quantify, probabilistically, the range of possible outcomes. This enables the project staff to establish a project's expected outcome, including the uncertainty range around it, which again can be translated into some measure for 'risk'. Expected outcome and risk can then be offset against each other, which in principle helps the decision-makers to decide whether to further mature a project. Importantly, the quantitative models also enable the users to understand sensitivities: which top drivers determine 'risk', and which top drivers are responsible for the 'expected outcome'? Can these uncertainties be reduced, thereby reducing 'risk'? Which options exist to steer the project into a more profitable direction as new information is being revealed in time? Should we actively acquire new information for a better design of the facilities to be constructed? If so, what is the value of that information? Which flexibility options in the facilities can be designed upfront to

allow striking the option when new information is being revealed? At what cost? How does this improve the project's *expected* reward?

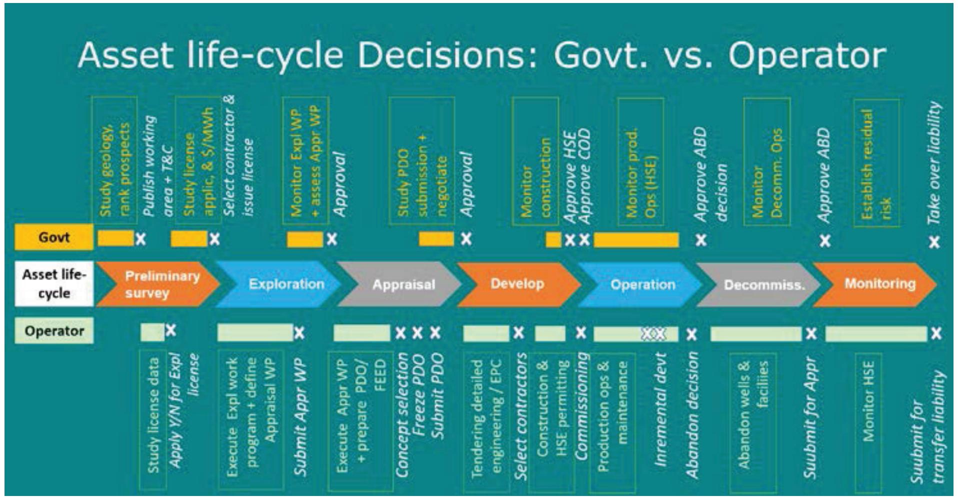
This type of questions, including the general business processes of project maturation and decision analysis to deal with complex investment decisions subject to large uncertainties, were studied as part of this activity.

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

After having delivered the two-day workshop in 2016, feedback was given by the class of some 20 participants. Their comments confirmed the perceived relevance and applicability of this topic to Indonesia. Some excerpts are given below:

- *"Even after having worked for over 8 years with an Indonesian geothermal Operator, I've never heard anything of what you've been teaching us on company decision-making. Yet, this knowledge seems crucial for expediting the development of Indonesia's geothermal resources."*
- *"The sooner you can give the full course, the better. Then we can apply your teachings earlier."*
- *"I hope someday this course will show the solution for Indonesian conditions. Then it can help us grow and build more geothermal energy in Indonesia."*
- *"We learned a new sophisticated way of how to formulate geothermal risk. It is a big opportunity for Indonesia to gain more knowledge and to tackle the problems in the geothermal industry."*
- *"The Government should be involved in this kind of workshops / courses."*
- *"We received such a lot of new information, especially on how to make decisions."*
- *"We liked the multidisciplinary approach in decision-making and how the various types of information from people with different backgrounds come together into one 'language'."*
- *"Very experienced and approachable presenter. Especially the exploration decision exercise was challenging and insightful".*
- *"I liked learning about the 'learning process' during the life-cycle of a geothermal development, and how anticipating on possible future new information conditions current decision-making."*

Indeed, developing a common 'language' between the government institutions and the geothermal operators seems to fulfil a dire need. But also improving a company's internal business processes will benefit from the methods and practices presented. The problem however is to further disseminate and maintain this practice in Indonesia. A major hurdle is that psychological barriers prevent people from embracing uncertainty, as they rather tend to reduce it, or even ignore it. This is a cultural and psychological attitude that takes a long time and a major repetitive effort to overcome, as experienced in the oil and gas exploration and production sector.



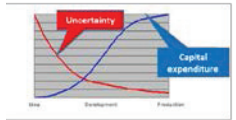
To expedite the development of a geothermal resource, government and operators need to understand in-depth each other's decision-making processes

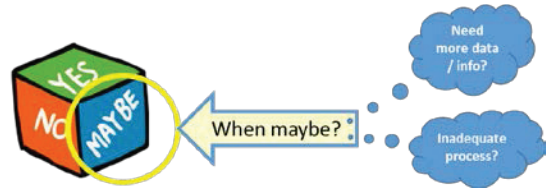
GEOCAP ACTIVITY IN THIS TOPIC

During the week's course (October/November 2017 at PPSDM, Jakarta) with some 20 participants (from institutes and geothermal operators such as ITB/UGM/Syiah Kualah universities, MEMR/ESDM, Halliburton, Pertamina, Supreme Energy), the following subjects were covered jointly by lecturers from TNO and ITB:

- Geothermal energy in Indonesia
- Geothermal asset maturation cycle and associated decisions
- Decision Gate process, Decision Analysis process
- Discounted Cash Flows, cost of capital and discount rate, tax regimes
- Decision criteria, Key Performance Indicators, capital efficiency
- Framing the problem
- Uncertainty modelling, basic probability theory, decision tree analysis
- Valuation, Value of Information, Value of Flexibility, option valuation
- Multi-criteria decision analysis
- Psychology related to uncertainty
- What do managers need to make decisions? What is a 'good' decision?
- Portfolio analysis, multi-asset modelling
- Balancing long-term vs. short-term objectives
    - What is a good investment climate?

