Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia

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This report was prepared by the Working Group for the 'Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia' under the Economic Research Institute for ASEAN and East Asia (ERIA) Energy Project. Members of the working group are from China, Indonesia, Japan, the Philippines, the Republic of Korea, Thailand, and Viet Nam. They discussed and agreed to approaches and the outcome of the study guidelines. These guidelines may differ from those normally used in each country.

Preface

The importance of geothermal energy is emphasised in the context of energy security and for global environmental issues since geothermal energy supplies stable electricity sources with low (almost no) carbon dioxide (CO_2) emissions.

Many Asian countries have been attempting the development of geothermal resources of their territories, although the types of geothermal resources vary from country to country. Countries with rich high temperature resources have been utilising their geothermal resources by conventional steam power generation. Even in countries without volcanoes, heat extraction from the deeper underground using enhanced/engineered geothermal system techniques and/or from shallow underground for direct use have been studied. However, geothermal utilisation in these countries has not been progressing mainly due to lack of information on the latest technology of development and sustainable use of geothermal resources.

The ERIA research project 'Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia' has started to develop guidelines for sustainable use of geothermal energy. To complete this mission, the working group of the Economic Research Institute for ASEAN and East Asia (ERIA) first analysed current geothermal use, technology, and management, and barriers and opportunities in each country. Then, based on the current status of technical barriers, the working group collected case studies concerning these problems with possible solutions. The guidelines have been developed based on compiled case studies from member countries.

Keiichi Sakaguchi

ERIA Working Group Leader

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Keiichi Sakaguchi

Working Group Leader

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List of Abbreviations

ADB	Asian Development Bank
ATES	Aquifer Thermal Energy Storage
BHE	Borehole Heat Exchanger
Cl	Chloride
COP	Coefficient of Performance
DU	Direct Use
EGS	enhanced (engineered) geothermal system
Fe	Ferrum (iron)
FiT	feed-in tariff
GHE	Ground Heat Exchanger
GIS	Geographic Information System
GL	Ground Level
GPP	Geothermal Power Plant
GSHP	ground source heat pump
K	Potassium
Mg	Magnesium
MR	Meteoric Recharge
msl	mean sea level
NCG	Non Condensable Gas
O	Oxygen
PG	power generation
pH	potential hydrogen (power of hydrogen)
PT	Pressure and Temperature
PTS	Pressure, Temperature, and Spinner
R&D	research and development
RHO	renewable heat obligation
RPS	renewable portfolio standards
TRT	Thermal Response Test

Measurements

GW_e	giga watt electric
K	Kelvin
kg/s	kilogram per second
kWh	kilowatt hour
MPa	mega pascal
MW_e	megawatt electric
MW_t	megawatt thermal
m/s	metre per second

toe	tonnes of oil equivalent
t/h	tonnes per hour
TWh	terawatt hour

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Executive Summary

Background, objectives, and scope

The importance of geothermal energy has been emphasised in the context of energy security and for global environmental issues since geothermal energy supplies stable heat and electricity sources with low, almost zero, carbon dioxide (CO_2) emissions.

Many eastern and south-eastern Asian countries have been attempting to deploy geothermal resources in their territories although the types of utilisation vary from country to country, from power generation to ground-source heat pump (GSHP), depending on the type of resources and energy needs. Countries with rich high-temperature resources have been utilising their geothermal resources for steam power generation. Other countries attempt to extract heat from deeper underground by enhanced/engineered geothermal system (EGS) technologies, or utilise shallow underground for conventional direct heat use or GSHP systems. However, geothermal deployment in these countries has not been progressing, largely due to lack of information on the latest technology of sustainable resource development.

The ERIA geothermal project 'Sustainability Assessment of Utilising Conventional and New-Type Geothermal Resources in East Asia' began in September 2013 to extract common and field-depending problems in terms of sustainability, finding solutions, and sharing information to improve technology for sustainable geothermal deployment in Asian countries. Geothermal experts from seven countries—China, Indonesia, Japan, the Republic of Korea (henceforth Korea), Philippines, Thailand, and Viet Nam—joined this project. At first, in order to extract common and individual problems related to maintaining sustainability of geothermal deployment, a census on the current status of geothermal deployment in member countries was made. It includes legal and political frameworks, technical and social barriers, among others. Then the most serious common technical barriers for sustainable use were extracted to intensively investigate finding solutions based on case studies. The final output of this study is a procedure guideline of sustainable development and utilisation of geothermal resources. This guideline should help engineers and managers who begin geothermal business. It may also be referred by related researchers. Beside the guideline, based on the result of the census on the current status, this report provides 'Recommendations to Policymakers' for more rapid, intensive, and appropriate use of geothermal energy.

Major findings

As results of the census on the current status (Chapters 2 to 4), recommendations to policymakers for more intensive utilisation of geothermal energy are provided as follows:

Energy policy

- National programmes and development plans should be provided explicitly for geothermal power generation.
- Long-term programmes for geothermal power generation are necessary because geothermal development takes five to seven years.
- All counties should issue CO_2 tax law for renewable energy (RE) development for the preservation of the environment.

Technology management

- Among geothermal power–generating countries, sharing production history and strategies for reservoir management and control of reinjection problems is recommended for sustainability of steam production.
- Anti-erosion, corrosion to acidic fluid, and mineral scaling are also common problems for reservoir management for sustainability of steam production. Collaborative research studies with steel companies and chemical companies for finding solutions for acidity, corrosion, and mineral scaling problem are recommended.
- Support from research institutions may be necessary for installation and sustainable use of GSHP systems to avoid overspecification, which can cause high installation cost, and underspecification, which can cause unsustainable use.

Technical barriers

- To promote geothermal power generation, governments should support research activities. International collaborative cooperation in research and development (R&D) on solving those problems above should also be supported.
- For direct use, governments should put incentives to use thermal use of geothermal energy (for example, in Korea, a renewable heat obligation [RHO] law is planned to be enacted in the near future).
- For promotion and sustainable use of GSHP, governments should support R&D on hydrogeological studies, case studies, and long-term monitoring. Also governments

should encourage international research collaboration on these topics.

Environmental constrains

- Enactment of laws inside national parks to isolate certain areas for geothermal development (energy zone) and to balance energy development with national forest conservation is recommended to keep the balance between geothermal development and environmental protection.
- All countries should issue CO_2 tax laws for promotion of RE development to preserve the global environment.

Social and political matters

- Governments should provide supportive systems for involvement of the local population in geothermal development projects.

Legal matters

- One-stop-shop type of legislation including environmental permission is desirable to promote geothermal utilisation.

Financial capacities

- Governments should subsidise the cost of exploration drilling and create laws for cost recovery of geothermal development to encourage private investment.
- Countries that do not have enough expertise, equipment, or personnel should be supported by countries with experts through bilateral agreements.
- Governments should support R&D through agencies, not by bank loans.
- For development, low interest loans from the Asian Development Bank, the Japan International Cooperation Agency, or the World Bank are available in most countries. Governments should promote these systems to local developers and/or investors.

Supportive measures

- Feed-in tariff (FiT) for geothermal power is recommended for countries where geothermal business has not matured.
- High credit in renewable portfolio standard (RPS) is recommended for geothermal power (cf. 10 percent in the Philippines).
- National programmes and development plans should be provided explicitly for geothermal power generation, with the provision of fiscal and non-fiscal incentives, such as tax exemptions, royalties, and subsidies (for example, in Korea, maximum 80 percent of GSHP installation cost for greenhouse; from local government, 30 percent; and central government, 50 percent).

- For risk management in the exploration stage, some government is desirable. Subsidies for exploration drilling (for example, in Japan, it is 50 percent) are recommended.
- Continuous R&D support from governments is important no matter how much geothermal power generation is materialised.
- As in Indonesia, governments should conduct basic resource surveys (for temperature distribution and geothermal model) based on geological, geochemical, and geophysical (3G) data.
- International cooperation is important not only from the R&D aspect but also for the business aspect.
- Only a few countries have national programmes for direct use and GSHP. National programmes for direct use and GSHP are recommended for ALL countries.
- RHO, like RPS for electricity, is recommended to promote renewable heat for district heating/cooling (for tropical countries).

Future concerns

- National programmes should be provided explicitly for geothermal power generation, direct use, and GSHP, with the provision of fiscal and non-fiscal incentives, for example, tax exemptions, royalties, and subsidies.
- It is important to enact laws inside national parks to isolate certain areas for geothermal development (energy zone) and to balance energy development with national forest conservation.
- Governments should support through agencies to reduce the long process of securing environmental permits for exploration.
- One-stop-shops for securing various permits and documentation for geothermal exploration and development are strongly recommended. (Not going to national and local, and environmental, and other government agencies).
- Small-scale geothermal development programmes for islands and remote rural areas (separated from the national grid) are recommended, with financial incentives and subsidies from government.
- International cooperation is recommended for the countries where geothermal power has not been intensively used and no technology developed.
- Geothermal laws should be provided explicitly for geothermal development, separate from mining laws or hot spring laws.
- Continuous R&D support from the government is important no matter how much geothermal power generation is materialised.
- Geothermal education courses should be provided at the university level.

- From a technological viewpoint, each country has different future concerns. Therefore, international collaboration not only in the Asian region but also through worldwide information channels should be provided in a practical manner, which is effective to increase human capacity.
- For countries with such specific problems, they should initiate collaborate research with countries having solutions to these problems.
- Geothermal education programmes and awareness of local people for public acceptance of geothermal development, emphasising advantage of geothermal power and heat is needed.

International cooperation

- Bilateral agreements between governments should be provided for countries without experience in geothermal installation such as Thailand and Viet Nam on pilot plant projects, identifying agencies to implement the project.

According to the results of the census on 'Technology and management of geothermal energy use' in Chapter 2, the highest technological interest related to sustainability of geothermal power generation and direct heat use are (in order of priority);

- monitoring and reservoir engineering,
- reinjection,
- anti-scaling, and
- anti-corrosion and anti-erosion.

For GSHP systems, no common interests on technology were found, but basic hydrogeological data collection and system monitoring were pointed out to be important for sustainable use.

Collection of case studies on these topics were conducted (Chapter 5) and guidelines for sustainable use of geothermal energy were made based on the compilation of these case studies (Chapters 6, 7). Case studies and guidelines were made separately for 'power generation and direct heat use' and GSHP since the necessary technologies are totally different for these two things.

Note that 'sustainability' in this report is mainly for the 'resource sustainability' and environmental sustainability is only partially discussed. Separate investigations are necessary to discuss environmental, economic, and/or social sustainability.

Although the solutions shown in the guideline may contribute to sustainable use of geothermal energy for some extent, continuous studies are needed for the future.

Recommendations to policymakers for more sustainable utilisation of geothermal energy are:

- For the present, the guidelines in this report (Chapter 7) should be distributed to geothermal developers, GHSP installation companies, and research institutes and be used as a result of review on the current best practices.
- Continuous study should be done for the sustainable use of geothermal energy in the future, especially for the topics listed above. Government support for such study is desired.

Chapter 1
Introduction

Many Asian countries have been attempting to develop the geothermal resources of their territories although types of geothermal resources vary from country to country. Countries with rich high-temperature resources have been utilising their geothermal resources by conventional steam power generation. Even in the countries without volcanoes, heat extraction from the deeper underground using enhanced/engineered geothermal system (EGS) techniques and/or from shallow underground for direct use has been studied. However, geothermal utilisation in these countries has not been progressing mainly due to the lack of information on the latest technology of development and sustainable use of geothermal resources.

Geothermal technologies, such as reservoir engineering, monitoring techniques, and scale-controlling techniques, which are all essential for sustainable utilisation of geothermal resources for both power generation and direct use, are worldwide common aspects.

This joint research project 'Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia' aims at extracting common and field depending aspects, finding common and/or individual solutions and sharing information to improve technology for sustainable geothermal utilisation in Asian countries. Geothermal experts from seven countries—China, Indonesia, Japan, the Republic of Korea (henceforth Korea), the Philippines, Thailand, and Viet Nam—joined this project. The final output of this study are a collection of case studies, and a guideline of sustainable development and utilisation of geothermal resources. Since the characteristics of geothermal systems are controlled by local geology and other environment factors, the case study collection will give a scope of the variation of geothermal systems to developing countries and governments. The manual or guideline will help governments in making recommendations or regulations for sustainable utilisation, which includes protection of the environment.

In the first year of the project (September 2013–June 2014), a review was made to extract common and individual problems related to maintaining sustainability in developed areas and installed systems for direct use of geothermal energy. Also, information on various techniques for resource/reservoir assessment, monitoring, scale-controlling, among others, was collected through a questionnaire to each member country. Chapters 2 to 4 provide the results of such review and information collection. Recommendations to policymakers for more intensive utilisation of geothermal energy are given in each section of this report.

In the second year of the project (September 2014–June 2015), based on the result of 'technology and management of geothermal energy use' in Chapter 2, several technical topics were selected to be common problems among member countries and thus investigated. Collection of case studies on these topics were conducted and guidelines for sustainable use of geothermal energy were made based on the compilation of these case studies. These results are shown in Chapters 5 to 7.

Chapter 2

Present Status

2.1. National Energy Policies

In this section, the current status of the national energy policy in each member country is introduced. A summary of the current status of energy policy will be given in tables and narrative descriptions at the end of this section.

China

The Law of Renewable Energies of China was issued in 2006. It shows the country support development and utilisation of renewable energies, including geothermal energy.

The Programming of Renewable Energies Development of China in the 12th 5-year Plan was issued in 2012. It arranged development targets of every type of renewable energy, including geothermal energy.

China's National Energy Administration, the Ministry of Finance, the Ministry of Land and Resources, and the Ministry of Housing and Urban-Rural Development jointly issued a document 'Guidelines on Promoting Geothermal Energy Development and Utilisation' in January 2013 (NEA, 2013). It defines the guiding thought for Chinese geothermal energy development and utilisation: (1) adjusting energy structure, (2) increasing renewable energy supply, (3) reducing greenhouse gas emissions, and (4) realising sustainable development. To meet the general requirement of technology advancement, environment friendliness, and economic feasibility, reasonable and effective utilisation of geothermal resources should be comprehensively promoted. The basic principles were government guidance, market pushing forward, adjusting measures to local conditions, and pluralistic development. The main target was determined, too. Towards the end of 12th 5-year plan in 2015, ground source heat pump (GSHP) application will reach 500 million square metres; installed capacity for geothermal power generation will reach 100 megawatt electric (MW_e); and total used geothermal energy will be equivalent to 20 million tonnes standard coal. Meanwhile, the guidelines give some preferential policies, including subsidy for geothermal electricity to enter the national grid. Under the policy, the Ministry of Land and Resources increased funds exploration of geothermal resources. The policy also attracted both state-operated and private enterprises to invest in geothermal business.

On the other hand, the rapid growth of the gross domestic product (GDP), together with high consumption of coal and cars, has led to China's environmental damage. After the heavy haze in 2013, the State Council issued the Action Plan of Air Pollution Prevention. Then Beijing issued the Beijing Action Plan of Clean Air 2013–2017, which stipulated a strategy of 'creating a clean energy system with mainly electricity and natural gas with assisted geothermal and solar energies'. The actual implementation for geothermal space heating replacing conventional boiler heating will get 50 percent of the investment allowance.

