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German-Indonesian Cooperation on Sustainable Geothermal Energy Development in Indonesia - Status and Perspectives

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ABSTRACT

In 2010 cooperation between Germany and Indonesia has been initiated in the field of sustainable geothermal energy development. Within this German project "Sustainability concepts for exploitation of geothermal reservoirs in Indonesia – capacity building and methodologies for site deployment" several research activities have been carried out which were closely accompanied by capacity building measures, such as a PhD-program in Germany with focus on Indonesian topics. Research activities and knowledge transfer were carried out bidirectional in order to strengthen science and technology for both, Indonesian and German partners.

In the field of exploration, low enthalpy geothermal green fields in magmatic (East Java) and amagmatic settings (North Sumatra) have been investigated. Also analyses on the controlling mechanisms of operated geothermal fields in North Sulawesi and West Java have been carried out. Regarding sustainable exploitation, we report on the integrated geoscientific monitoring networks that were established and on solutions developed for on-line fluid-chemical monitoring in operating geothermal plants. In the field of plant technology, the technical concept for a demonstration binary power plant as bottoming unit at an existing site has been elaborated and the construction of the demonstration binary power plant for Lahendong is ongoing.

In this paper, we are reporting on the objectives, status, progress and achievements of the scientific investigations. We suggest that the project findings can be applied to other locations in Indonesia and that they can be used for further developments. The realization of the demonstration binary power plant is carried out in another collaboration project which could be the basis for a more widespread deployment of binary power plants and for a decentralized use of geothermal energy in Indonesia.

1. INTRODUCTION

The republic of Indonesia is composed of many islands and widely extended. The country with the fourth highest population worldwide has to solve a giant demand on food and energy. Resources of oil and gas are limited in Indonesia and the existing infrastructure to reach the customers of the energy is not yet sufficient, as access to many remote areas in Indonesia is limited. Therefore, de-central, location adapted energy provision is crucial. Nearly one third of the Indonesian population has no access to the electricity grid and approximately 7.7 GW (~24%) of the installed power capacity is powered by diesel generators (Winarno et al., 2013). Renewable energy can contribute to the provision of energy especially in remote areas. Geothermal is one of these options and has huge resources in Indonesia: although geothermal already provides ~1.4 GWe electrical capacity, this represents only a small part (~4%) of the identified potential.

The Indonesian government plans an extension of the deployment of geothermal electricity until 2025 to 9.5 GWe that represents a significant part of the estimated resources of 27 GWe (Surya Darma et al, 2010). However, there is a gap in reliable technologies for solutions to provide de-central geothermal energy. In addition, human resources respectively engineers are rare to handle the extension of the capacity.

Further development of geothermal technology is as important as capacity building. In this context, a PhD-program was installed to support these goals. A comprehensive exploration program with different methods applied was partly focused on low enthalpy geothermal "green fields" in magmatic and amagmatic settings to further elaborate potential sites on Java, Sumatra, and Sulawesi for future deployment (Fig. 1). Additionally an integrated geoscientific monitoring network was established at the Wayang Windu geothermal field in West Java.

2. CAPACITY DEVELOPMENT

One of the limiting factors for the growth of geothermal energy supply in Indonesia is the availability of qualified human resources. To help overcome this limitation the Indonesian-German cooperation project supports initiatives to expand geothermal training in Indonesia. A number of initiatives were implemented: PhD program with 10 PhD positions (s. Fig. 2) in Exploration, Reservoir Engineering and Geothermal Plant Technology supervised in Germany¸ Indonesian-German expert and student exchange program, teaching, workshop and field camp programs at Indonesian partner institutions by German experts.