To allow hands-on practical exercises using quantitative models, a dedicated Geothermal Asset valuation tool had been developed, based on XL and therefore compatible with commercial statistical XL plug-in software, which had been installed on all classroom computers (the tool is discussed in the next chapter). This enabled all participants to experiment with Monte Carlo processing of their uncertain modelling input assumptions, resulting in statistical distributions for the project's Key Performance Indicators (KPI), together with the associated probabilistic time-series (e.g. p_{90}-p_{50}-p_{10} etc. forecasts). In a subsequent sensitivity analysis, the KPI histograms could then be analysed for which uncertain input variables contributed most to the computed uncertainty of a (output) KPI, thereby triggering a discussion on what remedial action would be possible to improve the project's expected performance, or reduce the project's risk.





CONTACT

Ali Ashat (ITB) labgeothermal@yahoo.com

Christian Bos (TNO) christian.bos@tno.nl

INVESTMENT DECISION SUPPORT TOOL FOR GEOTHERMAL OPERATORS

INTRODUCTION

As part of GEOCAP's decision support topics, a quantitative software prototype tool was developed, allowing geologists, engineers and economists to integrate their disciplines and knowledge within a common framework, and to do that probabilistically. The purpose of the tool is decision support / decision analysis for project proposals related to a relatively immature geothermal asset, i.e. early in its life cycle and in an early phase of project maturation. It may be seen as a 'screening' tool, filtering out the less attractive project definitions, thereby understanding better, which project definitions have more potential. The tool is designed to explore the effects of all uncertainties that one typically has when computing forecasts. The tool has been distributed to the participants of the October/November 2017 course at PPSDM, Jakarta. It is freely available to anyone else, without protection of the source code. This allows users to adapt the code as they wish and tailor it to their specific needs. The tool uses relatively simple, analytical equations to model all the physics, the planning of projects within the asset's life cycle, and the economics. Because of the analytical formulation, the tool does not allow reservoir heterogeneity to be modelled directly (i.e. by defining various geological layers and spatially heterogeneous, gridded reservoir property fields). Indirectly, however, representative correlations for the reservoir performance can be imported by the tool from a 3D numerical reservoir simulation study, if available. In addition, all wells are assumed to be identical, with differences only between injectors and producers.

The model is a *full-field*, *full-physics* Technical-to-Business XL-model consisting of coupled volumetric (Heat-In-Place), production (reservoir and well physics, thermodynamics of the steam turbine), and cashflow parts. It allows development plans to be assessed technically and economically. Output consists of a range of Key Performance Indicators (KPIs) and of various graphs of time-series etc. When combined with a Monte Carlo engine such as Crystal Ball or @Risk, the XL-model can compute stochastic time-series and histograms of KPIs. A particularly useful feature is the sensitivity analysis that can be done using Monte Carlo sampling. The model is targeted at geothermal assets (projects) that are relatively immature, i.e. assets with relatively large uncertainties for the non-controllable variables, and with a wide range of possible project definitions (controllable variables). Typically, such geothermal fields, or geothermal development projects, would be in the '*pre-feasibility*' or '*concept selection*' phase.

Results from studies done with this XL model may be used to narrow down (i.e. further frame) the possible project definitions to be elaborated in subsequent steps (FEED=Front-End Engineering and Design). In such further studies, more detailed models would be typically used.

If considered useful, the Indonesian users may agree to maintain the tool jointly, whether or not in collaboration with the tool developers.

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

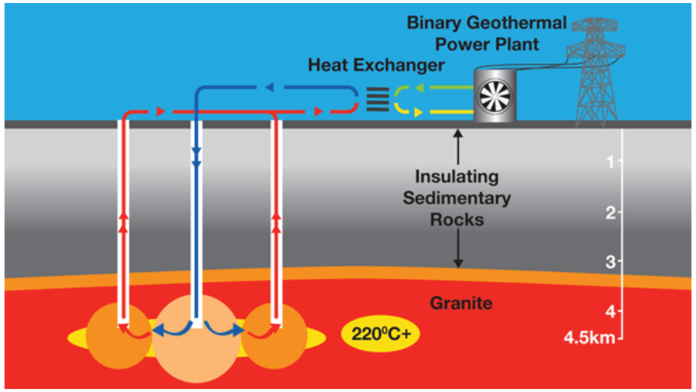
When designing the GEOCAP programme, discussions were held with ITB in Bandung about the need to have a geothermal asset evaluation tool available to all interested Indonesian parties, allowing them to compute probabilistically an asset's technical and economic performance over its life cycle. This resulted in the current version of the tool. To maximize accessibility to all, it was decided to programme it in XL, without any macros, and to leave the source code unprotected. This minimizes the feeling of a 'black box' and should facilitate the communication between the various disciplines, as they all can read directly what the XL code is doing. With a large number of output graphics, the user can also see directly what impact a change in assumptions has in terms of asset performance. A tool such as the GEOCAP asset evaluation tool could be regarded as a shared communication platform, even as a shared 'language', since all disciples are somehow represented in a common framework.

Also for government officials, it may be valuable to get acquainted with this communication platform as it may help them to better understand the company's perspective, including how the company perceives the pertinent risks. That again may help them understand whether a risk premium a company must negotiate with PLN, through the Power Purchasing Agreement tariffs, is reasonable.

GEOCAP ACTIVITY IN THIS TOPIC

The GEOCAP geothermal asset evaluation model was constructed by TNO in the Netherlands, in collaboration with ITB (Bandung) and IF Technology (Netherlands). The tool's development phases consisted of 1) functional specification, 2) software design, 3) tool construction, 4) testing, 5) debugging, 6) verification, 7) documentation, 8) dissemination / release. Below, a description of some headlines of the tool is given.