In addition, the Law of Tax of Environmental Protection of the People's Republic China will be implemented in 2106. Its exposure draft was issued in June 2015. However, carbon trade has been experimentally implemented in seven cities and provinces (Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Guangdong, and Hubei) since November 2013. The price was CNY10 per tonne at the beginning and would be CNY100 per tonne for target. The present price in Beijing is about CNY40–50 per tonne.

In the face of new changes to energy supply and demand pattern, and new trends of international energy development, in order to safeguard national energy security, the China's President emphasised the need to promote an energy revolution of consumption, supply, technology, and systems. Its purpose is to devote changing the traditional coal dominant energy structure, and turn to multiple energies supply mode. It provides greater opportunity for geothermal and other renewable energies. At present, the National 13th Five-Year Plan (2016–2020) of Energy Development is formulated according to this principle.

Indonesia

The Government of Indonesia issued the new Nation Energy Policy by promulgating Government Regulation No. 74 of 2014 in October 2014, to replace the previous Government Regulation No. 5 of 2006. The policy provides guidance for energy management in order to achieve national self-sufficiency and security on energy. In the national policy, the government projected the primary energy sources from new and renewable to be about 23 percent of total national in 2025, and 31 percent in 2050. The government has set the electricity generation of 115 GW_e (gigawatt, electric) in 2025 and 430 GW_e in 2050.

The Ministry of Energy and Mineral Resources, in January 2015, released a decree concerning the agreement on Planning of Electricity Generation of the State-Owned Electricity Enterprise for 2015 to 2024, including a short-term project in 2015–2019 of an additional 35 GW_e, where geothermal energy is set to contribute.

The government also issued a new Geothermal Law No. 21 of Year 2014 in September 2014 to replace the previous Geothermal Law No. 27 of Year 2003. The ratification of the law is to provide a stronger, comprehensive, and transparent legal basis in geothermal development. Based on the new law, the government is now formulating appropriate measures and/or regulations as a basis for implementing geothermal businesses, and these are to be established by the end of 2015. The feed-in tariff (FiT) system for geothermal energy is one of the issues to be formulated, to revise the previous and ineffective FiT.

Japan

The Government of Japan settled the Energy and Environment Convention in June 2011. An agreement on Innovative Energy and Environment Strategy was made in September 2011 in the convention, indicating the renewable energy target in 2030 of 30 percent of total power generation. In the process towards the agreement, dependence on nuclear power was discussed along three scenarios, where the zero-dependence scenario received 50 percent or more support in public comments from citizens.

Along with the Implementation of the Green Energy Revolution, which was declared in the Innovative Energy and Environment Strategy, the Principle Outline Plan on Green Policy was publicised in November 2012. Its basic direction is the restraint of dependence on nuclear and fossil fuels, guarantee of energy security, and adaptation of requirements towards environment-friendly systems.

The present electricity supply system in Japan is one obstacle against the promotion of renewable energy. To investigate problems of the current electricity supply system, a Specialised Committee for Electricity System Renovation was set up to discuss the separation of electric power generation and distribution.

The implementation of a FiT system for renewable electricity was agreed in Parliament in August 2011 and enacted in July 2012. Prices for geothermal power are ¥42/kWh (kilowatt-hour) for plants smaller than 15MW_e and ¥27.5/kWh for 15MW_e or larger (¥1 is nearly equal to 1 US cent). A CO_2 tax for climate change mitigation has not been adopted yet in Japan.

Geothermal energy is explicitly promoted as evidenced by FiT and other economic support provided by the Ministry of Economy, Trade, and Industry. According to the national energy plan, a goal of geothermal power capacity is 1,650 MW_e in 2030.

To promote renewable heat, a Support Programme for Accelerating Introduction of New Energy began in 2012 to give subsidies to municipals and the private sector for installation of renewable energy systems. Only a few ground coupled heat pump systems were accepted to be subsidised.

Republic of Korea

Geothermal utilisation in the Republic of Korea (henceforth, Korea) has been directly use, especially with GSHP installation, because there are no high temperature resources associated with active volcanoes or tectonic activity. GSHP installation in Korea has increased rapidly since the middle of the 2000s and total installed capacity is estimated to reach almost 800 MW_t at the end of 2014. This successful deployment has made the general public and people in the energy sector aware of what geothermal energy is, especially its nature of base-load electricity source. Information on recent stories of low temperature power generation, including enhanced geothermal systems (EGS) in Europe, Australia, and the United States (US) have caused decision-makers and industries in Korea to become interested in geothermal power generation, which led to the launch of the EGS pilot plant project at the end of 2010.

The Second National Energy Master Plan was set up in 2013 and was officially announced at the beginning of 2014. The six major tasks in this master plan are (1) transition to energy policy focused on demand management, (2) build a distributed generation system, (3) strike a balance with environmental and safety concerns, (4) enhance energy security and energy supply stability, (5) establish a stable supply system for each energy source, and (6) shape energy policy to reflect public opinion. The national plan for renewable energy was also revised in 2014 according to the master plan which led to the setting up of The 4th Basic Plan for New and Renewable Energy Technology Development, Utilisation, and Diffusion (2014–2035), and thus to fix new renewable energy R&D (research and development) and deployment policy. The new and renewable energy supply target by 2035 is 11 percent of the total primary energy consumption.

The total primary energy consumption at the end of 2013 reached around 280.29 million tonnes of oil equivalent (toe) of which renewable energy supplied 9.879 toe (3.521 percent). Geothermal energy by GSHP provided 53,995 toe which covered only 0.019 percent of the total primary energy consumption. The status and prospect of geothermal energy in the national target still does not seem significant. Fortunately, however, the government and the public acknowledge the importance of geothermal utilisation and the geothermal energy's share of market-stimulating incentives has become significant. Therefore, GSHP installation has progressed remarkably in recent years.

The main drivers of the rapid increase in GSHP installation are active government subsidy programmes and a special law for new and renewable energy (Mandatory Act). There are several subsidy programmes—Deployment Subsidy Programme, Rural Deployment Programme, and 1 Million Green Homes by 2020 Programme—through which the government subsidises 50 percent of total installation cost based on competition with a predetermined budget each year. Another powerful subsidy programme enacted from 2010 is the Greenhouse Deployment Programme for which the central government subsidises 50–60 percent and local government covers 20–30 percent, which means rural farmers pay only 20 percent of GSHP installation cost for greenhouses and aquaculture. The annual market from this special programme amounted to US$45.2 million in 2012.

In 2012, the Mandatory Public Renewable Energy Use Act was amended to state that: 'In all public buildings bigger than 1,000 square metres in area, more than 10 percent of annual energy use should be from new and renewable energy sources'. The minimum percentage is to increase annually: 11 percent in 2013, 12 percent in 2014, and so on. According to the Act, GSHP installation plans amounting to 120 megawatt thermal (MW_t) in 2012 and 135 MW_t in 2013 were reported, which would be realised two or three years after planning due to the construction period.

Although the pilot plant project of geothermal power generation started at the end of 2010 and targets 1 MW_e plants by the end of 2015, there has been no legal framework or supportive measures for geothermal power generation yet. This lack of a legal framework is the major barrier to active industry participation in the geothermal business. The government annually adjusts items in Renewable Portfolio Standard (RPS) and the Renewable Energy Certificate (REC) of each renewable energy source. Geothermal power generation was included in RPS with REC of 2.0 (highest) in 2014. Geothermal law is also expected to be set up as a part of the mining law in the near future.

A technical road map of greenhouse gas reduction technology in Korea states that there could be 200 MW_e of installed capacity with geothermal by 2030 in Korea, which is 1 percent of the technical potential of EGS geothermal power generation in the country. The outcome of the EGS pilot plant project, if successful, will be a milestone initialising the road map. This pilot plant project is expected to be scaled up to a level of 10 MW_e class by 2020.

Philippines

The thrust of the national energy programme laid out for 2013–2030 will focus on the following plans and programmes:

- Develop indigenous energy
- Expand use of natural gas
- Push sustainable fuels for transport
- Make energy efficiency a way of life
- Expand capacity and coverage of power supply
- Climate-proof energy infrastructure and facilities

At the onset of the new Aquino government in 2010, the energy sector has outlined the following three major pillars as its overall guidepost and direction: (1) ensure energy security, (2) achieve optimal energy pricing, and (3) develop a sustainable energy plan. Guided by the overall vision of providing Energy Access for More, the 2012–2030 Philippine Energy Plan (PEP) seeks to mainstream access of the larger populace to reliable and affordable energy services to fuel, most importantly, local productivity and countryside development. This energy plan is guided by President Aquino's social contract with the Filipinos, which aims to (1) alleviate corruption and promote transparency through energy contracting rounds, information, education, and communication (IEC), and public consultation activities; (2) reduce poverty by empowering the poor through electrification of rural areas; and (3) rapid, inclusive economic growth. Meanwhile, the United Nations Sustainable Energy For All Initiative Development aims for the country's transition towards to a low carbon society. PEP will also support and be at par with the ASEAN Plan of Action for Energy Cooperation, which will promote regional energy security and sustainability through aggressive implementation of action plans of the different programme components: (1) ASEAN Power Grid, (2) Trans-ASEAN Gas Pipeline, (3) Coal and Clean Coal Technology, (4) Renewable Energy, (5) Energy Efficiency and Conservation, (6) Regional Energy Policy and Planning, and (7) Civilian Nuclear Energy. The plan will also adhere to the APEC Green Growth Goals which include: (1) rationalisation and/or phase out of inefficient fossil-fuel subsidies that encourage wasteful consumption; (2) reduction of aggregate (regional) energy intensity by 25 percent in 2030 and 45 percent in 2035 (based on 2005 level) as an aspirational goal; (3) promote energy efficiency; and (4) incorporate low-emissions development strategies to economic development plans, among others.

Under the PEP are sets of specific work programmes that should contribute to the attainment of the broad policy and programme network. The Power Sector Development plans on power systems, transmission highways, distribution facilities, and missionary electrification provide the platform to put in place long-term reliable power supply to improve the country's transmission and distribution system. The Fuelling Sustainable Transport Program aims to find alternative ways to fuel the transportation sector. Specifically, this seeks to convert public and private vehicles from diesel and gasoline into compressed natural gas (CNG), liquefied petroleum gas (LPG), and electric power. More so, the Indigenous Energy Development Program plans to diversify the energy mix fuelling the Philippines by further developing the country's indigenous resources. Meanwhile, the National Renewable Energy Plan foresees the increase in renewable energy-based capacity by 2030. The Energy Efficiency and Conservation Program will look into developing energy security in the country. This aims to lay the foundation for legislation and policies to develop local energy auditors and energy managers, encourage the development of energy efficient technologies, and provide incentives for the effective promotion of efficiency initiatives in the energy market sector. The last of the major work plans included in the Philippine Energy Plan is the Natural Gas Master Plan. With technical assistance from the Japan International Cooperation Agency, and the World Bank, the Department of Energy will evaluate the opportunities, critical infrastructure, and required investments for the development of the natural gas industry.

The Philippine Energy Sector Reforms and Programs for 2013–2030 plans to improve the indigenous options of the country by promoting more aggressive exploration of fossil fuels and development of indigenous oil and gas. Currently, the country's 16 sedimentary basins have a combined potential of 4,777 million barrels of fuel equivalent or 689.8 million tonnes of energy of oil and gas reserves. Meanwhile, the National Renewable Energy Plans and Programs aim to increase the renewable energy-based power capacity of the country to 15,304 MW_e by 2030, which is almost triple its 2010 capacity level of 5,438 MW_e. Geothermal energy is often mentioned together with other sectors under renewable energy (**Table 2.1-1**). For geothermal alone, there is a projected addition of 1,495 MW_e of installed capacity by year 2030, and this will bring the total power capacity from geothermal at close to 3,500 MW_e. Adding up the contribution of the other renewable energy sources from hydro, biomass, wind, solar and ocean, the national programme aims to increase renewable energy based power capacity to 15,300 MW_e by 2030.

Currently, there is no carbon emission tax charged to renewable energy sources, but it is targeted to be issued in 2015 in line with the establishment of the ASEAN Economic Community. It must be noted that the proposed carbon emission tax is only applicable to the oil and gas industry. It is valued at US$20 per tonne of CO_2 emissions with 10 percent efficiency gain for use of oil and coal in the country.

Table 2.1-1. Estimated Capacity Addition of 9,865 MW in the Philippines

Sector	Installed Capacity, (MW) as of 2010	Target Capacity Addition by				Total Capacity Addition (MW) 2011-2030	Total Installed Capacity by 2030
		2015	2020	2025	2030		
Geothermal	1,966.0	220.0	1,100.0	95.0	80.0	1,495.0	3,461.0
Hydro	3,400.0	341.3	3,161.0	1,891.8	0.0	5,394.1	8,724.1
Biomass	39.0	276.7	0.0	0.0	0.0	276.7	315.7
Wind	33.0	1,048.0	855.0	442.0	0.0	2,345.0	2,378.0
Solar	1.0	269.0	5.0	5.0	5.0	284.0'	285.0
Ocean	0.0	0.0	35.5	35.0	0.0	70.5	70.5
TOTAL	5,438.0	2,155.0	5,156.5	2,468.8	85.0	9,865.3	15,304.3

MW = megawatt.
Source: Department of Energy (DOE) (2011).

Thailand

The Thailand Energy Master Plan 2015–2035, emphasising energy security, social acceptance, and environment-friendliness (EPPO, 2014) is summarised below.

1. Promote energy, petroleum, and renewable energy industries as a new industry strategy and enable these industries to generate income from domestic demand and increase employment.
2. Promote and drive the energy sector to generate income for the country. As a strategic industry, investment in energy infrastructure will be increased to make Thailand a regional centre for the energy business, building upon the competitiveness of its strategic location.
3. Reinforce energy security through the development of the electrical power grid and exploration of new and existing energy sources, both in Thailand and abroad. Energy sources and types will also be diversified so that Thailand will be able to meet its energy needs from various sustainable energy sources.
4. Regulate energy prices to ensure fairness as well as reflect the production costs by adjusting the role of the oil fund into a fund that ensures price stability. Subsidies will be available for vulnerable groups. The use of natural gas in the transport sector will also be promoted, whereas the use of gasohol and biodiesel will be promoted for use in the household sector.
5. Support the production, use, and research and development of renewable and alternative energy sources, with the objective of replacing 25 percent of the energy generated by fossil fuels within the next decade. Comprehensive development of the energy industry will also be promoted.
6. Promote and drive energy conservation by reducing power usage in the production process by 25 percent in the next two decades. The use of energy

efficient equipment and buildings will be promoted, while clean development mechanisms will be used to reduce the emission of greenhouse gases and tackle global climate change. Systematically raise consumer awareness to use energy efficiently to conserve power in the production and transport sectors, as well as in households.

The Department of Alternative Energy Development and Efficiency (DEDE) targets to produce 1 MW_e electricity from geothermal in accordance with the 10-year Renewable and Alternative Energy Development Plan. The development of geothermal energy will emphasise joint investment between the community and the private sector to promote sustainable development and participation of local residents. It will also study renewable energy promotion measures to ensure small power producers of stable revenue streams and success of the project.