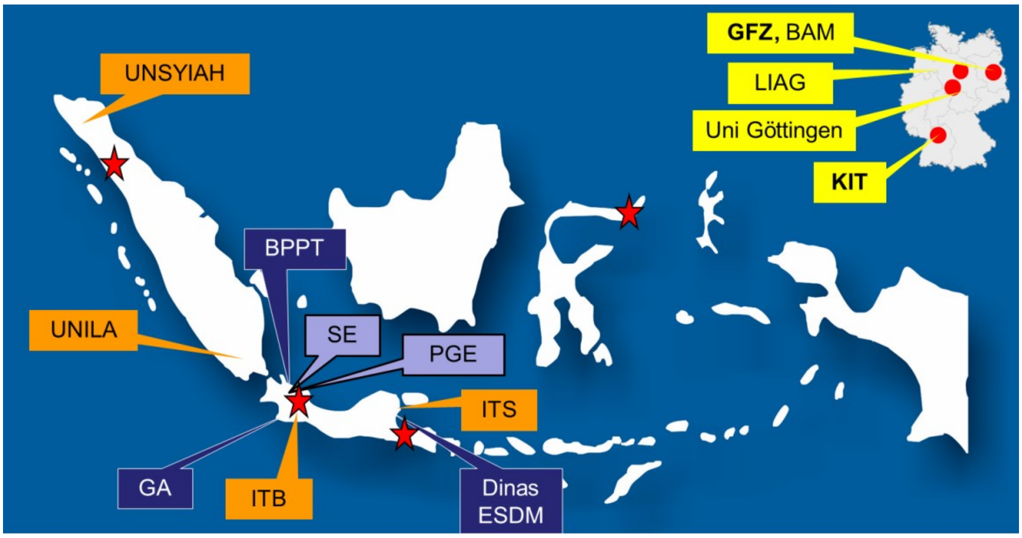

Figure 1: Project partners and the established network in Germany and in Indonesia. Field investigation sites: Sipoholon, Wayang Windu, Tiris, Lahendong (denoted by red stars, from left to right).

Mochamad Nukman[1]	Geothermal exploration involving structural geology and hydrochemistry in the Tarutung Basin, Northern Central Sumatra (Indonesia)
Muksin Umar	A fault-controlled geothermal system in Tarutung (North Sumatra, Indonesia) derived from seismological study
Sintia Windhi	Magnetotelluric Investigation of the Sipoholon Geothermal Field, Indonesia
Wiyono	Seismic exploration for decentral geothermal power plants in Indonesia
Maren Brehme	Hydraulic and hydrochemical modelling of a geothermal reservoir in Indonesia
Muhamad Andhika	Control of silica precipitation kinetics in synthetic geothermal brines
Amela Keserović	Geothermal systems in Indonesia – Influence on the corrosion resistance of stainless steel materials
Yodha Nusiaputra	Design optimization of binary power plant module
Andri Hendriyana[2]	Microseismic imaging of geothermal reservoir exploitation in West Java
Rasi Prasetio	Development and application of isotope and artificial tracers as new quantitative techniques for the Wayang Windu hydrothermal System

Figure 2: PhD program within the project framework (funding by BMBF, [1]DAAD and [2]DIKTI)

3. FIELD INVESTIGATIONS

Indonesia represents a complex subduction zone setting that is subdivided into a wide variety of extensional, strike slip and compressional sub regimes and hosts abundant magmatic geothermal activity. Understanding alteration patterns and structural controls on geothermal activity in this magmatic region is the most critical issue for defining successful site specific exploration and utilization strategies. A suite of different methods and techniques is required to image and characterize hidden geothermal systems in high and medium to low enthalpy regions. Methods applied consist of structural geology, geochemistry, hydrological investigations, passive seismology, magnetotellurics, active seismics and gravity monitoring.

3.1 Sipoholon / Tarutung (North Sumatra)

Whereas most of the geothermal systems in Indonesia are controlled by volcanic activity, geothermal systems at the Sumatra Fault System might be controlled by faults and fractures. Therefore the Sumatra Fault System provides a unique geologic setting to evaluate the influence of structural controls on geothermal activity. The investigations carried out in North Sumatra allow constraints between fault dynamics and geothermal activity in the Tarutung Basin in north central Sumatra. Methods applied are structural geology and geochemistry methods (Nukman et al., 2013), passive seismology (Muksin et al., 2013a and 2013b), magnetotellurics (Niasari et al., 2015) and active seismic (Krawczyk et al., 2015). The combined interpretation resulted in an updated conceptual model of the geothermal resources in this region that might be used for future exploitation (s. Fig. 3 and Fig. 4).

The geothermal system in Tarutung seems to be controlled mainly by the fault setting where the source of the hot fluid is originated from below the fault and transported to the northeast.