The model consists of a volumetric part, which computes the Heat-In-Place and the theoretically maximum possible electrical power capacity from this Heat-In-Place, based on a given economic lifetime and some empirical correlations. The (volcanic) reservoir is assumed to be non-depletable over the asset's life cycle, both in terms of fluid/mass-in-place and in terms of heat-in-place. Produced fluid is assumed to be replenished by injected fluid and/or natural water influx (meteoric water, other groundwater), heat is assumed to be unlimited in production terms, as over 90% of the Heat-In-Place is assumed to be in the solid minerals of the rock, which would re-supply the heat to the re-injected cooled-down fluids in the pores at an, in practical terms, unlimited rate. In addition, it is assumed that in practical terms Heat-In-Place and mass/heat production is hardly influenced by whether the reservoir fluids consist of steam plus water, or just water. Existing studies argue that this difference can be assumed to be negligible. Based on the steady-state well inflow equation, the model then computes the mass and heat production per well. The steady-state inflow equation corrects the drainage area per well for the number of (initial and incremental) wells. The given (initial) skin-factor per well influences the well's productivity. A user-defined skin build-up rate (factor/year) results in the well's productivity to decline over the years, until a skin-removal workover is scheduled and the skin factor is re-set at the original value. The user can supply the workover frequency. The workover opex will be accrued to the cash-out cashflow.



Wells with individual, heterogeneous properties and separate field-sectors (e.g. fault-blocks) cannot be modelled. All wells are assumed to be identical, and the reservoir is just one body with a constant reservoir-boundary pressure that does not deplete in time. For input variables that are heterogeneous in space and/or changing in time, it is assumed that they can be adequately represented by field-wide average values. This assumption is a coarse simplification and should in principle be verified by calibration to more detailed models. However, as a first approximation it may well be a valid assumption. All yearly average production is corrected

for a given load time (uptime) factor, or for the given number of running hours per year. Total field production is the sum of all individual well production rates, unless constrained by surface facilities. A targeted plateau production can be given: the model will automatically drill additional wells if the target is not being met (e.g. due to well deterioration, or if the target rate is increased in a given year). The number of production wells to be drilled each year is then used to calculate the yearly drilling expenditure (drillex) and, hence, depreciation, tax and net cash flow. The user can supply a producer to injector ratio. When specifying / computing a new production well, the corresponding number of injectors will be automatically drilled and accrued to the drillex, and later to the well-opex (e.g. for the number of workovers to be done). Drillex tax depreciation also follows automatically.

Below are some examples of input and output of the GEOCAP tool.

Name of field / project GT-field

Flow Variables

		Select Units
Formation thickness	1500	m
Permeability	1.00E+00	Darcy
Viscosity of water	0.03	kg/(m*s)
Average reservoir pressure	2.41E+07	Pa
Bottomhole pressure	1.70E+07	Pa
External drainage radius	900	m
Wellbore radius	0.09	m
Total area of reservoir	1.00E+02	km2
Flow skin factor (can be negative or positive)	5	
Yearly skin factor increase rate for wells (%)	15%	
Average reservoir rock porosity (%)	10%	
Rock density (kg/m3)	3000	
Rock specific heat (kJ / kg*C)	0.85	
Along hole depth of single well (m)	7000	
Produced water temp at wellhead, Tx (C)	280	
Injection temp, T-outlet (C)	180	
Average ambient temp (C)	10	

Production variables

Select units for the loadtime per year:	Percent
Loadtime per year, in the units chosen above	0.95
# wells total	10
# well-slots per cluster	20
Capex to be added if # well-slots exceeded ($ MM)	117
Producer / Injector ratio	3
Max. allowable # years in row @ NCF<0	3
Select pump e-consumption calculation	Equation
Pump e-consumption, tech specs (kW) -->	1000
Pump efficiency, equation (%) -->	65%
Well cost scaling factor	1.5
Conversion efficiency - choose the source to use	Sarmiento
If van Wees, enter relative efficiency -->	0.6
Associated conversion efficiency value -->	13%
What method to use to calculate MWth and MWe:	Sarmiento

Phasing variables

First year of evaluation	2017
COD (First year of production)	2021.8
# years from end of prod to abd (monitoring	3
Workover rig capacity - max # wells/yr	12
Workover duration (days)	30

Well-related costs

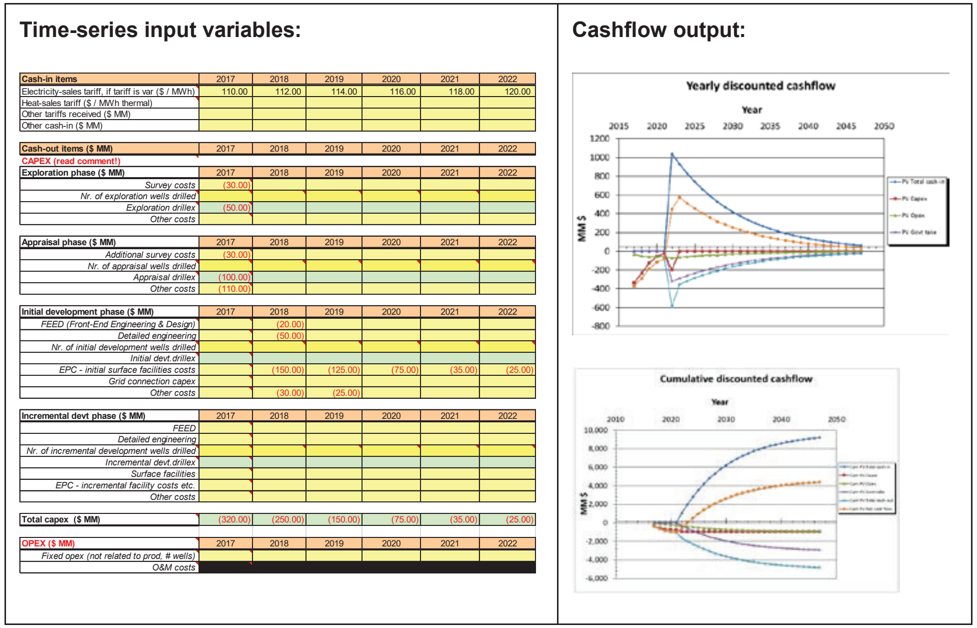
Drill & compl. cost per dev. well ($ MM)	15.00
Well stimulation cost ($ MM)	10.00
Workover cost per well ($ MM)	1.52
Avg W/O frequency (every *n* yrs)	6
Well opex ($ MM/well/yr)	0.37
Select field abandonment cost calculation:	Percent
Value ($ MM) -->	200
Percent (% cum capex) -->	12%