Viet Nam

Viet Nam's latest energy master plan named Energy Master Plan No. 7 for 2011–2020 considering to the period up to 2030. This master plan emphasises gradually forming and developing the competitive electricity market, and diversifying the patterns of investment and business on electricity. The government exclusively manages the national electricity networks. The sale out price of electricity follows the free markets. The national electricity production that will be produced and imported is 194 billion–210 billion kWh in 2015, 330 billion–362 billion kWh in 2020, and 659 billion–834 billion kWh in 2030.

One of the targets of the master plan is to prioritise the development of renewable energy sources, develop these rapidly, and increase the proportion of electricity from the renewable sources gradually. The proportion of renewable energy that is 3.5 percent of the total in 2010 would be 4.5 percent in 2020 and 6 percent in 2030.

According to the Energy Master Plan No. 7 of Viet Nam, the government will invest to construct the national electric network or to construct the in situ electric power plants such as small hydroelectric power plants, solar cells, wind power, and diesel engines to supply electricity to the rural areas. In 2011–2015, the Government invested to expand the national electric network to supply 500,000 households in rural areas; the electricity generated from renewable energy sources would supply 377,000 households in rural areas. In 2016–2020, 200,000 households in rural areas would be supplied electricity from the national network whereas 231,000 households in rural areas would be supplied from renewable energy sources.

The current status of all member countries is summarised in **Tables 2.1-2** to **2.1-5**, based on the answers to the questionnaire given to each member country. Questions on current status are as follows:

- What is the national energy master plan in your country?
- Is CO_2 tax already issued?
- Is there priority to indigenous and renewable options?
- Is geothermal energy explicitly mentioned?

Table 2.1-2. National Energy Master Plan

Country	What is the national energy master plan in your country?
China	12th Five-Year-Plan of Energy Development of the People's Republic of China
Indonesia	Master plans for 2006–2005: Presidential Decree No. 5 Year 2006 concerning National Energy Policy. Followed by blueprint on National Energy Management issued by Ministry of Energy and Mineral Resources (MEMR)
Japan	Energy plan: 1, 650 MW_e of geothermal power plant in 2030 in 'Law on promotion of development and production of energy-environment suitable goods'
Republic of Korea	The Second National Energy Master Plan (2014): 11% of primary energy supply with renewables by 2035
Philippines	2012–2030 Philippine Energy Plan: (a) Ensure energy security, (b) Achieve optimal energy pricing, (c) Develop a sustainable energy plan
Thailand	Government promoted renewable energy as a national master plan
Viet Nam	Energy Master Plan No. 7 – prioritise the development of renewable energy sources

MW_e = megawatt electric.
Source: Compiled by authors.

Table 2.1-3. CO_2 Tax

Country	Is CO_2 tax already issued?
China	Law of Tax of Environmental Protection of PRC (Exposure Draft) was issued in June 2015. But CO_2 trade had been experimentally implemented in 7 cities and provinces since November 2013, with price of CNY20–50 per tonne recently.
Indonesia	No CO_2 tax issued yet
Japan	No CO_2 tax issued yet
Republic of Korea	No CO_2 tax issued yet
Philippines	No CO_2 tax implemented yet, but is targeted to be issued in 2015
Thailand	No CO_2 tax issued yet
Viet Nam	No CO_2 tax issued yet

Source: Compiled by authors.

Table 2.1-4. Priority to Indigenous and Renewable Options

	Priority to indigenous and renewable options?
China	Indigenous resources with coal in the near future. Proposed 'roof limitation for fossil fuel' is to be installed.
Indonesia	RE sources are set to contribute ~17 percent of national energy mix in 2025.
Japan	Yes, country gives priority to indigenous and renewable options.
Republic of Korea	RE is supported through RPS and various subsidy measures.
Philippines	Yes. The National Renewable Energy Plans and Programs (PESRP) plans to improve indigenous options of the country. National Renewable Energy Program (NREPP) aims to increase RE-based power capacity to 15,304 MW by 2030.
Thailand	Priority to indigenous and renewable options, especially to solar and wind energies.
Viet Nam	EMP No. 7 - invest to construct the national electric network, to construct in-situ electric power plants (small hydro-electric, solar cells, wind power, and diesel engine to supply electricity for the rural areas).

MW = megawatt, RE = renewable energy, RPS = renewable portfolio standard.
Source: Compiled by authors.

Table 2.1-5. Status of Geothermal Energy

	Is geothermal energy (GE) explicitly mentioned?
China	GE is mentioned as one of renewable energies in the Law of Renewable Energy of the PRC.
Indonesia	GE is mentioned as one of renewables.
Japan	GE is explicitly promoted as evidenced by FiT and other economic support provided by Ministry of Economy, Trade, and Industry.
Republic of Korea	GE is mentioned as one type of renewable energy.
Philippines	GE is mentioned as one of the renewables.
Thailand	One of energy.
Viet Nam	GE is mentioned as one type of renewable energy.

FiT = feed-in tariff, GE =geothermal energy.
Source: Compiled by authors.

Summary of the current status of energy policy

- All seven governments have a national energy programme.
- All seven countries have priority to indigenous and renewable options in their national energy programmes.
- In most countries, geothermal energy is one of the renewable energies.

Recommendation to policymakers

- National programmes should be provided **explicitly** for geothermal power generation since geothermal energy may need special care because of its uncertainty in the subsurface.
- The Philippines and Japan have national energy master plans towards year 2030, and Korea to 2035, but other countries have shorter plans. **Long-term programmes** for geothermal power generation is necessary because geothermal development takes 5–7 years.
- CO_2 tax law will be implemented in China and is forthcoming for the Philippines in 2015. All counties should issue CO_2 tax law for RE development to preserve the environment.

2.2. Present Status of Geothermal Use

The present status of geothermal use in each country is shown in **Table 2.2-1**. All seven countries use geothermal energy. PG, DU, and GSHP stand for power generation, direct use, and ground source heat pump, respectively. Power generation is dominant in the Philippines and Indonesia, whereas direct use and GSHP are dominant in China and Korea, reflecting resource base and climate. Japan has all power generation, direct use, and GSHP, but direct use is almost for bathing only. Thailand has a binary power plant and Viet Nam has direct use facilities.

Table 2.2-1. Present Status of Geothermal Use in Each Country

Country	Installed Capacity			Used (produced) Energy			Data Source
	PG (MW_e)	**DU** (MW_t)	**GSHP** (MW_t)	**PG** (GW_e-h/y)	**DU** (GW_t-h/y)	**GSHP** (GW_t-h/y)	
China	27.8	6,089	11,781	155.1	20,801	27,864	Zheng et al. (2015)
Indonesia	1,341.0	2.3	NA	9,332.32	11.8 *	NA	MEMR (2013a), Lund et al. (2010)
Japan	540.1	2,099.5	44.0	2,688.82	7138.9	NA	TNPES (2013), Lund et al. (2010)
Republic of Korea	NA	43.7	792.2	NA	164.9	580.7	Song and Lee (2015)*
Philippines	1,848.0	NA	NA	10,230.5	NA	NA	Department of Energy (2014)
Thailand	0.3	NA	NA	NA	NA	NA	DEDE (2012)
Viet Nam	0.0	30.7	NA	NA	22.36	NA	Nguyen et al. (2005)

DU = direct use, GSHP = ground source heat pump, NA = not available, PG = power generation.
Notes: *For Korea, data are estimated as of 31 December 2014; used energy of GSHP corresponds to the pure geothermal contribution (subtracting electrical energy for running the HP) of heating energy only.
Source: Compiled by authors.

2.3. Potential Survey

All seven countries have an existing geothermal energy resource assessment. A volumetric method was used for most countries, but with different bases. Since resource assessment is not a purpose of this study, we will not inspect details of these different volumetric methods, but resources assessment method should be standardised internationally. There are ongoing assessment programmes of geothermal resources and reserves under the International Energy Agency – Geothermal Implementing Agreement (IEA-GIA) and the International Geothermal Association.

Tables 2.3-1 to **2.3-7** show numerical values of geothermal energy potential and assessment methods for each country.

Table 2.3-1. Geothermal Potential of China

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	>150°C	200–3,000	2,781(MWe)	Duo (2014)
	b) EGS	>150°C	3000–8000	12.6×10^4 (EJ)	Wang et al. (2013)
ii) Direct use		>25°C	200–3,000	18×10^6 (TJ)	Wang et al. (2013)
Method of assessment	Volumetric method (National Standard of China, 2010)				

Source: Compiled by authors.

Table 2.3-2. Geothermal Potential of Indonesia

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	High: >225 Med: 125–225 Low: <125	1000–3000	28,910 (MWe)	Ministry of Energy and Mineral Resources (2013b)
	b) EGS	–	–	–	
ii) Direct use		NA	NA	NA	
Method of resource assessment	Based on Indonesia National Standard (SNI 13-5012-1998): Geothermal potential is divided into two groups: resource and reserve. The resource is divided into two classes: speculative and hypothetic. The reserve is classified into three groups: possible, probable, and proven. Resource assessment is based on Indonesia National Standard (SNI 13-6171-1999 and SNI 13-6482-2000): The speculative resources estimated by using power density of the prospective area. The power density is estimated as 5, 10, and 15 MW_e/(km^2 of the area) for low, medium, and high temperatures, respectively. The hypothetic and reserve are estimated by using a volumetric method. Geothermal physical parameter value for potential estimation of the reserve is assumed based on three temperature regimes: high (>225°C, medium (125–225), and low (<125) by assuming uniform/lumped heat content of reservoir. The reserves are calculated by using reservoir thickness between 10002000 m, 100% water saturated, rock porosity of 10%, heat capacity of rock 0.8–1.0 kJ/kg°C, plant life 30 years, thermal to electric conversion 10%. The cut-off temperatures are 90, 120, 180°C for low, medium, and high temperatures, respectively. These calculations are simulated by a statistical approach of Monte Carlo.				

Source: Compiled by authors.

Table 2.3-3. Geothermal Potential of Japan

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	150 <	3 km *	23,000 (MWe)	Muraoka et al. (2008)
	b) EGS	NA	5 km	450,000 (MWe) All Japan 45,000 (MWe) Surveyed areas	Hori (1990)
ii) Direct use convention GSHP		No data 10–25°C	No data 20–100 m	No data	
Method of resource assessment	i)-a) by volume method for the resources lying shallower than the depth of basement rock. NEDO's priority areas, for which resource assessment including economic analysis has been done, have 950 MWe of resources (reserve). i)-b) is based on resources analysis for HDR by CRIEPI. ii) GSHP may be used everywhere in Japan and resource assessment has not been done. However, according to the borehole heat exchange analysis based on groundwater flow and heat transfer simulation, heat extraction rate in quaternary sediment varies from 30 to 70 W/m due to groundwater speed, showing wide spatial variation.				

Source: Compiled by authors.

Table 2.3-4. Geothermal Potential of the Republic of Korea

Category		Temperature range (°C)	Depth Range (m)	Geothermal Potential	Source reference
i) Power production	a) Hydrothermal				
	b) EGS	> T_0+80, T_0 is surface temperature	3,000–10,000 for theoretical, 3,000–6,500 for technical	6,974,567 (MWe) for theoretical 19,567 (MWe) for technical	Song et al. (2011)
ii) Direct use		NA	NA	NA	
Method of assessment	Beardsmore et al. (2010) based on volumetric method				

Source: Compiled by authors.

Table 2.3-5. Geothermal Potential of the Philippines

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	>180	1,500–3,000	3,337 (MWe)	Pastor et al. (2010)
	b) EGS	NA	NA	NA	
ii) Direct use		NA	NA	NA	
Method of assessment	Volumetric reserve estimation using Australian code and minimum temperature of 180 °C.				

Source: Compiled by authors.

Table 2.3-6. Geothermal Potential of Thailand

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	130	100–500	0.3 (MWe)	Korjedee (2002)
	b) EGS	NA	NA	NA	
ii) Direct use		NA	NA	NA	
Method of assessment	No official assessment yet.				

Source: Compiled by authors.

Table 2.3-7. Geothermal Potential of Viet Nam

Category		Temperature Range (°C)	Depth Range (m)	Geothermal Potential	Source Reference
i) Power production	a) Hydrothermal	100–185	210–1000	400 (MWe) [2]	Hoang (1998)
	b) EGS	NA	NA	NA	
ii) Direct use		30–105	0–210	NA	2005
Method of resource assessment	The volume methods were used for thermal capacity basing on the surface temperatures and the flow rates of the hot springs. The predicted capacity of electric generation was assessed basing on a comparison with the capacity of existing geothermal plants in Nevada, United States of America, including Brady, Soda Lake, Steamboat, Stillwater, and San Emidio. Volume method using heat content between surface to 3 km depth using geothermal gradient map and heat capacity of rocks is just generally used in some geothermal resources in Viet Nam.				

Source: Compiled by authors.

2.4. Development Trends of Geothermal Energy Use

Table 2.4-1 shows development trends of geothermal energy use in each country. All seven countries target capacity addition within 5 years. However, the significance of the development plan differs from country to another country.

Table 2.4-1. Development Trends of Geothermal Energy Use in Each Country

Country	Target Capacity Addition			
	Power generation	**Direct use**	**GSHP**	**Date**
China	100 MW_e (National plan)	3,700 MW_t (National plan)	18,200 MW_t (for residential, office buildings, school, hospital, mall, etc.) (National plan)	by 2019
Indonesia	1,160 MW_e (National plan)	NA	NA	by 2019
Japan	Several small binary (50 kW_e–1 MW_e) and a 40 MW_e (by private sector with government's support)	No specific plan	GSHP at 990 units (2011) to increase for next 5 years (Estimation by related organisation)	by 2019
Korea, Republic of	Pilot plant, EGS technology (1-3 MW_e) (Estimation by institute)	No significant development	>100 MW_t new installations each year (for large office buildings, green-house, small residential houses) (Estimation by related organisation)	by 2019
Philippines	1,465 MW_e (Fronda et al., 2015) (National plan)	NA	NA	by 2030
Thailand	at least 5 MW_e (Estimation by institute)	Spa, drying system would be supported by hot springs	No application	by 2019
Viet Nam	20 MW_e (estimation by institute)	Agricultural drying, industrial process heat, bathing, swimming	Projects to find out potential and application for office buildings and residential houses	by 2019

kW = kilowatt, MWe = megawatt electric, MWt = megawatt thermal, NA = not available.
Source: Compiled by authors.

Some countries include geothermal development in national plans whereas only the private sector or institutes have plans in other countries. National plans on geothermal development may help its promotion since countries where geothermal development is advancing, such as the Philippines and Indonesia, have national plans.

Only China has a clear plan for all power production, direct use, and GSHP. No other countries have plans for direct use, whereas all countries show targets for power production. Long-term programmes for geothermal power generation are necessary because geothermal development takes five to seven years. China, Japan, and Korea, which have cold seasons, have targets for GSHP.

Recommendations to policymakers

- National development plans should be provided explicitly for geothermal power generation, in conjunction with the national programmes on fiscal and non-fiscal incentives, for example, tax exemptions, royalties, and subsidies.