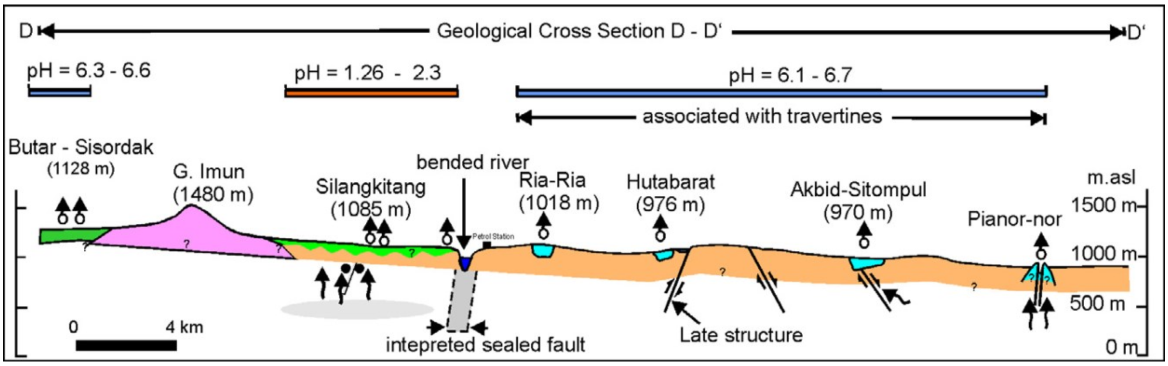

Figure 3: Geologic cross-section incorporating the distribution of thermal manifestations, lithology and structures identified in the Tarutung Basin (from Nukman et al., 2013)

While the active seismic experiments helped to delineate and follow shallow structural elements, the magnetotelluric and passive seismic investigations allow the interpretation of deeper structures and clearly show the difference between the Sarulla prospect in the south and the Tarutung basin (s. Fig. 4a).

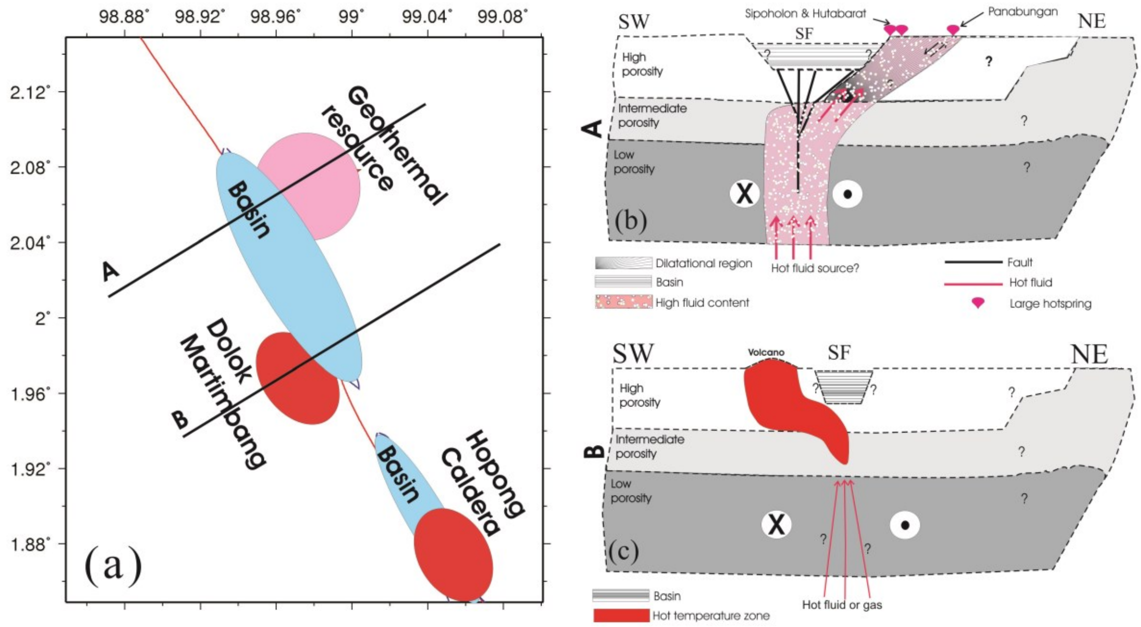

Figure 4: The new conceptual model derived from the attenuation tomography (Muksin et al., 2013b) and complemented by the Vp/Vs tomography results (Muksin et al. 2013a) describing four different clusters in Tarutung: (a) the map view of the new conceptual model of the Tarutung geothermal field, (b) the structure of the Tarutung geothermal area along the cross-section A and (c) the magmatic system of the Martimbang volcano indicated by the profile B. (from Muksin et al., 2013b)

3.2 Lamongan / Tiris (East Java)

Magmatic settings involving active volcanism are potential locations for economic geothermal systems due to high temperature and steam pressure. Indonesia, located along active plate margins, hosts numerous areas of active volcanism and, therefore, belongs to the regions with greatest geothermal potential worldwide. However, tropical conditions and steep terrain reduce the spectrum of applicable exploration methods, in particular in remote areas.