Economic variables

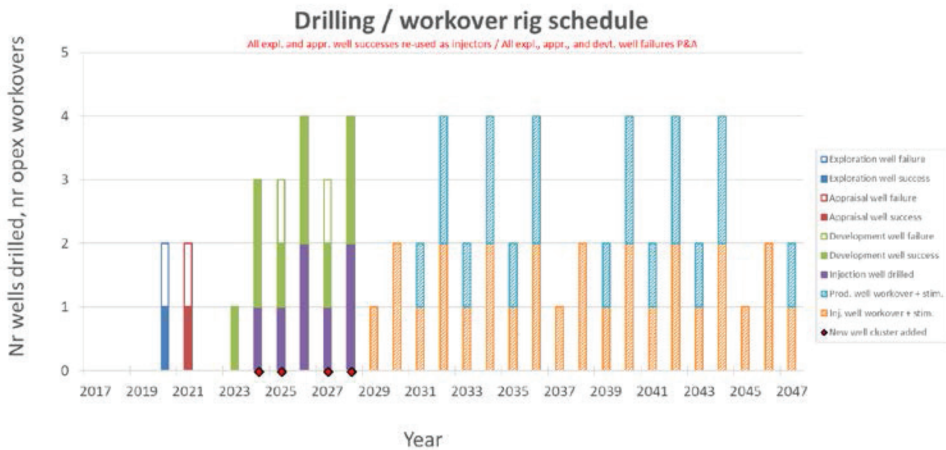
Variable water opex ($/m3 water)	0
Royalty (% of electricity sales)	12%
Is royalty tax deductible: Y/N?	N
Tax (% taxable income)	22%
Select type of depreciation scheme:	DDB
Depreciation (nr years)	10
Salvage value of asset (%)	10%
Capex multiplier	1.05
Fixed opex multiplier	1.26
O&M costs calculation method:	Percent
O&M yearly costs (% of capex) -->	0.10
Discount rate (%)	13%
Discounting reference year	2017
Who pays for connection to grid?	TSO
Target economic life (years)	50
e-Price / MWh tariff fixed/var?	FIX
e-Price / MWh tariff if fixed ($/MWh)	80

Suggested values for well cost

TNO calculation of well cost ($ MM)	*22.43*
DOE calculation of well cost ($ MM)	*15.12*



The drilling schedule is a combination of input and calculated results of well success, based on some user-defined drilling success learning curve, and on a given producer/injector ratio. The successful wells define the field's production rate.



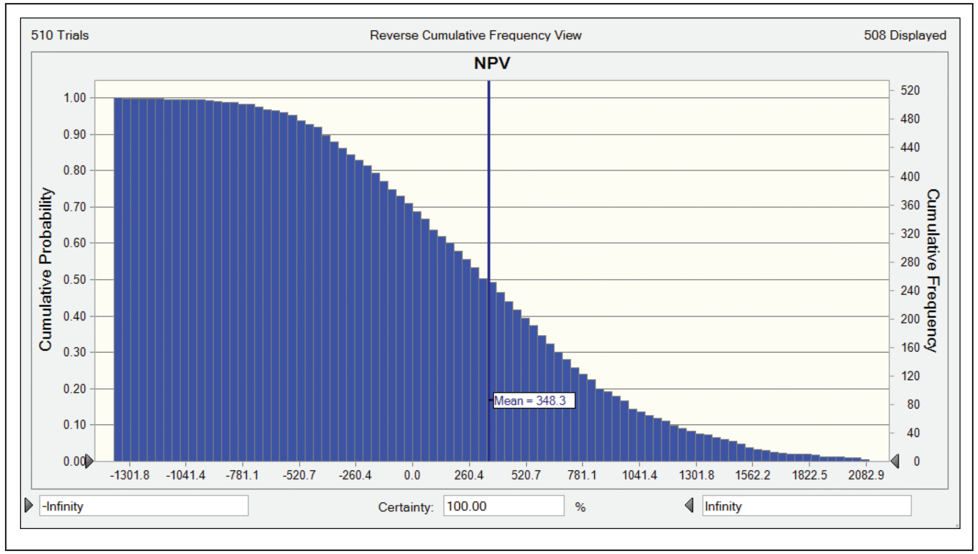
Eventually, the field's life-cycle performance is captured in series of so-called Key Performance Indicators (KPIs). When combined with a statistical XL plug-in (such as Crystal Ball or @Risk), all KPIs can be computed probabilistically and be displayed as (cumulative) histograms (or probability density functions). This allows the project team to understand risk and upside potential, to design risk mitigation strategies, and/or to design flexibility options to 'chase the upside'. The list of KPIs is given below:

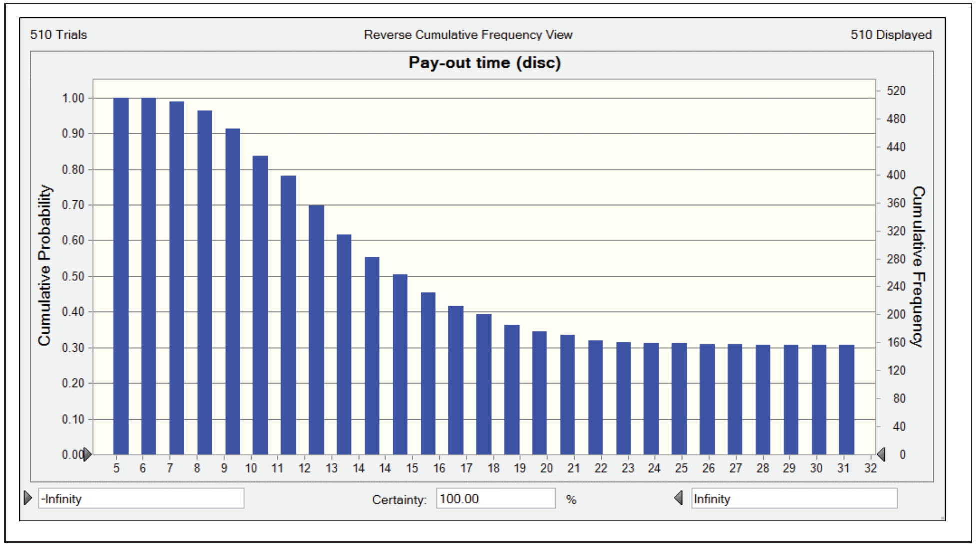
Project Key Performance Indicators Hotrock