2.5. Technology and Management of Geothermal Energy Use

Table 2.5-1 shows the topics of interest for sustainable use of geothermal energy pointed out by each country. These topics are listed in the order of priority (based from China, Indonesia, the Philippines, and Japan):

1. Monitoring and reservoir engineering
2. Reinjection
3. Anti-scaling
4. Anti-corrosion and anti-erosion

In Korea, the sustainable issue of geothermal power generation is not of common interest yet. They focus on sustainability of GSHP, among others. Thailand and Viet Nam have yet to develop a binary system for sustainable use of geothermal energy. The study of the second year of this project was decided based on this result.

Table 2.5-1. Topics of Interest for Sustainable Use of Geothermal Energy (marked boxes indicate higher priority for each country)

<table>
<tr><th>Country</th><th>a) Reinjection</th><th>b) Monitoring and Reservoir Engineering</th><th>c) Anti-corrosion and Anti-erosion</th><th>d) Anti-scaling</th><th>e) Others</th></tr>
<tr><td rowspan="3">China</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">a) In key cities of geothermal utilisation, the Geothermal Resources Administration stipulates that geothermal district heating has to install reinjection.</td></tr>
<tr><td colspan="5">b) Geothermal monitoring is popularly carried out in key cities and developing areas.</td></tr>
<tr><td>Indonesia</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Japan</td><td>X</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>Republic of Korea</td><td colspan="4">e) Sustainability issue of geothermal energy is not of common interest yet because no systematic deep geothermal utilisation is operating now. There are concerns about sustainability of GSHP system, especially on water level change and subsurface temperature sustainability.</td><td>X</td></tr>
<tr><td>Philippines</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td>Thailand</td><td colspan="4">e) To develop a binary system</td><td>X</td></tr>
<tr><td>Viet Nam</td><td colspan="4">e) To develop a binary system</td><td>X</td></tr>
</table>

GHSP = ground source heat pump.
Source: Compiled by authors.

Recommendations to policymakers

Power generation

- For geothermal power generating countries, changes in reservoir characteristics and reservoir engineering properties including injection issue is a common technology problem for reservoir management for sustainability of steam production.
  - Sharing production history and strategies for reservoir management and control of reinjection problems among power generating countries is recommended.
- Anti-erosion, corrosion to acidic fluid, and mineral scaling are also common problems for reservoir management to sustain steam production.

- Collaborative research studies with steel companies and chemical companies for finding solutions for acidity, corrosion, and mineral scaling problem are recommended.

Ground source heat pump

- Support from research institutions may be necessary for decent installation and sustainable use of GSHP system to avoid over specification, which causes high installation cost, and under specification, which causes un-sustainable use.

References

Department of Alternative Energy Development and Efficiency (DEDE) (2012), *The Renewable and Alternative Energy Development Plan for 25 Percent in 10 Years (AEDP 2012–2021),* Department of Alternative Energy Development and Efficiency.

Department of Energy (DOE) (2011), 'The National Renewable Energy Plans and Programs,' The 2012–2030 Philippine Energy Plan.

Department of Energy (DOE) (2014): *Indicative Geothermal Capacity Additions. Energy Resources*. Available at: https://www.doe.gov.ph/doe_files/pdf/04_Energy_Resources/Stat-GeoAddition.pdf

Energy Policy & Planning Office (EPPO) (2014), 'The Thailand Energy Master Plan 2015–2035'.

Fronda, A., M. Marasigan, and V. Lazaro (2015), 'Geothermal Development in the Philippines: Country Update', *Proceedings of the World Geothermal Congress 2015.*

Hoang, H.Q. (1998), 'Overview of Geothermal Potential of Vietnam', *Geothermics,* 27(1), pp.109–115.

Hori, N. (1990), 'Cost Evaluation and Technology Development of Large Scale HDR', *Chinetsu,* 27, pp.148–158 (in Japanese).

Korjedee, T. (2002), Geothermal Exploration and Development in Thailand, Geothermal and Volcanological Research Report of Kyushu University, No. 11, 56–66.

Lund, J.W., D.H. Freeston, and T.L. Boyd (2010), 'Direct Utilization of Geothermal Energy 2010 Worldwide Review', *Proceedings of the World Geothermal Congress 2010.*

Minister of Energy and Mineral Resources (MEMR) (2013a), Decree No. 2 Year 2010, revised by No. 15 Year 2010, revised by No. 1 Year 2012, revised by No. 21 Year 2013 concerning acceleration on electricity development using geothermal.

Ministry of Energy and Mineral Resources (2013b), Geothermal Area Distribution Map and Its Potential in Indonesia, December 2013.

Muraoka, H., K. Sakaguchi, M. Komazawa, and S. Sasaki (2008), 'Assessment of Hydrothermal Resources Potential in Japan 2008', Abstract of GRSJ 2008 Annual Meeting, B01 (in Japanese).

Nguyen, T.C, D.G. Cao, and T.T. Tran (2005), 'General Evaluation of the Geothermal Potential in Vietnam and the Prospect of Development in the Near Future', *Proceedings of the World Geothermal Congress 2005*.

Pastor, M.S., A.D. Fronda, V.S. Lazaro, and N.B. Velasquez, (2010), 'Resource Assessment of Philippine Geothermal Areas', *Proceedings of the World Geothermal Congress 2010*. Available at: http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/1616.pdf

Song Y. and T.J. Lee (2015), 'Geothermal Development in the Republic of Korea: Country Update 2010-2014', *Proceedings of the World Geothermal Congress 2015.*

Song, Y., S.-G. Baek, H.C. Kim, and T.J. Lee (2011), 'Estimation of Theoretical and Technical Potentials of Geothermal Power Generation using Enhanced Geothermal System', *Econ. Environ. Geol*., 44(2011), pp.513–523 (In Korean with English abstract and illustrations).

Thermal and Nuclear Power Engineering Society (TNPES) (2013), *Present Status and Trend of Geothermal Power Generation 2012* (in Japanese).

Wang, G., K. Li, D. Wen, W. Lin, L. Lin, Z. Liu, W. Zhang, F. Ma, and W. Wang (2013), 'Assessment of Geothermal Resources in China' *Proceedings of the 38th Workshop on Geothermal Reservoir Engineering*, Stanford University, California.

Zheng, K., Y. Dong, Z. Chen, T. Tian, and G. Wang (2015), 'Speeding Up Industrialized Development of Geothermal Resources in China – Country Update Report 2010–2014', *Proceedings of the World Geothermal Congress 2015.*

Chapter 3
Barriers and Opportunities

3.1. Technical and Other Barriers

3.1.1. Technical barriers

a) Power generation

Table 3.1-1 shows technical barriers for geothermal power generation for three stages: exploration, installation (development), and sustainable use based on the answer from each country.

Common problems for exploration for power generation are:

- Drilling success: testing of new methods and applications to increase the success rate of exploration wells such as remote sensing, 3D inversion of MT, radon survey, and joint geophysical imaging,
- Geophysical survey: see **Table 3.1-1**, and
- Public acceptance: national and local governments should support RE projects.

Common problems for installation of power generation are:

- Drilling success of production well,
- Reservoir characterisation, and
- Acidic and high silica fluid.

Common problems for sustainability of power generation are:

- Sustainable reinjection: experience in different geothermal reservoirs,
- Reinjection fluid return (short circuit),
- Decline of production wells (pressure drawdown),
- Scaling in injection wells,
- Acidic fluid corrosion,
- Shallow groundwater into reservoir, and
- Geo-hazard (landslide, subsidence, typhoon, volcanic eruption, earthquake).

For all exploration, installation and sustainable power generation, more research fund is needed. International collaborative cooperation in R&D on solving those problems above is needed.

Table 3.1-1. Technical Barriers for Geothermal Power Generation for Different Stages

Country	Exploration	Installation (development)	Sustainable use
China	Well logging instruments and circulating technique in high temperature geothermal drilling	Domestic product limited in 5MW, no big capacity.	Sustainable reinjection has not yet done
Indonesia	Low drilling success ratio	Fluid characteristics (acidic fluid, high silica)	Decline of production well (5 to 10% per year in average) and reinjection well (scaling); Geo-hazards (landslide, earthquake, volcanic activity)
Japan	Limit of geophysical methods (Resistivity image does not always show reservoir shape.)	Success rate of production well drilling Minimisation of environmental impact	Scale, pressure decline, short circuit (reinjection fluid control)
South Korea	Lack of deep well information, such as temperature, stress and fracture distribution	Lack of experience in deep drilling, measurement and reservoir engineering Difficulty of securing proper technical services and procurements	-
Philippines	Environmental permits (tree cutting permit, access to national parks, etc.), social acceptance and access permits, insurgents, finding good permeability and high temperature for the first three exploration wells.	Simultaneous sustainability testing, establishing production sharing and injection interference, drilling interference. Matching of right power conversion system with reservoir characteristics to optimise resource and efficiency	Reservoir drawdown; mineral scaling in wells, surface pipeline network and reservoir; acidity of production fluids and attendant corrosion; reinjection returns; influx of shallow groundwater into reservoir; landslide risks and surface facilities' damages due to super-typhoon
Thailand	Geophysical survey and drilling technique	-	-
Viet Nam	Geophysical survey, drilling, reservoir modelling	-	-

Source: Compiled by authors.

Direct use (conventional)

Table 3.1-2 shows technical barriers for conventional direct use for three stages; exploration, installation (development) and sustainable use based on the answer from each country. Technical problems for direct use are:

- Success rate of well drilling,
- Scales,
- Reinjection, and
- Low-permeability.

International collaborative cooperation in R&D on solving those problems above is needed. Another point is that many countries gave NA for direct use, which shows that advantage of direct use is not well recognised and systematic use is not very common in these countries that is related to:.

- Public awareness,
- Lack of system designer, and
- Lack of multi-purpose use and cascade use.

Geothermal experts should act to raise public awareness. Governments should put incentives to use thermal use of geothermal energy. (In South Korea, renewable heat obligation, or RHO, is planned to be enacted in the near future).

Table 3.1-2. Technical Barriers for Direct Use for Different Stages

Country	Exploration	Installation (development)	Sustainable use
China	Successful rate for production well drilled in fractured reservoir	-	Reinjection for sandstone reservoir
Indonesia	-	-	-
Japan	-	-	Scale, interference of wells (hot spring)
South Korea	-	-	Mostly, insufficient flow rate due to low permeability of fractured reservoir in crystalline rocks
Philippines	-	-	-
Thailand	-	-	-
Viet Nam	-	-	How to use energy efficiently

Source: Compiled by authors.

b) GSHP

Table 3.1-3 shows technical barriers for GSHP for three stages: exploration, installation, and sustainable use based on the answers from each country.

Table 3.1-3. Technical Barriers for GSHP for Different Stages

Country	Exploration	Installation	Sustainable Use
China	-	-	-
Indonesia	-	-	-
Japan	Geological and hydrological database, especially, estimation of groundwater flux	Drilling cost	Control of annual heat exchange balance (extraction and/or injection)
South Korea	-	Lack of information on subsurface thermal properties associated with hydrology	Lack of long-term performance analysis in conjunction with monitoring of subsurface temperature and/or water level variation
Philippines	-	-	-
Thailand	Case study	-	-
Viet Nam	Need to do the detail research	Need to have one pilot installation	-

Source: compiled by authors

Problems for GSHP are derived from:

- Lack of case study (showing successful case),
- Lack of hydrogeological database,
- Drilling cost, and
- Lack of information on long-term performance (for example, monitoring subsurface temperature).

Governments should fund domestic R&D for hydrogeological studies, case studies, and long-term monitoring. Also, international research collaboration is essential to share the knowledge obtained in each country. Drilling cost may be reduced by both mass production and technical improvement suitable for each local geology, which means that drilling cost can also be reduced by the accumulation of knowledge and number of installations supported by R&D on case studies, hydrogeological studies, and long-term monitoring.

Recommendation to policymakers

- For promotion of geothermal power generation, governments should support research activities for all three stages of exploration, development, and sustainable use. International collaborative cooperation in R&D on solving those problems above should also be supported.
- For direct use, governments should put incentives to use thermal use of geothermal energy.
- For promotion and sustainable use of GSHP, governments should support R&D on hydrogeological studies, case studies, and long-term monitoring. Also governments should encourage international research collaboration on these topics.

3.1.2. Other barriers

Table 3.1-4 shows competitors to geothermal energy use in each country, including geothermal power, direct use, and GSHP. Natural gas and other renewable energies are competitors for both power generation and GSHP.

Table 3.1-4. Other Barriers for Geothermal Energy Use: Competitors

Country	Competitors
China	For power generation, hydropower in Yunnan province (South Western China).
Indonesia	For power generation, cheaper coal energy sources, subsidies on diesel oil.
Japan	For GSHP, air-source heat pump (normal air-conditioner using electricity) is a strong competitor.
South Korea	For GSHP, natural gas is the strongest competitor, especially for heating.
Philippines	For power generation, natural gas.
Thailand	For power generation, solar farms, biomass, and wind energies.
Viet Nam	NA

GSHP = ground source heat pump, NA = not applicable
Source: Compiled by authors.

3.2. Environmental Constraints

Tables 3.2-1 to **3.2-3** show the current status of environmental protection legislation related to geothermal development in each country.

Table 3.2-1. Environmental Protection Legislation Related to Geothermal Development

Country	Environmental Protection Legislation
China	Law of Environmental Protection of China. Covers air, water, and land.
Indonesia	Environmental Law No. 32 Year 2009 and Presidential Regulation on Environmental Permits No. 27 Year 2012 containing legislation on water, landscape, noise, etc.
Japan	Environmental Impact Assessment Law for development; Hot Spring Law – for drillings; National Park Law - Soil and Rock extraction
South Korea	Groundwater Law – all boreholes must be reported on depth and purpose prior to drilling
Philippines	Water Quality Management Act of 2004 (RA 9275) Philippine Clean Air Act of 1999 (RA 8749); National Land Use Bill (pending)
Thailand	Protection of national parks (no development in national parks)
Viet Nam	Law on Environmental Protection and the Decrees and Circulars and Decisions under this law are issued by the government or the Ministry of Natural Resources and Environment.

Source: Compiled by authors.

Table 3.2-2. Requirement of Environmental Impact Statements and/or Reports

Country	Requirement of Environmental Impact Statements/Reports
China	Yes, for any project of industry, energy and renewable energy, an Environmental Impact Estimation Report is required before construction.
Indonesia	Yes, based on Presidential Regulation on Environmental Permits No. 27 Year 2012. The lower limit is ≥ 55 MWe. For small-scale (< 55 MW_e) the environmental monitoring system is needed.
Japan	Yes. Environmental Assessment Law requests reports for GPPs of ≥ 10 MW_e.
South Korea	Yes. According to Groundwater law, results of environmental impact assessment must be submitted if somebody is to use groundwater.
Philippines	Yes. Certificate of non-coverage for 3G. For <50 MW_e, ECC and IEE checklist report is required. For >50 MWe, ECC and EIS report is required.
Thailand	No
Viet Nam	Yes. Depending on the scale of the power projects but there is no specific regulation for geothermal power project yet.

GPP = Geothermal Power Plant, MWe = megawatt electric, 3G = geological, geochemical and geophysical surveys, ECC = Environmental Compliance Certificate, EIS = Environmental Impact Statement, IEE = Initial Environmental Examination

Source: Compiled by authors.