Our exploration study demonstrates how green-field exploration mainly based on hydrochemistry and petrology (Deon et al., 2013) and passive seismic monitoring (Jaya et al., 2013) helps to characterize hidden low enthalpy geothermal fields in remote tropical areas to delineate further site specific exploration and possible exploitation strategies.

3.3 Lahendong (North Sulawesi)

Lahendong is a magmatic structurally controlled geothermal reservoir in North Sulawesi (Indonesia). The investiagtions carried out are combining structural geology, hydrochemistry including isotopes as well as geochemistry and permeability determination (Brehme et al., 2013). The integration of all data into a thermal-hydraulic model allows prediction of reservoir behaviour and supports the sustainable use of it. Methods used throughout the study are structural mapping, fault plane analysis, field based determination of physicochemical properties of well and spring waters, discharge measurements in rivers, analysis of major and minor elements as well as isotopes of waters (Wiegand et al., 2013) and rocks in the laboratory completed by investigations on permeability of rocks. Modelling of hydrochemical water properties was done using PHREEQC and subsequently a thermal-hydraulic modelling was carried out with Feflow.

A compartmentalisation of the reservoir was derived from stress field analysis of the tectonic elements in combination with hydrogeological interpretation. Temperature anomalies and loss of river water suggest surface water infiltration into fault zones. The Lahendong geothermal field is subdivided into two sub-reservoirs by horizontally less permeable fault zones and permeable fracture patterns parallel to the strike of the main fault. The study shows that geological-structural analysis in combination with hydrothermal- and geochemical investigations are the essential tools for geothermal reservoir characterization and sustainability prediction of geothermal energy exploitation.

3.4 Wayang Windu (West Java)

Wayang Windu geothermal field in West Java is situated in a complex tectonic setting between many active volcanoes. Understanding of the structure and the dynamics of geothermal reservoirs and hydrothermal systems in the south of Bandung is essential for the assessment of the geothermal resource and its sustainable exploiataion. The co-existence of a large variety of intense surface manifestations like geysers, hot-steaming grounds, hot water pools, and active volcanoes suggest an intimate coupling between volcanic, tectonic and hydrothermal processes in this area. We deployed a geophysical network around geothermal areas starting with a network of 30 seismic stations including high-dynamic broadband Güralp and Trillium sensors (0.008 - 100 Hz) and 4 short-period (1 Hz) sensors from October 2012 to December 2013. We extended the network in June 2013 with 16 short-period seismometers. Finally, we deployed a geodetic network including a continuously recording gravity meter, tilt-meters, a GPS-station and a meteo station (s. Fig. 5 and Fig. 6).

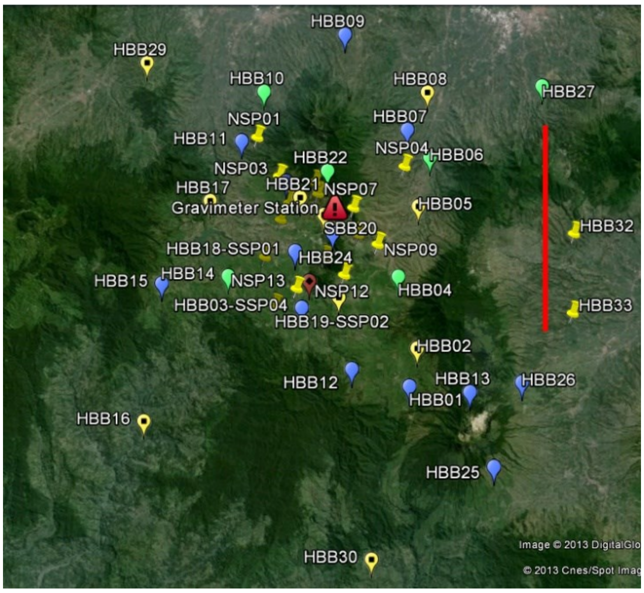

Figure 5: Seismic monitoring stations in and around Wayang Windu geothermal field and Papandayan volcano (as of September 2013). The red triangle marks the position of the gravity station (s. Fig. 6) and the red line represents a distance of 15 km.