Discount rate = 13%; Average flow = 1565.30 L/s; 5 wells/platform; Prod : Inj ratio = 1.00
Royalty = 2.5% & not tax-deductible; Tax = 25%; Depreciation period = 10 yrs

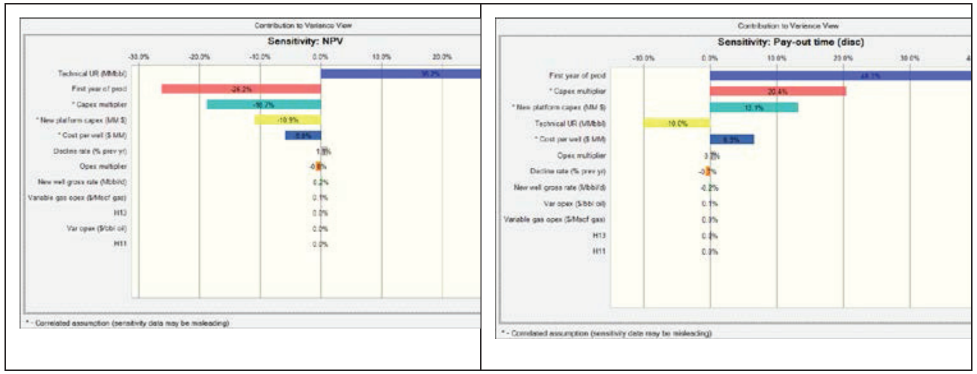
KPI	Value	Unit	Comment
Cumulative electricity produced over evaluation period	64.6	TWh	
PV Electricity sales @ PV 13%, ref 2017	797.9	$ MM	
PV Government take @ PV 13%, ref 2017	193.1	$ MM	Note: no Loss Carry Back implemented / Govt may use different discount rate
NPV @ PV 13%, ref 2017	303.8	$ MM	
IRR	20.9%		
Maximum exposure (undiscounted CF)	-536.2	$ MM	Max. undiscounted exposure in year 2024
Maximum exposure (discounted CF)	-335.3	$ MM	Max. discounted exposure in year 2024
PIR undiscounted	5.43	ratio	
PIR discounted	0.82	ratio	
PV Capex / MW	0.72	$ MM/MW	For power plants, a rule of thumb is $2 million/MW installed capacity
Unit Technical Cost (undiscounted cost/MWhe)	19.20	$/MWhe	
Unit Technical Cost (PV cost/MWhe)	7.18	$/MWhe	[PV(capex+opex) / cumulative MWh produced over life-time]
Unit Technical Cost (PV cost/PV MWhe)	51.50	$/MWhe	[PV(capex+opex) / PV(MWh produced over life-time)]
Levelized Cost of Electricity (PV break even price)	55.05	$/MWhe	Use Data-What If Analysis-Goal Seek" (set NPV=0); see comment cell A16
Pay-out time (undiscounted cashflow)	10	years	
Pay-out time (discounted cashflow)	13	years	
Nr of add'l well clusters constructed	2	well clusters	1st add'l well cluster operational in year 2026
Nr of production + injection wells drilled	15	wells	@ avg. gross liquid rate per prod well = 1565.3 L/s
W/O rig availability: max. # wells / yr exceeded?	No	year	
Productive life of asset	23	years	Still producing at end of evaluation period
Effective capacity of field	403	MW	
Upside potential	0	MW	Effective MW of field > max theor. power capacity ref. Sarmiento

In addition, some possible histograms are displayed:





Also, some sensitivity analysis features follow below:



CONTACT

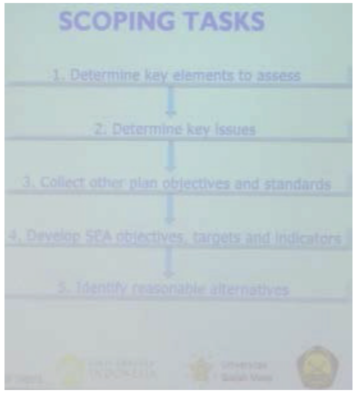
Ali Ashat (ITB) labgeothermal@yahoo.com
Christian Bos (TNO) christian.bos@tno.nl

STRATEGIC ENVIRONMENTAL ASSESSMENT FOR SUSTAINABLE GEOTHERMAL ENERGY DEVELOPMENT

INTRODUCTION

In the development of geothermal energy (GTE) potential in Indonesia there are many issues that play a role, and these are not only technical issues. Although the Indonesian Government is strongly supporting the geothermal energy development as one of the clean, renewable and reliable energy supply systems, there is a tension between this policy and policies to protect forests, though both aim to reduce carbon emissions. Up to 42% (some sources mention even 58%) of the nation's geothermal resources are located in forest areas with a legal status of 'Protected' or 'Conservation' forest. Uncontrolled development initiatives can have undesired social, ecological and economic consequences. In GTE development, this continued tension between forest conservation and exploration and between ecosystems functioning and exploitation of reservoirs puts spatial planning under pressure.