Table 3.2-3. Other Environmental Protection Matters

Country	Others (applicable permits, etc.)
China	CO_2 tax will be implemented popularly after experimental implementation of CO_2 trade in 7 cities and provinces.
Indonesia	Geothermal development should meet spatial use managements especially as regulated by: 1. Forestry Law No. 41 Year 1999 containing legislation on forest for other uses, protection and conservation areas. 2. Law on Spatial Planning No. 26 Year 2007 containing legislation on planning for spatial use and protection.
Philippines	Pollution Control, Watershed Management Social Acceptability – National Integrated Protected Areas System, National Commission on Indigenous People
Viet Nam	Not applicable yet, but the environmental law also encourages the development of renewable energy.

Source: Compiled by authors.

Summary of current status

- All countries have existing laws governing national parks and maintaining air, water standards and land use. Such laws are important to protect local environment but that prevent geothermal developments.
- A CO_2 tax law will be implemented in China and also forthcoming for the Philippines in 2015.

Recommendation to policymakers

- Enactment of a law inside a national park to isolate a certain area for geothermal development (Energy Zone) and to balance energy development with national forest conservation is recommended to keep the balance between geothermal development and environmental protection.
- All counties should issue CO_2 tax law for promotion of RE development to preserve the global environment.

3.3. Social and Political Issues (Social Awareness)

Table 3.3-1 shows the level of recognition on geothermal energy in each country. There is a clear tendency that in countries that have many geothermal power plants but not many GSHPs, such as in Indonesia, Japan, and Philippines, geothermal power generation is widely recognised, while GSHP is not. On the other hand, in countries where GSHP has an installation rate but not geothermal power plants, such as in China and South Korea, GSHP is widely recognised while geothermal power generation is not. Education may be needed for poorly installed countries to promote geothermal energy use. (Recommendations to policymakers on this matter will be given in section 3.7.)

According to the answers from geothermal power producing countries, most typically in the Philippines, it seems involvement of the local population is becoming more important for geothermal development projects.

Table 3.3-1. Is Geothermal Energy Recognised?

Country	Recognised in general public?			Recognised in decision-making level?			Are benefits and advantages known?			To what extent local population informed/involved in project development?		
	PG	DU	GSHP	PG	DU	GSHP	PG	DU	GSHP	PG	DU	GSHP
China	△	○	○	△	△	○	△	△	○	×	△	△
Indonesia	△	△	×	○	×	×	△	△	×	△	△	×
Japan	△	×	△	○	×	△	○	×	△	△	×	×
South Korea	×	×	△	△	×	○	△	×	△	×	×	×
Philippines	○	×	×	○	×	×	○	×	×	○	×	×
Thailand	△	×	×	△	×	×	○	×	×	×	×	×
Viet Nam	△	○	×	△	△	×	△	△	×	×	○	×

Note: PG = power generation: DU = direct use: GSHP = ground source heat pump.
○ = Well recognised, △ = Somewhat, × = Negligible.
Source: Compiled by authors.

Recommendation to policymakers

Governments should develop supportive systems for the involvement of the local population to geothermal development projects.

3.4. Legal Matters

Tables 3.4-1 to **3.4-4**5show geothermal legislation system in each country.

All countries except South Korea have legislation for power generation while most countries don't have legislation for GSHP. Direct use is in between.

Recommendation to policymakers

A one-stop-shop type of legislation including environmental permission is desirable.

Table 3.4-1. Does a Specific Geothermal Legislation Exist?

	Power generation	Direct use	GSHP
China	Yes, Renewable Energy Law of 2009 version	Yes, Renewable Energy Law of 2009 version	Yes, when using open system of groundwater
Indonesia	Yes	Yes	No
Japan	Yes, for drilling only	Yes, for drilling only	Yes, for drilling only
South Korea	No	No	No
Philippines	Yes, Renewable Energy Act of 2008	NA	NA
Thailand	No	No	No
Viet Nam	No	No	No

NA = not applicable
Source: Compiled by authors.

Table 3.4-2. Part of Mining Legislation or Separate Legislation?

Country	Power generation	Direct use	GSHP
China	Yes, part of mining legislation	Yes, part of mining legislation	When GSHP uses groundwater as source, needs licence from administration of water
Indonesia	Separate law: Geothermal Law No. 27 Year 2003, followed by Government Regulation No. 59 Year 2007, and some ministerial regulations and decrees	Legislated in GL27, but no further legislation (in this case a government regulation) following to regulate direct uses. Legislated in GL27, but no further legislation (in this case is a government regulation) following to regulate direct uses. Legislated by local government regulations for common spring water and groundwater uses	NA
Japan	No, but of hot spring law for drilling	No, but of hot spring law for drilling	No, but of hot spring law for drilling
South Korea	Possibly	Possibly	-
Philippines	Separate	NA	NA
Thailand	No	No	No
Viet Nam	No, but mining legislation applied for hot water	No, but mining legislation applied for hot water	No

GSHP = ground source heat pump, GL27 = Geothermal Law No. 27 of Year 2003, NA = not applicable.
Source: Compiled by authors.

Table 3.4-3. What Licences Are Required?

Country	Power generation	Direct use	GSHP
China	Qualifications for design and implementation	Qualifications for design and implementation	Qualifications for design and implementation
Indonesia	Geothermal business licence	Spring and ground water uses, tourism licence	NA
Japan	1) Drilling in hot spring area, 2) environmental assessment (if 9 MW<), 3) construction in natural park, 4) usage of river water, etc. (conditional)	1)Drilling in hot spring area, 2) construction in natural park (if located in national park)	None
South Korea	-	-	-
Philippines	Department of Energy (DOE) certificate of registration, DOE certificate of accreditation, registration with board of investments, certificate of endorsement by DOE	NA	NA
Thailand	None	None	None
Viet Nam	1) Exploration of hot water, 2) exploitation of hot water, 3) investment, 4) environmental protection, 5) construction of power plant, 6) producing electricity	1) Exploration of hot water, 2) exploitation of hot water, 3)investment, 4) environmental protection depending on a certain projects.	NA

Source: Compiled by authors.

Table 3.4-4. Who Is the Licensing Authority?

Country	Power generation	Direct use	GSHP
China	National development and reforming committee and DRC for provinces/registrations	Ministry of land and Resources	Ministry of Land and Resources
Indonesia	Local government or Minister of Energy and Mineral Resources	Local government	-
Japan	1) Prefecture government under supervision of MOE, 2),3) MOE, 4) MLITT	Ministry of Environment (MOE)	Ministry of Land, Infrastructure, Transport and Tourism (MLITT)
South Korea	-	-	Korea Energy Management Corporation (KEMCO)
Philippines	DOE thru Renewable Energy Management Bureau	NA	NA
Thailand	Ministry of Energy	Ministry of Energy	Ministry of Energy
Viet Nam	1), 2) Ministry of Natural Resources and Environment 3)-6) See below*	The permits are depending on the scale of the project.	NA

Note: *Viet Nam:

3) Ministry of Planning and Investment (If the investment capital > US$50 million) or Provincial People's Committee (If the investment capital < US$50 million).
4) Ministry of Natural Resources and Environment, 'Provincial and of Natural Resources and Environment' or the 'People's Committee of District' depends on types or scales of the projects.
5), 6) Ministry of Trade and Industry (if the power plant > 3MWe) (Road Map), Provincial People's Committee (if the power plant < 3MWe).

Source: Compiled by authors.

Table 3.4-5. Is it Taxable?

Country	Power Generation	Direct Use	GSHP
China	Yes*	Yes*	Yes*
Indonesia	Property tax, income tax, forestry fee, royalties	Property tax, income tax, forestry fee, royalties	No
Japan	No	No	No
South Korea	No	No	No
Philippines	Yes, for the first 7 years	No	No
Thailand	No	No	No
Viet Nam	Yes, following mining law	Yes, following mining law	NA

*China: The owner of the enterprise (power generation, direct use, GSHP) should pay tax generally.
Source: Compiled by authors.

3.5. Financial Capacities

Tables 3.5-1 to **3.5-4** show current status of financial capacities for geothermal power generation, direct use and GSHP in each country.

Table 3.5-1. Does a Drilling Risk Guarantee Exist?

Country	Power Generation	Direct Use
China	No	No
Indonesia	No	No
Japan	Yes, Ministry of Economy, Trade and Industry (METI) supports half of drilling cost for each production well. Successful drilling, money is paid back to developer.	No
South Korea	No	No
Philippines	No. But there are foreign insurance companies which is an option of the steam field developer.	NA
Thailand	No	No
Viet Nam	No	No

NA = not applicable.
Source: Compiled by authors.

Table 3.5-2. Are There Companies Specialised in Geothermal Projects? (planning, drilling, field testing, reservoir engineering, production)

Country	Power Generation	Direct Use	GSHP
China	Yes. Jiangxi Huadian Electric Power Co. Ltd.	Yes. Sinopec Star Petroleum Co. Ltd. and Sichuan Kangsun Energy Development Co. Ltd.	Yes, a lot
Indonesia	Yes	No	No
Japan	Yes, many	Yes, but only few	Yes, a few consultants, drilling and TRT exist.
South Korea	Yes, a few for project development	-	Yes, there are many and covers all aspects.
Philippines	Yes, only EDC has technical ability for entire geothermal value chain, while others provide only for varying stages of exploration, development and production (e.g. PGPC, Aragorn Power, Petro Energy Resources, etc.)	NA	NA
Thailand	No	No	No
Viet Nam	No	No	No

EDC = Energy Development Corporation, NA = not applicable, PGPC = Philippine Geothermal Production Company, TRT = thermal response test.
Source: Compiled by authors.

Table 3.5-3. Are There Financial Institutions Providing R&D Grants or Banks Providing Development Loans and/or Guarantees?

Country	
China	Yes. Banks provide loans for GSHP project mainly, but also for direct use and power generation projects. Governments provide grants of energy saving for DU and GSHP.
Indonesia	Loans from national agencies: Geothermal fund/loans provided by Government Investment Agency, by government owned banks.
Japan	Yes, METI (JOGMEC and NEDO) support R&D. JOGMEC mainly support for exploration and drilling and NEDO support for facilities (small binary, scale, etc.). MEXT supports for new technology including EGS.
South Korea	Yes, KETEP as a government funding agency; KEMCO for various subsidies and long-term, low-interest loans.
Philippines	Non-government-related in general. GOCCs would tap WB-IFC and JBIC for funding needs. For private sector, loans are given by large local banks
Thailand	Yes, Department of Groundwater Resources (DGR), PTT Public Company Limited (PTT), and Department of Alternative Energy Development and Efficiency (DEDE)
Viet Nam	Yes, Energy and Environment Partnership with the Mekong Region (EEP), WB, ADB, NDF and UNDP.

Note: ADB = Asian Development Bank, DU = direct Use, GOCC = Government-owned and controlled corporation, GSHP = ground source heat pump, IFC = International Finance Corporation, JBIC = Japan Bank for International Cooperation, JOGMEC = Japan oil, Gas and Metals National Corporation, KETEP = Korea Institute of Energy and Technology Evaluation and Planning, KEMCO = Korea Energy Management Corporation, METI = Ministry of Economy, Trade and Industry, Japan, MEXT = Ministry of Education, Culture, Sports, Science and Technology, Japan, NEDO = New Energy and Industrial Technology Development Organization, Japan, NDF = Nordic Development Fund, R&D = research and development, UNDP = The United Nations Development Programme, WB = World Bank.
Source: Compiled by authors.

Table 3.5-4. Are There Private Investors?

Country	Power Generation	Direct Use
China	Yes, Jiangxi Huadian Electric Power Co. Ltd.	Yes. Sichuan Kangsun Energy Development Co. Ltd.
Indonesia	Yes	Yes. Limited for bathing and tourism
Japan	Yes	Yes
South Korea	Only a few	Some for GSHPs
Philippines	Yes, they are directly involved in exploration, delineation and development. (e.g. EDC, PGPC, PNOC renewables, etc.)	NA
Thailand	None	None
Viet Nam	Yes	Yes

EDC = Energy Development Corporation, Philippines, GSHP = ground source heat pump, PGPC = Philippine Geothermal Production Company, PNOC = Philippine National Oil Company.
Source: Compiled by authors.

Summary of current status and recommendation to policymakers

- Drilling risk is not guaranteed except in Japan. Governments should subsidise the cost of exploration drilling and create laws for cost recovery of geothermal development to encourage private investment.
- Countries which do not have expertise, equipment, and manpower should be supported by countries with expertise through bilateral agreements.
- Governments should support R&D through the agency not by bank-loans.
- For development, low interest loans by the Asian Development Bank, the Japan International Cooperation Agency, or the World Bank are available in most countries. Governments should promote these systems to local developers and/or investors.

3.6. Supportive Measures

Supportive measures for geothermal energy use by the government in each country are described below.

China

- The government support through the national 'Guidelines on Promoting Geothermal Energy Development and Utilisation' for power generation, direct use, and GSHP.
- Subsidy of electricity price for grid (for power generation) will be introduced as another support. GSHP projects will pay for electricity by lower residential electricity price (used to pay higher industrial electric price.)
- There is no RPS or FiT for geothermal power generation. FiT and RPS for wind power and solar PV power exist.

Indonesia

- The government provides initial surface geo-scientific data for each green geothermal working area.
- Electricity price subsidies, but for all sources (not only geothermal).
- Indonesian government assignment for national electrical company to buy electricity produced by using geothermal.
- Tax incentives for power generation are also implemented (tax incentives for material/equipment importation).
- Feed-in Tariff: MEMR Regulation No. 22/2012; however not effective yet (higher price is expected).
- Ceiling price only for geothermal: Minister of Energy and Mineral Resources (MEMR) Regulation No. 02/2011, ceiling at 9.7 US cents/kWh. But the price of geothermal electricity will be decided (would be raised) based on the cost at each place (11.8–29.6 US cents/kWh, targeted to be issued June 2014).

Japan

- Electricity: The government provides subsidy for exploration well drilling (up to 50 percent) and PA activities (100 percent).
- R&D supported by the government.
- FiT Law for renewable energy including geothermal power generation was enacted in 2012:
  - ✓ For 15 MW or larger geothermal power plant (GPP), FiT price is 27.3 JPY/kWh for 15 years.
  - ✓ For GPP smaller than15 MW, FiT price is 42 JPY/kWh for 15 years.

  Comment: The FiT price for smaller class was set for promoting smaller binary systems. 15 years is normal payback period for commercial geothermal power production with power cost of 20 JPY/kWh.

- Heat pump installation is subsidised by federal and local government.
- Other support includes a subsidy based on the Act on Special Grants to Local Governments and Other Special Measures concerning Local Public Finance.

South Korea

- Electricity: RPS in South Korea has become an effective substitute for FiT since 2012. Geothermal energy was included in 2014 with highest REC (of 2.0).
- Heat pump: Strong government subsidy programmes and mandatory renewable energy act for heat pumps. In 2012, the Mandatory Public Renewable Energy Use Act was amended.