Figure 6: Gravity-meter gPhoneX 128 (right) in the specially constructed new observation building (left): the pillar of the gravity-meter is completely decoupled from the building. An additional installation of a Trillium compact seismic sensor and a tilt-meter on the pillar is used for detailed signal analysis and comparison of the gravity signal with the signals of the seismic network.

First results of the 3D-microseismicity analysis are very encouraging and will be presented in a separate paper (Jousset et al., 2015).

4. GEOTHERMAL PLANT TECHNOLOGY

The goal of the Indonesian government, to increase sustainable geothermal exploitation within the next decade, can additionally be supported by developing innovative plant concepts. Efficient and reliable plant technology considers the specific preconditions and requirements of a site where production and injection wells shall be installed to maintain sustainable conditions in the reservoir. Main challenges refer to plant efficiency and geothermal fluid loop optimisation, geochemical issues, infrastructure integration, and ambient conditions.

4.1 On-Line-Fluid Monitoring, corrosion and scaling

During the operation of a geothermal plant, chemical reactions between the geothermal fluid and either the reservoir rocks (during fluid re-injection) or the plant components can occur and damage both, the reservoir by clogging the pores and the plant materials by corrosion and scaling. Therefore, understanding the geochemical reactions helps evaluating potential risks during plant operation. Geochemical processes, relevant for geothermal energy production at Indonesian sites were investigated in the field and the lab scales.

For the installation of a binary plant at a geothermal site in Northern Sumatra (see below) it has been calculated that silica will be highly oversaturated at fluid temperatures after cooling down in heat exchangers (< 100 °C). Therefore, pre-experiments are performed to assess silica scale formation after heat extraction and fluid re-injection into the reservoir. Lab experiments focus on silica formation processes induced by changes in p-T-conditions in synthetic brines (Andhika et al., 2015).

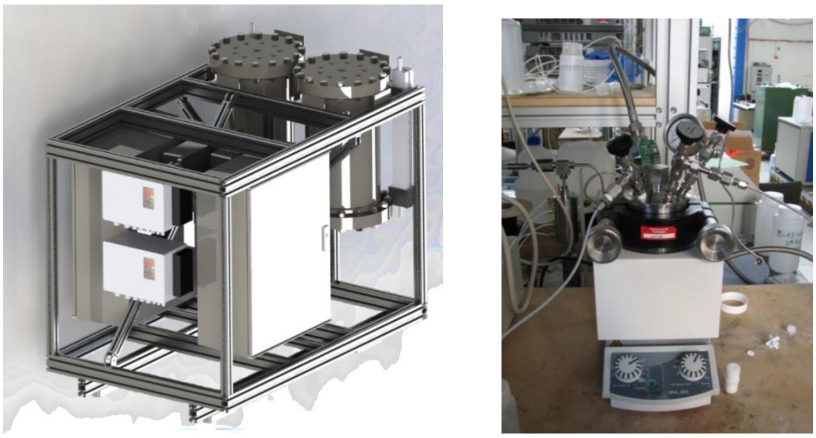

Figure 7: On-line fluid-chemical monitoring device (left: design sketch) for the installation in the thermal water loop of operating geothermal plants. It also comprises an autoclave with an ultrasonic-measuring-cell for the online determination of silica scaling under different pressure, temperature and fluid conditions (right: laboratory setup)

As the physico-chemical composition of geothermal brines are of major interest for effective and sustainable power generation an on-line fluid-chemical monitoring device for operating geothermal plants is developed (s. Fig. 7). It is designed for continuous measurements of pressure, temperature, pH, density, electrical conductivity and viscosity on multiple inlets that can be scanned in programmable time intervals. This will allow for the analysis of processes in the thermal water loop of geothermal plants, e.g. by obtaining the parameters before and after a heat exchanger and other relevant components (pumps etc.) when operated in the flow-through modus. The two pressure vessels (200°C, 20 bar) also allow closed loop operation with original or synthetic fluids and the possibility to inject additional chemicals e.g. scaling inhibitors etc. and material investigations in a small corrosion cell.