According to the Environmental Protection and Management Law No 32/2009, which is strengthened by the Ministry of Environment Decree No 9/2011 regarding the Generic Guidelines of Strategic Environmental Assessment (SEA), every policy, plan and program that may impact environmental and/or social aspects must be subject to SEA in order to ensure sustainable development. SEA is a mandatory requirement ensuring that sustainable development principles have become a basis of and have been integrated into the development of Policy, Plan and/or Programmes (PPP). The key principles of SEA are (i) the involvement of relevant stakeholders, (ii) a transparent and adaptive planning process, (iii) consideration of alternatives, and (iv) using the best possible information for decision and policymaking.



RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Encouraging provincial and district governments to develop geothermal energy is a big challenge, as expertise and understanding of energy scenarios and energy development is limited. In addition, there is a strong need to bring about much better awareness and acceptance with local populations in areas where exploration and exploitation of geothermal resources is to take place. Another challenge is lack of knowledge and skills to implement SEA as a structural and integral part of planning practice in Indonesia.

SEA should improve both the (spatial) geothermal energy planning process and the information used in this process. Currently the planning process in Indonesia hardly makes use of spatial information. Subsequently there is little attention for the spatial implications of policies and interventions, and the analysis of spatial information is hardly ever used to consider alternatives and cumulative effects. In European countries, the spatial context plays an indispensable role in the planning process and specific tools and techniques are available to do this. It is therefore considered important to explore how (i) spatial information and Geographic Information Systems (GIS), (ii) Spatial Decision Support Systems (SDSS) that include scenario development and dynamic modelling and (iii) participatory approaches like Participatory GIS (PGIS) can be used to help to identify and structure the problem(s), find and compare possible solutions, and monitor and evaluate the proposed GTE activities.

In this work package, special emphasis was given to these aspects because it will greatly enhance the spatial planning, management and decision-making process for GTE development. Besides that, this work package also aims to analyse existing rules and regulations and develop a SEA training manual for sustainable GTE development that contributes to the harmonization of societal and environmental considerations in the field of geothermal energy.
The long-term objective of work package is to increase the capacity of staff working in the field of SEA for geothermal energy as a tool to gain up to date knowledge and practical skills in SEA for GTE development to enhance sustainable GTE planning and decision-making in Indonesia.

GEOCAP ACTIVITY IN THIS TOPIC

Besides the development of training materials and a SEA training manual for sustainable GTE development, also a stakeholder workshop and training course were organised. The stakeholder workshop took place in May 2016 and the main objectives of the workshop were to i) disseminate SEA on GTE development to stakeholders involved in GTE and ii) get feedback/input/remarks for the training course held in October 2017.

The main aim of the 4 days training course was to increase the SEA implementation capacity in the GTE sector. The topics offered during the training follow the generic steps to be carried out in the implementation of SEA for GTE development, as can be seen in the flyer announcing this training. The participants represented a balanced mix of GTE experts, staff from government institutions, academics and NGO's.

Overview of main training modules:

1. Introduction in SEA for GTE

What is SEA and how is it conducted worldwide and in Indonesia? This module includes three presentations and one assignment. The first presentation is on SEA in a worldwide perspective and according to international practice. The second one on SEA in Indonesia and the third one on Existing rules & regulations related to SEA for GTE development in Indonesia. As part of the assignment, participants were asked to write down and discuss the main differences between SEA and EIA.

2. GTE policies and plan objectives and screening

What are the main geothermal energy policy, plan and programme objectives and how are they related? When is SEA required? These questions were dealt with in the presentations and a brainstorm exercise.

3. Preparation or SEA Implementation

Why and What is Strategic Thinking in SEA?

How to prepare an SEA for GTE Development?

This training session contains presentations and related guided exercises. The first one clarifies the concept of strategic thinking in SEA and the difference with strategic planning. The second one explains what should be considered in preparing a SEA according to the Government regulations on SEA in Indonesia.

4. Scoping

What are the main activities in scoping and who to involve and how? In this session, an introduction into scoping and an overview of its main activities is given (key elements of GTE development, key sustainability issues, other PPP objectives, SEA objectives, targets & indicators, and alternatives & options). Each activity was explained in more detail in separate training sessions, including presentations, videos and guided exercises. Scoping results in the preparation of a scoping report and scoping guidelines.

Figure 68 Participants working in three groups on guided exercises

alternatives and justify preferred alternative(s), g) prepare an environmental assessment report (Environmental Impact Statement, EIS).
It should be noted that in Indonesia scoping and assessment activities are all part of assessment.

What are optimal locations for GTE development? Though GTE is a sustainable energy source, the plant and associated infrastructure can have impacts. As part of the assessment, participants learned how Spatial Multi Criteria Evaluation (SMCE) could be used to establish alternative locations for particularly pipelines and other related GTE infrastructure. Wayang Windu geothermal power plant was used as case study.

6. Recommendation for improvement of the proposed GTE PPP, Quality Assurance and Validation

How to incorporate the results of the assessment into the GTE policy, plan or programme? How good is the SEA? What is its validity? This training session included a presentation on recommendations for improvement of a GTE PPP, quality assurance criteria & its methods and validity criteria & its methods.

Figure 69 Presentations by participants of the stakeholder workshop and the four days training

CONTACT

Joan Looijen (University of Twente, ITC): j.m.looijen@utwente.nl

Raymond Nijmeijer (University of Twente, ITC): r.g.nijmeijer@utwente.nl

Triarko Nurlambang (University of Indonesia): triarko@ui.ac.id; triarko@gmail.com

Dyah Rahmawati Hizbaron ((Universitas Gadjah Mada); emmahisbaron@gmail.com

GEOTHERMAL DATABASE INTEGRATION

INTRODUCTION

Indonesia has the goal to significantly increase geothermal power generation in the future. Subsurface data availability and a regional geothermal resource evaluation are key in stimulating geothermal development. It makes it easier for new companies to enter the area and it helps research projects. A legal framework could enforce geothermal (e-) reporting and data supply to the government, which could then be made available internally and publicly, with the appropriate restrictions, through a web portal.