Philippines

- The government provides benefits across the production chain:
  - ✓ Share reduction from 6 percent to 1.5 percent gross income for geothermal
  - ✓ Subsidies for R&D through RE Trust Fund
  - ✓ Duty-free importation for 10 years
  - ✓ Special realty tax not to exceed 1.5 percent of original costs
  - ✓ And many more…
- Other support: RE Act provides fiscal and non-fiscal incentives for RE investors.
- RE Act also provides for establishment of Renewable Portfolio Standard (RPS) system. (No FiT for geothermal but for wind and solar.)

Thailand

- There are governmental supportive measures for R&D, but no other support such as tax incentives, royalty, exemptions, nor FiT or RPS (FiT for other RE but not for geothermal because there are no cost data for geothermal yet).

Viet Nam

- Government has not provided supportive measures for geothermal yet. (FiT for wind power exists and other support for solar power exists, though.)
- Research project on geothermal potential survey.

Tables 3.6-1 and **3.6-2** summarise the supportive measures in each country from three aspects, law & programmes, financial support (subsidies, tax royalty, and exemptions), and FiT or RPS.

Table 3.6-1. Supportive Measures in Each Country (Legal and Financial Support)

Country	Does national supporting programme exist? (Law & programmes)			Other support (subsidies, tax incentives, royalty, exemptions)		
	Power Generation	Direct Use	GSHP	Power Generation	Direct Use	GSHP
China	Yes	Yes	Yes	Yes	Yes	Yes
Indonesia	Yes	No	No	Yes	No	No
Japan	Yes	No	No	50% subsidy for exploration drilling, 100% subsidy for PA	No	Yes by local or federal government
South Korea	No	No	Yes, various acts	No		Yes, by RE Act
Philippines	Yes	Yes, recent DOE programme	Yes, recent DOE programme	Yes, RE Act incentives (fiscal & non-fiscal); subsidy only for R&D	No	No
Thailand	Yes but not explicitly for geothermal	No	No	No royalty, no tax incentives	No	No
Viet Nam	Yes but not explicitly for geothermal	No	No	No government support	No	No

DOE = Department of Energy, Philippines, PA = public acceptance, RE = renewable energy, R&D = research and development.
Source: Compiled by authors.

Table 3.6-2. Supportive Measures in Each Country (FiT or RPS)

Country	Are there FiT or RPS?		
	Power Generation	Direct Use	GSHP
China	No RPS for geothermal	No	Subsidy for Energy Saving of Building. Grant for Demonstration of Renewable Energy
Indonesia	in future (ceiling price increase @11.8-29.6), tax incentives	No	No
Japan	yes, .>15 MW (~27JPY/kWh);<15 (~42JPY/kWh)	No	No
South Korea	RPS with REC of 2.0	No	No but discussing about Renewable Heat Obligation
Philippines	Yes, RPS but no FiT for geothermal, FiT for wind/solar	No	No
Thailand	No FiT/RPS	No	No
Viet Nam	No	No	No

RPS = Renewable Portfolio Standard, MW = megawatt, kWh = kilowatt hour, JPY = Japanese Yen, REC = Renewable Energy Certificate, FiT = Feed in Tariff.
Source: Compiled by authors.

Recommendation for policymakers on power generation

- FiT for geothermal is recommended for the countries in which geothermal business is not matured.
- High credit in RPS (mandate) is recommended (for example, 10 percent in Philippines).
- National programmes should be provided **explicitly** for geothermal power generation, with provision of fiscal and non-fiscal incentives, ex. Tax-exemptions, royalties, subsidies, etc.
- For risk management in exploration stage, some support from the government is desirable. Subsidies for exploration drilling (for example, in Japan 50 percent) are recommended.
- Continuous R&D support from the government is very important no matter how much geothermal power generation is materialised.
- Like Indonesia, the government should conduct basic resource surveys (temperature distribution, geothermal model based on 3G [geological, geochemical, and geophysical] data).
- International cooperation is important, not only from R&D aspect but for business aspect also.

Recommendation for policymakers on direct use and GSHP

- Only a few countries have national programmes for direct use and GSHP. National programmes for direct use and GSHP are recommended for ALL countries.
- National programmes should be provided with the provision of fiscal and non-fiscal incentives, such as tax exemptions, royalties, and subsidies (for example, in South Korea a maximum 80 percent of GSHP installation cost for greenhouse – 30 percent from local government and 50 percent from the central government).
- Renewable heat obligation (RHO, like RPS for electricity) is recommended for promotion of renewable heat for district heating/cooling (for tropical countries)

3.7. Information Channels for Public Awareness

Table 3.7-1 shows the summary of information channels for public awareness on geothermal energy in each country. There is a clear analogue with social awareness shown in section 3.3; in countries where geothermal power plant has been highly installed but not GSHP, such as in Indonesia, Japan, and Philippines, geothermal power generation has information channels while GSHP does not. On the other hand, in countries where GSHP is highly installed but not geothermal power plant, such as in China and South Korea, GSHP has information channels while geothermal power generation does not. Efforts for providing information channels may be needed to promote geothermal energy use.

Table 3.7-1. Availability of Information through Certain Information Channels

Country	Academia (public schools or university level)			Professional societies, special conference & workshops			Through media or special events			Any other channel (special campaigns or demonstration centres, etc.)		
	PG	DU	GSHP	PG	DU	GSHP	PG	DU	GSHP	PG	DU	GSHP
China	×	△	○	○	○	○	△	△	○	×	×	△
Indonesia	△	×	×	○	×	×	△	×	×	△	×	×
Japan	△	×	△	○	△	○	○	△	○	△	×	△
South Korea	△	×	○	△	×	○	×	×	△	×	×	△
Philippines	△	×	×	△	×	×	△	×	×	△	×	×
Thailand	△	×	×	△	×	×	△	×	×	△	×	×
Viet Nam	△	△	×	×	×	×	△	△	×	×	×	×

PG = Power generation, DU = direct use, GSHP = ground source heat pump.
○ = Often yes, △ = Sometimes yes, × = Mostly no.
Source: Compiled by authors.

Recommendation to policymakers

The advantages of geothermal energy use should be advertised through any government information channel so that social awareness of geothermal energy will be raised for both the decision-making level and public citizens.

3.8. Future Concerns

Tables 3.8-1 to **3.8-3** show answers to the question What could/should be done to further develop geothermal use in your country on three different aspects?

Table 3.8-1. Future Concerns on Political or Governmental Support

Country	Political or government support (e.g., tax or subsidy)		
	Power generation	**Direct use**	**GSHP**
China	Need issue detailed rules of implementation for subsidy of grid electricity price.		
Indonesia	Tax exemption, subsidy on electricity produced by geothermal (including interesting electrical price scheme). Government policy on small-scale geothermal development, especially in the eastern parts and rural parts.	Government policy on direct uses application, especially for agriculture crops processing.	
Japan	Further deregulation (for development near hot spring resorts and inside national park), to shorter lead-time including environment assessment, continuity of support, R&D	Education (enlightenment)	Expansion of subsidy
South Korea	Proper legislation, high REC in RPS, risk guarantee scheme	NA	Proper legislation guaranteeing optimum design and installation
Philippines	Government regulatory agencies must pave the way for the IPP's to explore and develop geothermal resources. Regulators must provide easy access to environmental permits, local community permits, and local government unit endorsements.		
Thailand	R&D support from overseas	R&D support from overseas	R&D support from overseas
Viet Nam	legal framework, more R&D investment	Provide subsidy	More R&D investment

GSHP = ground source heat pump, NA = not applicable, REC = Renewable Energy Certificates, RPS = Renewable Portfolio Standard, R&D = research and development.
Source: Compiled by authors.

Table 3.8-2. Future Concerns on Technology and/or Instrument

Country	From the point of view of technology and/or instrument		
	Power generation	Direct use	GSHP
China	Research for big capacity (>5 MW_e) of geothermal power generation set. The capacity factor in Yangbajain GPP is little lower than world average due to low technical level of local workers and lower efficiency of domestic-made generator.	Research on improvement of reinjection techniques for sandstone reservoir	Research for efficiency increasing
Indonesia	Small-scale and binary technologies	Agriculture crop processing	
Japan	High efficiency EGS, high resolution monitoring of reservoir and its surroundings, sustainable low temperature binary system	Case studies of cascade and multi-purpose use	Lower drilling cost, heat-pump specialised for GSHP with higher performance, nationwide suitability map.
South Korea	Customising deep drilling and well completion technologies R&D on reservoir engineering and monitoring technologies	NA	Providing subsurface information to enhance performance of GSHP
Philippines	-Tackling corrosive fluids (acidic reservoirs) -Making the corrosion-resistant materials more affordable -Commercial use of acid inhibition chemicals		
Thailand	Need experience	Need experience	Need experience
Viet Nam	technology and instrument	experiences	technology and instrument

MW_e = megawatt electric, GPP = geothermal power plant, EGS = enhanced geothermal system, GSHP = ground source heat pump.
Source: Compiled by authors.

Table 3.8-3. Future Concerns from Social and/or Economic Viewpoint

	Power generation	Direct use	GSHP
China	Enhance strategic consideration for CO_2 emission reduction, especially for keeping original ecology in Tibet	-	-
Indonesia	Social aspect: dissemination of advantage of geothermal energy development	Economical study on direct uses application, especially for agriculture crops processing	-
Japan	Public acceptance especially to hot spring owners	Public acceptance	Education (enlightenment), legally binding promotion action (like South Korea)
South Korea	Promotion of geothermal among public and providing public risk guarantee/insurance scheme	NA	Standardisation: standard procedure for optimal design of GSHP to avoid over-design
Philippines	Local government meddling into the commercial affairs of the IPPs, stricter environmental rules on permitting process which delays the project start-up, non-supportive indigenous and local people	Develop geothermal resource for direct use such as heating and cooling in different sectors – household, agriculture, aquaculture, industrial processes, as well as GSHPs	
Thailand	Case study	Case study	Case study
Viet Nam	Social awareness	Social awareness	Social awareness

NA = not applicable, IPP =
Source: compiled by authors

Tables 3.8-1 to **3.8-3** suggest that demonstration and education, for all power generation, direct use, and GSHP, are needed to raise social awareness and public acceptance in the regions where geothermal exploitation is not yet advancing.

Recommendations for policymakers on power generation

- National programmes and development plans should be provided **explicitly** for geothermal power generation, with provision of fiscal and non-fiscal incentives, ex. Tax-exemptions, royalties, subsidies, etc.
- Enactment of a law inside a national park to isolate a certain area for geothermal development (Energy Zone) and to balance energy development with national forest conservation.
- Government should support through agencies to reduce long process of securing environmental permit for exploration.
- One-stop-shop for securing various permits and documentation for geothermal exploration and development is strongly recommended. (Not going to national and local, and environmental and other government agencies)
- Small-scale geothermal development programme for islands and remote rural areas (separated from the national grid) is recommended, with financial incentives and subsidies from government.
- International cooperation is recommended for the countries where geothermal power has not been intensively used and no technology developed.
- Geothermal Law should be provided **explicitly** for geothermal development, separate from Mining Law or Hot Spring Law.
- Continuous R&D support from the government is very important no matter how much geothermal power generation is materialised.
- Geothermal education course should be provided in university level.
    - For example, in the Philippines, geothermal engineering course is supported by the EDC (a private company) with the local universities in the geothermal sites.
    - International geothermal training course is provided by UNU, Auckland Univ., and Japanese universities through NEF (New Energy Foundation). Beside internet, other information channel may be needed.
- From the technological view point, each country has different future concerns. Therefore international collaboration, not only in the Asian region, but through worldwide information channels, should be provided in a practical manner, which is effective to increase human capacity.
- For countries with such specific problems, they should initiate collaborate research with countries having solutions to these problems.

- Geothermal education programme and awareness of local people for public acceptance of geothermal development, emphasising advantage of geothermal power is needed.

Recommendations for policymakers on direct use and GSHP

- National programmes should be provided for direct use and GSHP in viewpoint of green-energy, with provision of fiscal and non-fiscal incentives, ex. Tax-exemptions, royalties, subsidies, etc.
- From a technological view point, each country has different future concerns. Therefore international collaboration, not only in the Asian region, but through worldwide information channels, should be provided in a practical manner, which is effective to increase human capacity.
- Geothermal education programme and awareness of local people for public acceptance of geothermal direct use, emphasising advantage of geothermal heat is needed.

3.9. International Cooperation

Table 3.9-1 shows on-going international R&D frameworks and/or frameworks needed to foster further development in each country. China, Thailand, and Viet Nam emphasise the necessity of international cooperation. Among these three countries, China is interested in EGS mostly, while the other two countries need case studies of small scale binary systems. Government supported international R&D frameworks are active only in South Korea and Japan.

Table 3.9-1. Ongoing International R&D Frameworks and/or Frameworks Needed for Further Development

Country	International R&D frameworks
China	International cooperation is necessary for learning new technology and equipment from the world, especially in EGS research and development.
Indonesia	IGA activities (through Indonesia Geothermal Association)
Japan	- Bilateral study cooperation of micro seismicity for EGS with the United States. - Bilateral collaboration between AIST and KIGAM. - GSHP database project in CCOP. - IGA and IEA/GIA activities.
South Korea	- Annexes (Annex III, VIII and XI) of IEA/GIA. - Bilateral collaboration between KIGAM and AIST GSJ.
Philippines	- R&D's to address specific issues by individual IPPs. Currently there is no country-wide collaborative R&D nor is there any R&D that is mandated and supported by the government on geothermal energy production.
Thailand	Thailand needs one successful location in concrete construction before some measures released in legislative control and supporting (West Thailand, areas of hot springs). This can be done by providing R&D support. Case studies are needed.
Viet Nam	Viet Nam needs the cooperation/assistance of scientists and consultants in the geothermal development field. (e-Asia (JST) for R&D, Geo-fund (World Bank) for development).

AIST = National Institute of Advanced Industrial Science and Technology, Japan, CCOP = Coordinating Committee for Geoscience Programs, EGS = Enhanced (Engineered) Geothermal System, GSHP = ground source heat pump, IEA/GIA = International Energy Agency/Geothermal Implementing Agreement, IGA = International Geothermal Association, IPP = Independent Power Producer, JST = Japan Science and Technology Agency, KIGAM = Korea's Institute of Geoscience and Mineral Resources, R&D = research and development.

Source: Compiled by authors.

International R&D frameworks found in **Table 3.9-1** are:

- International Geothermal Association (IGA): China, Indonesia, Japan, and the Philippines have affiliated societies of IGA while South Korea, Thailand, and Viet Nam have private members of IGA.
- International Energy Agency – Geothermal Implementing Agreement (IEA-GIA): Only Japan and South Korea are member countries among the seven countries in this study.
- Coordinating Committee for Geoscience Programs in East and Southeast Asia (CCOP): All seven countries are member countries (with Cambodia, Malaysia, Papua New Guinea, and Singapore).

To be active member in those international frameworks may be one solution to do effective information exchange, but still domestic support for travel costs to attend meetings are needed.

For funding from international or governmental sources, the Japan Science and Technology Agency (JST)'s bilateral R&D framework and the World Bank's geo-fund for development may be available.

3.10. Other Relevant Issues

Table 3.10-1 shows other relevant issues raised from some countries to be added. Detailed explanations are shown after the table.