Many components in geothermal fluids are highly reactive and can cause serious damage to the plant materials. Exact knowledge on the behaviour of installed plant materials depending on fluid chemistry, as well as of the temperature, pressure and flow conditions is essential in order to prevent corrosion, reduce material costs and increase reliability of components. The effects of these parameters on suitable materials were investigated in the laboratory with artificial brines conditioned to the in-situ field parameters (Keserovic et al., 2015).

4.2 Development of small scale binary power plants

Besides the exploitation of high enthalpy geothermal fields, the development of low enthalpy resources is an important aspect to significantly increase the sustainable utilization of Indonesia's geothermal resources. With small scale geothermal binary power plants it is possible to use low enthalpy geothermal resources. Furthermore, binary power plants can be used as bottoming units for geothermal flash or dry steam power plants increasing the installed capacity.

Geothermal small scale energy provision in remote areas requires a holistic approach by addressing challenges in geothermal exploration, reservoir engineering, and power plant engineering. At many locations in Indonesia medium enthalpy / medium temperature resources can be found at depths of about several hundred meters, for example at 300-500 meters at Blok Langkoan, Lahendong geothermal field, North Sulawesi (Azimudin et al., 2001) or at about 600-800 meters at Atadei, East Nusa-Tenggara (Nanlohy et al., 2003), that could be utilized by means of flexible small scale binary power modules. Also power plant engineering and operation could be simplified significantly for such sites. Flexible plant sizes applicable at different geothermal sites can be realized based on modular setup and enable reliable operation and low maintenance. A 60 kWe prototype of such a versatile small scale binary unit has been developed in the project framework and presented at the WGC 2010 in Bali.

In addition to the development of standalone binary power plants for remote areas, a demonstration binary power plant as a bottoming unit of an existing power plant is subject of the collaboration with Indonesian partners at Lahendong, North Sulawesi. The installed capacity will be about 550 kWe and the auxiliary power consumption is estimated to be lower than 20% (Frick et al., 2015)

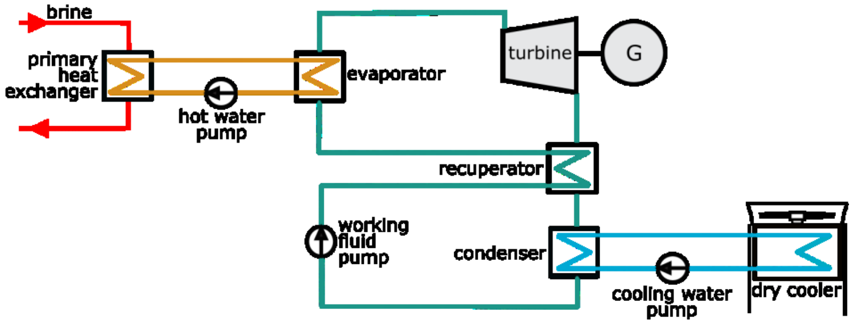

Figure 8: Technical concept of the demonstration power plant (from Frick et al., 2015)

The main components are subject to arrive in Indonesia in spring 2015. Commissioning is planned for autumn 2015 and the power plant will be handed over to Indonesia after an intensive training, optimization and research period in 2016.

5. CONCLUSION AND OUTLOOK

The Indonesian-German collaboration project on sustainable geothermal exploitation concepts with adapted methodological approaches for different sites and geological settings created an enormous bandwidth of distinct datasets. This results in better understanding of possibilities and limitations of the different methods as well as a better and sometimes new insight into the conceptual models of the geothermal sites investigated. Passive seismic networks that are deployed for a long time proofed to give excellent rock physical parameters and structural information in a very high resolution. In combination with quantitative structural geology and magnetoelluric investigations and an integrated interpretation approach, structure controlled geothermal systems can be better understood. Monitoring in and around exploited geothermal fields will give additional information for the processes in the reservoir involved during extraction and recharge. This understanding will support long-term sustainable operation.

The next step will be to determine the geothermal potential in selected (remote) areas with small-scale communities, the knowledge of technology to evaluate and to access the potential reservoir and to implement a sustainable thermal water loop. This could be the base for a large-scale deployment of small-scale power plants for remote areas. Networking with and involvement of additional international partners in the definition of future research tasks beyond this bilateral cooperation has already been started.

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