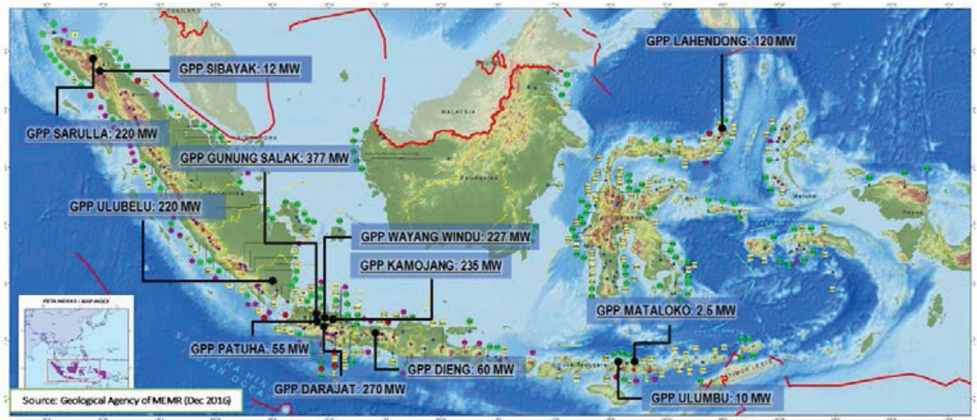


Figure 70 Installed geothermal power in Indonesia, December 2016

RELEVANCE FOR AND APPLICABILITY TO INDONESIA

Geothermal energy has the benefit of being renewable and does not contribute to global warming. However, it does have to compete with other (non-renewable) sources of energy such as coal and oil and gas. Subsurface data availability and a regional geothermal prospectivity analysis can decrease the costs in the exploration phase and increase the success rate of geothermal projects.

Subsurface data in Indonesia is mostly not publicly available and companies are not obliged to supply data to a government organisation. There is room for improvement, which could benefit geothermal development.
As an example, there is the comparison between The Netherlands and Germany. In the Netherlands, most subsurface data is publicly available where in Germany it remains within the company that acquired the data. As a result, geothermal development in Germany is minor compared to The Netherlands, even though the companies have similar geology.

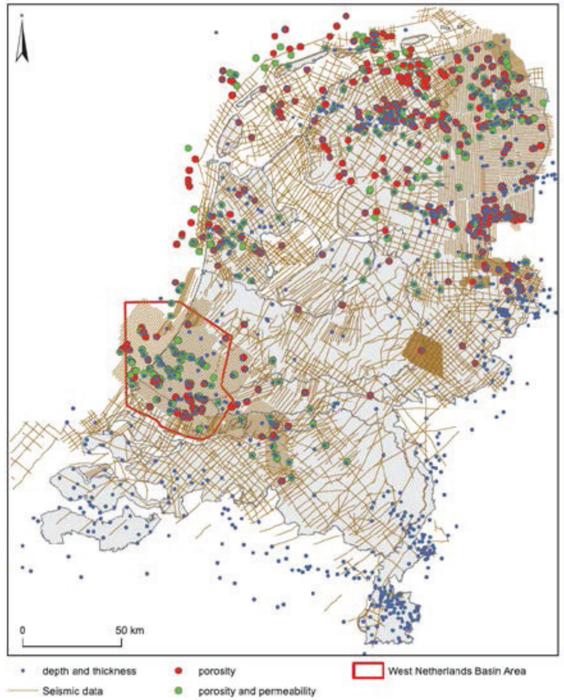


Figure 71 Seismic survey and well data availability in onshore The Netherlands

GEOCAP ACTIVITY IN THIS TOPIC

The work has mainly been focussed on three activities:

1. GIS web portal database, structure and design
2. Geothermal resource evaluation and e-reporting strategy workshop
3. Development of a geothermal resource assessment methodology

1- GIS web portal database, structure and design

A structure and design for the GIS web portal was proposed: ESRI GIS software and their ArcGIS API4 JavaScript library which will make use of an ArcGIS map server, which holds all the data. In addition, a second opinion was given on the "Development proposal Indonesian Geothermal Data Centre". An ArcMap database has been setup with data from the green book (Profil Potensi Panas Bumi Indonesia) from MEMR. This information has been translated into English and put as metadata of geographical data items such as licences. Additionally other datasets such as wells data, temperature measurements, heat flow values and volcano locations have been added. MEMR has created a webportal based upon these recommendations: http://igis.esdm.go.id/igis/

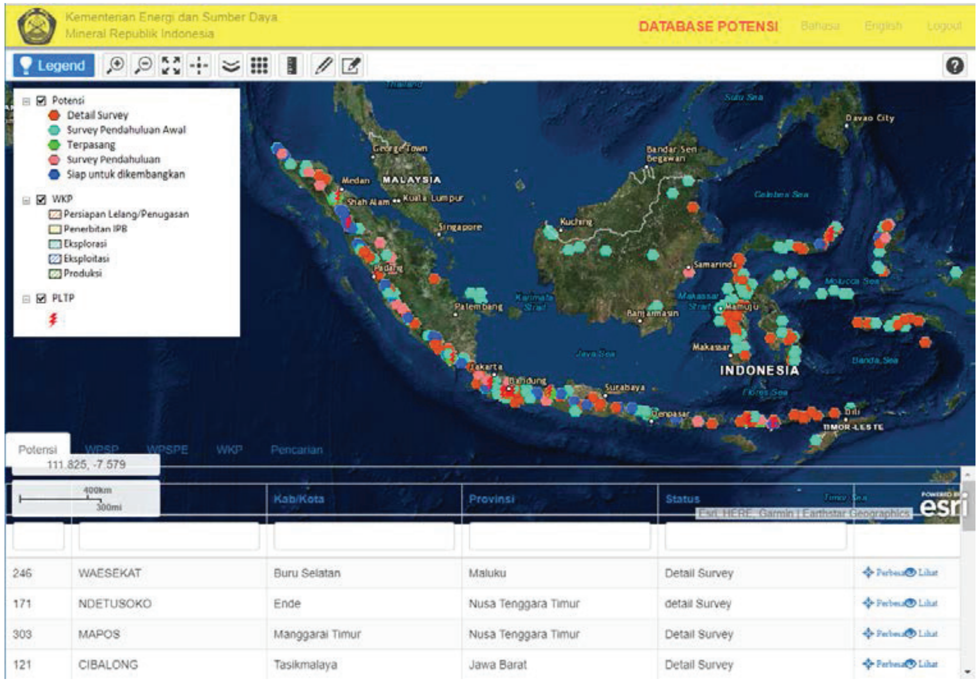


Figure 72 Screenshot from the webportal http://igis.esdm.go.id/igis/potensi/index