Table 3.10-1. Other Relevant Issues

Country	Other Relevant Issues
South Korea	-Need for standard guideline for statistics of geothermal direct-use including GSHP
Philippines	Drilling cost and Tariff: important for economics of a geothermal project
Thailand	- One successful pilot plant in concrete construction (see **Table 3.9-1**) - Government subsidies for renewable energies
Viet Nam	-Importance of establishing one geothermal power pilot in Viet Nam to pave the way to geothermal development

GSHP = ground source heat pump.
Source: Compiled by authors.

Need for standard guideline for statistics of geothermal direct-use (Korea)

- We need to have a standard guideline for statistics of geothermal direct-use including GSHP, which may be quite important in national renewable energy statistics because GSHP is getting more and more dominant direct-use type worldwide (although we must admit only three North-east Asian countries are active at the moment). Different from geothermal power generation, there is significant uncertainty in statistics of direct-use, especially in estimating produced thermal energy even assuming that the installed capacity is known. This is more serious in estimating energy use through GSHP. Under the Annex VIII Geothermal Direct Use of IEA Geothermal, we have just initiated a task to analyse each country's statistical method and to recommend a guideline. Therefore, we may consider to provide member countries' own methodology, if any, and to collaborate with IEA Geothermal for devising a better method.

Drilling cost and Tariff (Philippines)

- Drilling Cost – The costs of geothermal well drilling dictated by the prices in the oil and gas industry, and the well costs have been spiralling up for the last five years. This affects the economics of specific projects, and makes the smaller capacity projects less attractive for exploration and development.
- Tariffs – Like the drilling cost, tariffs are one of the most important, if not the most important, parameter in the economics of a geothermal project. The government needs to provide additional incentives to make each project economically viable, and to continue to protect the industry for any future regulatory risks.

Government subsidies for renewable energies (Thailand)

- In the future, Thailand must find new renewable energy to replace gas or coal materials which will be gone in the next 20 years. Geothermal energy is one of resources to be found throughout western Thailand (area of hot-springs, at which behaviour of possible deeper reservoir is not well-known) and can be in place as well as solar, wind, and biomass. The government subsidises extra financial support for these energy types, including R&D. How would Thailand achieve success in further deployment of renewable energy and be good example of new development for reduction of carbon foot print is a matter of importance.

Importance of establishing one geothermal power pilot (Viet Nam)

- EEP Mekong is the only ongoing project. As for the private sector in Viet Nam, two companies are investing in developing two geothermal power plants but it is a long way to get the electricity because it depends much on the fund for the projects. It is very significant if there is one geothermal power pilot in Viet Nam such as the Fang in Thailand. It is a good example to show to the people, government officials, investors then they will pay more attention on geothermal development. This pilot should be implemented by Vietnamese government with the support and assistance of international geothermal scientists and consultants.

For standard guidelines for statistics of geothermal direct-use including GSHP, a future ERIA project or other international R&D framework such as IEA-GIA may be able to handle the issue. Drilling cost, tariffs, and government's subsidies, all matters of economics, may be investigated further in a future ERIA project if needed. For pilot plants, bilateral cooperation with government support may be effective.

Recommendation to policymakers

Bilateral agreements between governments should be provided for Thailand and Viet Nam on a pilot project, identifying agencies to implement the project.

Chapter 4

Case Studies on Sustainable Use of Geothermal Energy

4. Introduction of Chapters 4 and 5

The topics of interest for sustainability of geothermal power generation and direct heat use pointed out in Section 2.5 are summarised below in order of priority (based on input from China, Indonesia, the Philippines, and Japan):

1. Monitoring and reservoir engineering,
2. Reinjection,
3. Anti-scaling, and
4. Anti-corrosion and anti-erosion.

For ground source heat pump (GSHP) systems, no common interests were found, but basic hydrogeological data collection and system monitoring were pointed out to be important for the sustainable use of GSHP. On the other hand, in Section 4.1, the importance of international cooperation was pointed out.

Therefore, we decided to collect case studies from each member country concerning these topics to find possible solutions for sustainable use of geothermal energy. Thus case studies are presented in the next section. These case studies are compiled and used as a base of the guidelines shown in the following chapters.

Although the solutions shown in the following sections and chapters may contribute to the sustainability of geothermal use to some extent, continuous studies are needed for future use. As listed in 'Recommendations to Policymakers', these topics are a matter of importance to be studied continuously and cannot be solved by our current project only.

Note that 'sustainability' in this report is mainly for 'resource sustainability' and environmental sustainability is only partially discussed (on subsidence and brine disposal to rivers). Separate investigations are necessary to discuss environmental, economic and/or social sustainability.

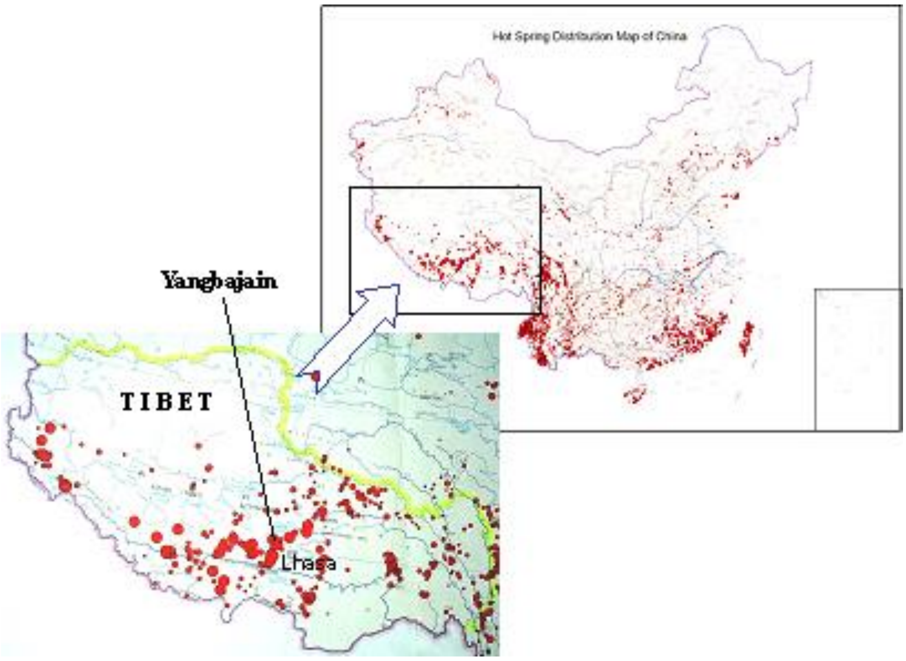
4.1 China: Comparison of Yangbajain and Xiaotangshan Geothermal Fields

A. Case Study on Yangbajain Geothermal Power Station

4.1.A1. Introduction: Yangbajain Geothermal Power Station

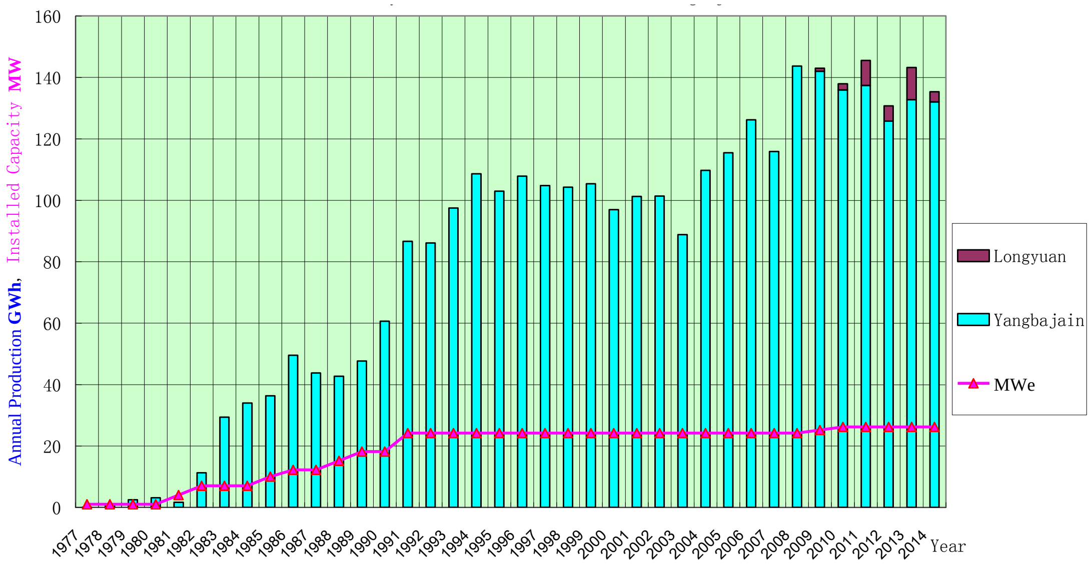
The Yangbajain Geothermal Power Station is located 90 kilometres (km) northwest of Lhasa, the capital of Tibet Autonomous Region, China (**Figure 4.1-A1**). Its elevation is 4,300 metres (m) above sea level, the highest geothermal power station in the world. It started power generation of 1 MW_e in 1977. At that time its fluid was 153°C in temperature with wellhead pressure of 0.33 MPa (mega Pascal). The total flow of steam and water was 72 m^3/h. It generated 600 kWh per hour. During 1981–1991, 8 units of 3 MW_e each (including one unit of 3.18 MW_e) were installed progressively. These completed a total installed capacity of 24.18 MW_e (1MW_e unit retired). Its annual power generation was 87 million kWh in 1992. Then it exceeded 100 million kWh in 1984. It reached a highest record of 140 million kWh in 2008. It is about 130 million kWh in recent years (**Figure 4.1-A1**). Up to 2014, the station has generated 3,100 million kWh in total.

Figure 4.1-A1. Yangbajain Location Map



Source: Edited by authors based on Shangyao Huang: Hot Spring Distribution Map of China (1993) and K. Zheng et al. (2012), Geothermal resources development in Tibet, China.

Figure 4.1-A2. Annual Production and Installed Capacity of Yangbajain Geothermal Power Station



Source: Edited by authors based on the statistics data of Yangbajain Geothermal Power Station.

The station uses two stages of flash technique. The geothermal fluid came from the Yangbajain shallow reservoir. After exploitation for dozens of years the capacity of the shallow reservoir has declined. But the variation of annual production shown in **Figure 4.1-A2** was caused not by resources or technical reason. It is restricted by the deployment of the power grid. When power supply decreased demand, geothermal power generation was required to reduce production.

The rated speed of 3 MW_e unit is 3,000 r/min, and main steam pressure is 0.42 MPa with a temperature of 145°C. The primary entering steam pressure is 0.17 MPa with a temperature of 118°C at a flow rate of 22.5t/h. The second entering steam pressure is 0.05 MPa with temperature of 102°C and the same flow rate. The exhaust steam pressure is 0.008 MPa. Per tonne of thermal fluid produces electricity of 7 kWh in average. The transfer efficiency of heat-electricity is 9 percent. Its capacity factor is 69 percent in winter, but lower in summer.

The Yangbajain geothermal power station supplied Lhasa's electricity demand for 50 percent in general situations and 60 percent in winter in the 1990s. At present, the Central Tibet grid has enlarged its total installed capacity. Geothermal power has reduced its proportion. There is a lack of energy resource (rare coal and oil) in Tibet. In order to protect the local fragile ecology environment, it is not permitted to transfer coal into

Tibet. The Tibet power grid is independent without connection to the national grid. The Central Tibet grid is formed by hydropower mainly. There is small electrical power from light oil, solar photovoltaic, and wind power, amongst others, except geothermal power generation.

Figure 4.1-A3. Yangbajain Geothermal Power Station,

Outdoor View (left) and Indoor View (right)

Source: Photo by Keyan Zheng.

4.1.A2. Geothermal reservoir and its exploitation in Yangbajain

The Yangbajain geothermal field covers an area of 35.6 km^2. But the high temperature area, which is suitable for power generation, is 5.6 km^2. The shallow reservoir is sand and gravel deposits of the Quaternary period at a depth of 120–300 m. It is covered by a silty soil layer and local hydrothermal alteration (silica sinter). This shallow reservoir yields wet steam for power generation. The average wellhead working pressure of steam is 0.3 MPa with 150°C in temperature at flow rate of 95 t/h for single well. The proven reserves are 34 MW_e. Besides, deep reservoir is fractured granite. It was completed exploration in 1990s. Its proven reserves are 30 MW_e. Well ZK4001 drilled a depth 1,459 m had wellhead working pressure of 1.5 MPa with a temperature of 200°C and a flow rate of 360 t/h, in which the steam flow rate is 37 t/h.

The developer was concerned that exploiting the deep reservoir would reduce recharge at the shallow reservoir. Therefore they didn't use the deep reservoir until 2008. In 2009 a full flow unit (screw expander) of 1 MW_e started to use the flow partially from well ZK4001. In 2010 another 1 MW_e unit started operation using the same flow. The power station has a total installed capacity of 26.18 MW_e. Its annual power production is about 140 million kWh.

Reinjection tests have been carried out in the Yangbajain geothermal field several times using tail water from the power station. But the injection rate was so small that it was not in a production scale. It was not due to technical difficulties, but due to low-level management and personnel quality. The discharge from the power station was used partly for space heating, greenhouses, and swimming, amongst others, whilst the bigger part was discharged into the surface river of Zangbu. The higher contents of Arsenic (As), (Hydrogen sulphide (H_2S), and Florine (F) have contaminated downstream river.

4.1.A3. Sustainability problem in Yangbajain

The Yangbajain geothermal power station is a contrary example for sustainable development. This is the first practice of high temperature geothermal exploration and development by China. Due to lack of geothermal technicians, no experience, and poor management, a lot of imperfections existed.

Geological reconnaissance and integrated scientific investigation discovered strong surface geothermal manifestations in the Yangbajain area in early 1970s. The first exploration hole was drilled in 1975. But it erupted by high temperature fluid when at 38.89 m depth. The Tibet Geothermal Geological Team was established in 1976, with hydrogeologists but no professional geothermal geologists. They carried out ‘seeking heat from heat’ tests. Exploration well drilling and power station building were conducted only in the vicinity of natural high temperature manifestations. Well ZK316 was buried after eruption and subsiding. Wells ZK322 and ZK312 were damaged after hydrothermal eruption. Especially, about a decade later, all manifestations including the boiling fountain and hot lake disappeared.

The reinjection of thermal tail water from the power station wasn’t carried out properly mainly due to poor skills of the crew team. Reinjection wells weren’t disposed in time when partially jammed. Finally the well wasn’t able to reinject. Although the surface subsidence was monitored especially for shallow reservoir area, no counter-measures were considered for prevention. (In comparison, the Wairakei geothermal power station in New Zealand was built 2 km away from the geothermal well site. The well site is also far away from the geothermal manifestation area. So their surface manifestations, well site and power station building avoided disadvantageous effects on each other.)

The shallow reservoir has encountered declining pressure and decreasing temperature, which reduced the yield. There was an incomplete daily record, but no reservoir engineering study, no countermeasure and remedy were conducted. In fact, the shallow reservoir exploitation should be shut down in advance, and then transferred into deep reservoir development. However the enterprise did not change, and did not intend to change.