2- Geothermal resource evaluation and e-reporting strategy workshop

A four-day course was developed presenting the status in The Netherlands concerning:

- Geothermal resources
- Geothermal licensing and support schemes
- Geothermal reporting and data release

Brief overviews of the status in Indonesia are also presented allowing to compare the two countries. Indonesia only has indirect use of geothermal energy whereas in the Netherlands it is only direct use because of lower subsurface temperatures. The activities of oil and gas and geothermal in the Netherlands mainly overlap whereas in Indonesia they are separated geographically and by geological setting. Also, in Indonesia there is a difference in type of data. For instance seismic is used in oil and gas and in geothermal gravity and electromagnetic data is used. As a results oil and gas data is very useful in the Netherlands for the evaluation of geothermal potential whereas in Indonesia this is not the case.

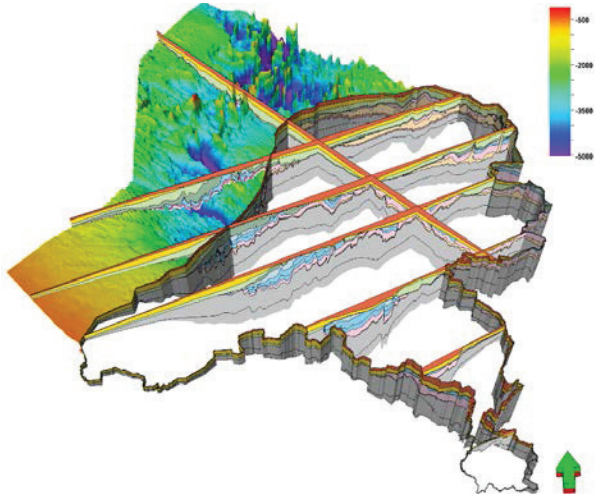


Figure 73 3D subsurface model of The Netherlands covering both the on- and offshore areas. This model was constructed using publicly available data such as seismic surveys and well logs.

Most of the subsurface data in the Netherlands is collected by the government and made public. The government also finances regional nationwide studies using this data, resulting in 3D models of the subsurface, which can be used as a starting point for geothermal exploration. In Indonesia most of the data is not public. It could be interesting for geothermal development to increase the amount of public data in Indonesia.

Several of the items discussed could be interesting for the Indonesian geothermal setting. These will be taken on board in discussion with the ministry on future developments on for instance an updated e-reporting scheme or an updated storage environment for subsurface data.

3- Development of a geothermal resource assessment methodology

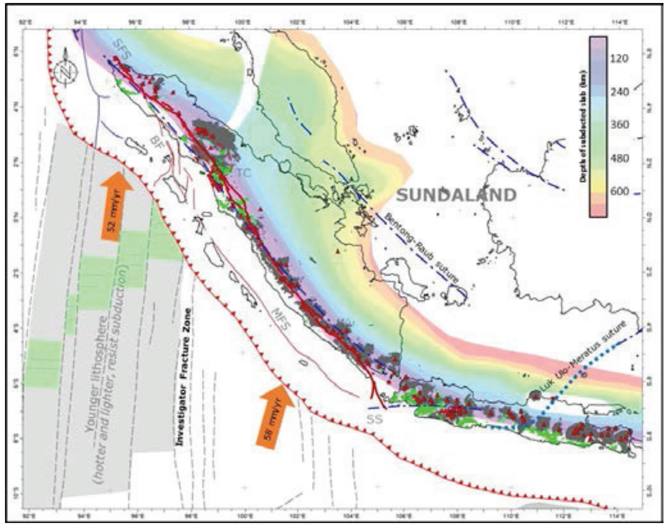


Figure 74 Tectonic setting of Sumatra and Java

Fauzi and Lukman have started their PHD's at Utrecht University under the supervision of prof. Jan Diederik van Wees. Fauzi will focus on Flores which is earmarked to become a geothermal island and Lukman focusses on Sumatra. They have started gathering data and familiarizing themselves with the methodologies used in Europe (geoelec) and The Netherlands (thermogis). This methodology is designed for sedimentary basins. Fauzi and Lukman will look into adapting the method for volcanic areas and possibly also investigate the sedimentary basins on the two islands. This includes improving the understanding of regional tectonic volcanism and acquiring additional data such as MT data.

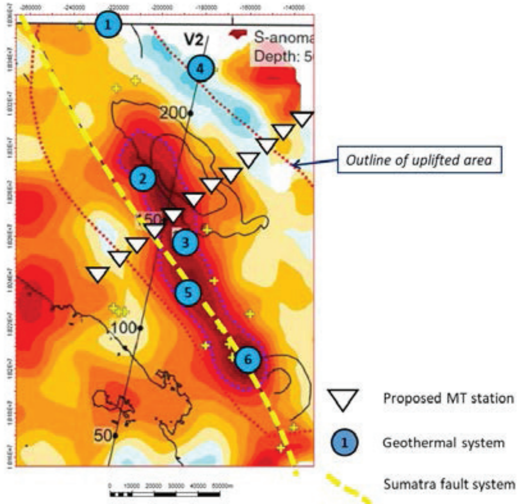


Figure 75 Proposed MT survey across the Toba Caldera, Sumatra

CONTACT

Mark Vrijlandt (TNO): mark.vrijlandt@tno.nl

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GEOCAP Handbook

GEOCAP contribution to the Geothermal development in Indonesia