Lessons learned: Causes of failure in sustainability

- Lack of systematic survey: 'Seeking heat from heat' type of exploration.
- Failure in implementing reinjection: The importance of injection was recognised at the start of production but problems related to: 1) poor skills of drilling and operating crew, and 2) scaling in initial injection cools, prevented the successful full implementation of reinjection.
- No prevention of subsidence: Caused abolished well and dry-out of natural manifestation.
- Delay of change in strategy in reservoir management: Although the shallow reservoir encountered pressure and temperature drop, they did not change the production zone into deep reservoir, causing a drastic decline in production.

Figure 4.1-A4. Hot Lake (left) and Boiling Spring (right) before Disappearance in Yangbajain

Source: Photo by Keyan Zheng.

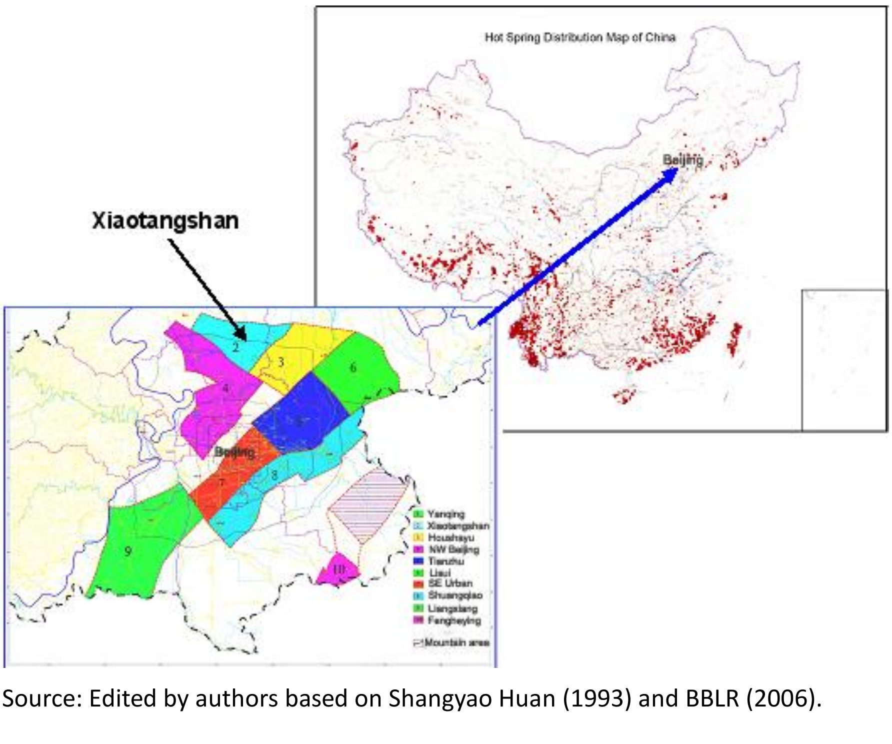
B. Case study on Xiaotangshan Geothermal Field

4.1.B1. History

The Xiaotangshan hot spring had its highest temperature of 53°C. Its earliest historic record is found to be 700 years old in the Yuan dynasty. A later warlord occupied it as a private villa. After liberation in 1948, the Xiaotangshan Hot Spring Sanatorium was built to serve the people. In order to ensure the thermal water supply for physiotherapy, exploration of hot mineral water was carried out in 20 km^2 area from 1956 to 1958 (**Figure 4.1-B1**). The total drilling depth reached 4,281.33 m with deepest depth of 433 m. Finally, 0.6 km^2 of distribution area of 37°C thermal mineral water was delineated. The exploration holes didn't transfer into production wells. The hot springs kept their artesian situation.

More than ten hot springs had existed in Xiaotangshan area, but in the early 1970s the hot springs petered out. In order to maintain a hot water supply, well drilling was started at that time. Thereafter well drilling and exploration enlarged the range, and well depth became deeper and deeper. The deepest well has reached 2,935 m. The highest temperature has been 83°C. There are now 70 or more wells in the field: 34 production wells, ten reinjection wells, two monitoring wells, and other reserved or retired wells.

Figure 4.1-B1. Xiaotangshan Location Map



Source: Edited by authors based on Shangyao Huan (1993) and BBLR (2006).

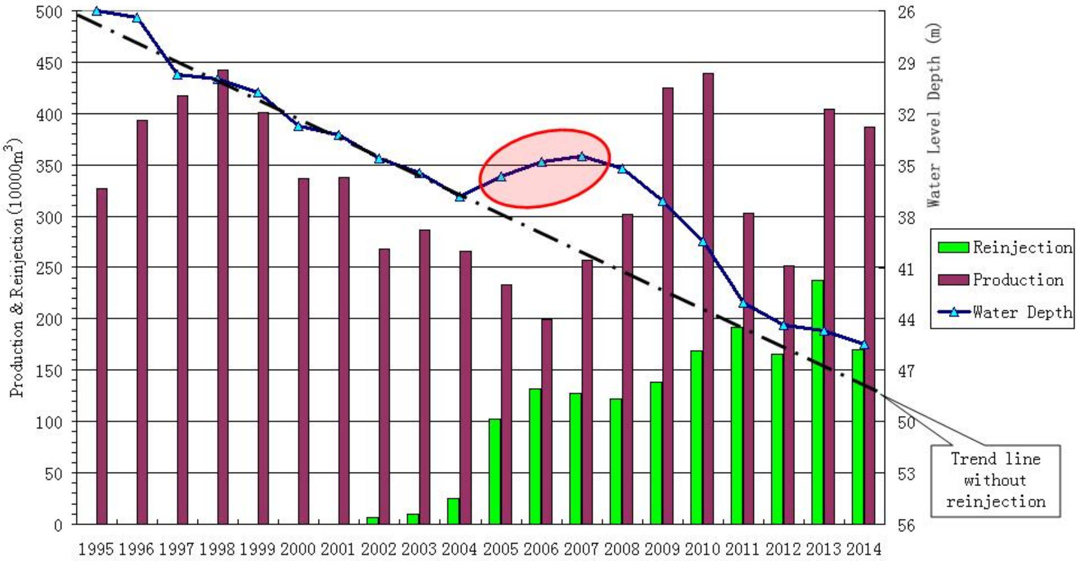
Geothermal resources management has been implemented in the Beijing area. New well drilling needs to be approved in advance. A production well needs injection well(s) which capacity match the production capacity. Geothermal tail water reinjection was started in 2002 in the field when 70,000 m^3 was reinjected that year. It had increased so rapidly that the annual reinjection was 248,000 m^3 in 2004 and was 1,027,000 m^3 in 2005. The reinjection rate reached the scale of production.

Figure 4.1-B2. Lower Water Level of the Eastern Spring (right) and the Western Spring (left) in Xiaotangshan Hot Spring Sanatorium

Note: Water level in the early 1970s.
Source: Photo by Keyan Zheng.

Such reinjection brought enormous positive effects. The thermal water level in the year ensuing is higher than the previous year in the corresponding month. The annual average water level rose three years continuously (**Figure 4.1-B3**). The first year it rose 1.20 m, the second year it rose 0.84 m, and in the third year it rose 0.35 m. The total rise is 2.39 m.

Figure 4.1-B3. Production and Reinjection with Water Level Behaviour in Xiaotangshan

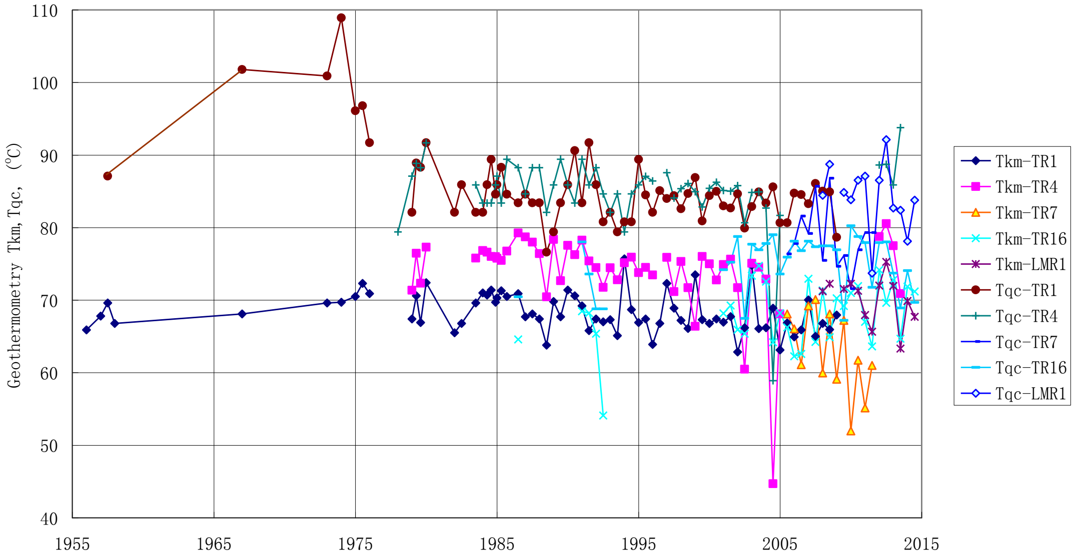


Source: Edited by authors based on the monitoring data from Beijing Geothermal Engineering Institute.

Figure 4.1-B3 shows the relationship among water level behaviour, annual production, and reinjection in the Xiaotangshan geothermal field in the last 20 years. During the first half of the period when there was rare reinjection, the water level showed a continuous declining. While in the latter half of the period, the large scale reinjection caused the water level to rise. (Note that it has not 'reduced the slope of declining' as usually be seen.) The rising trend can be seen as the red circle in **Figure 4.1-B3**. Later years, annual reinjection rate was kept around 1.3-1.9 million m^3, among which the maximum number of 2.38 million m^3 was recorded in 2013. However enlarged production made the water level decline again.

In addition, integrated geothermal monitoring including water chemistry, water level, and water quantity, has been carried out since 1956 in the geothermal field. It is the longest history of geothermal monitoring in China. **Fig 4.1-B4** shows the monitoring of geothermometry during the past 58 years as an example.

Figure 4.1-B4. Behaviour of K-Mg (Tkm) and Quartz (Tqc) Geothermometry in Xiaotangshan



K = potassium, Mg = magnesium.

Source: Edited by authors based on the monitoring data from Beijing Geothermal Engineering Institute.

4.1.B2. Sustainability of the Xiaotangshan Geothermal Field

Xiaotangshan geothermal field could be a typical model for sustainable geothermal development. The area of the geothermal field was 0.6 km^2 trapped in 1958 but it is 168 km^2 now. It has increased 280 times. The total artesian flow of the hot spring was 1.30 million m^3 in 1958. Now the field is exploited about 4.00 million m^3, three times more than before. Geothermal resources management has been carried out in the field. It controlled the water level, even raising the level sometimes.

Sustainable development in Xiaotangshan geothermal field could be kept in the future. Under certain conditions of production and reinjection, the geothermal water level could be controlled within a gentler slope of decline.

Figure 4.1-B5. Installation of Geothermal Reinjection Well in Xiaotangshan Field

Source: Photo by Keyan Zheng.

Lessons learned

- Successful reinjection in production scale may recover water level.
- Monitoring of water chemistry including geothermometry, water level, and water quantity is important.
- Resources management was achieved by water level control.

References

Beijing Bureau of Land and Resources (BBLR) (2006), 'Beijing Programme of Geothermal Resources Sustainable Use 2006–2020,' pp. 24 (in Chinese).

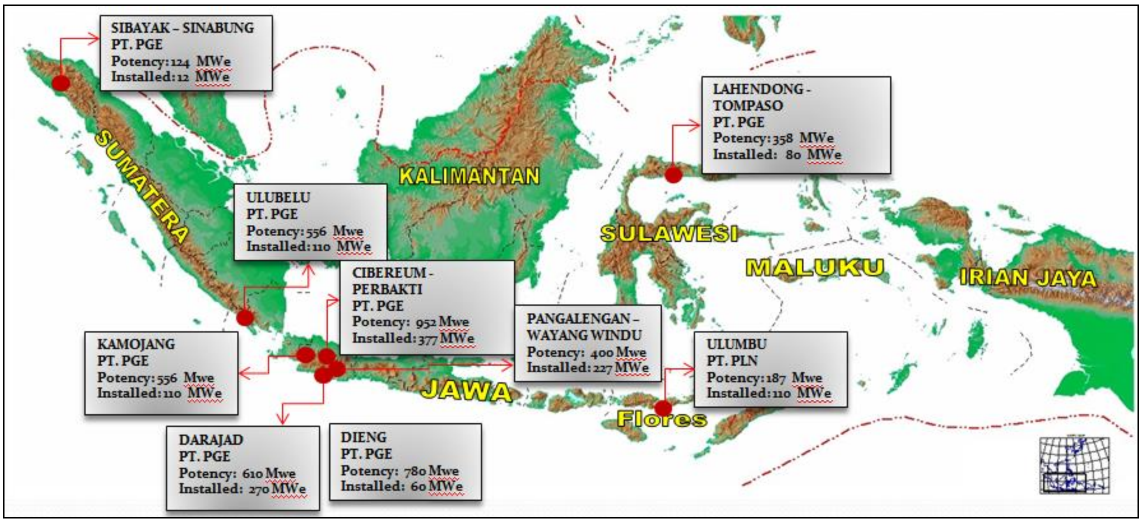
Dunzhujiacan (1985), 'A Pearl of the Roof of the World,' China Pictorial Publishing Company. (in Chinese)

Shangyao Huang (1993), 'Hot Spring Distribution Map of China,' Geographical Map Publishing House (in Chinese).

4.2. Indonesia: Summary of Six Geothermal Fields

The purpose of using geothermal energy in Indonesia is to generate electricity. Indonesia generates geothermal electricity from 10 geothermal fields. To do this in Indonesia, continuous supplies of geothermal fluids to power plants are always technical matters of concern. In the Indonesian case study in six geothermal fields, namely Kamojang, Salak, Wayang Windu, Lahendong, Dieng, and Darajat, common technical problems are identified in all components of the production system – in the reservoirs, in the well (production and reinjection), in the pipelines, and in the turbines. The reservoir problems are mainly induced by physical characteristic changes such as temperature and pressure changes. Common well, pipeline, and turbine problems are mineral deposition (scaling) and corrosion. To discuss the sustainable use of geothermal energy from Indonesia's geothermal fields, we divide the topics into energy efficiency, fluid production, fluid reinjection, monitoring activity, and problems encountered. The case study is summarised as follows, and as listed in **Table 4.2-1**.

Figure 4.2-1. Geothermal Power Plants in Indonesia



Source: Compiled by Geological Agency of Indonesia.

Kamojang Geothermal Field

The Kamojang field is a steam dominated system, having been exploited since the 1980s marked by generation of power plant units 1-2-3. Since then, the reservoir temperature decrease due to reservoir fluid mixing with recharged cooler water, is one of the common technical problems. The temperature problem induced a drop in pressure in the reservoir. Physical characteristic changes in the reservoir and other problems such as scaling in production wells caused a decline of geothermal fluid production to about 3–4 percent in average per year. To solve the decline of production fluid, some reserve and 'make-up' wells are provided. In addition, new production zones were identified to ensure the expansion of production.

Ever since the temperature decrease was identified, the reinjection strategy has been always reformulated to avoid mixing problem. Another problem is scaling, occurring in production wells, pipelines, gathering pipes, and also in the turbine. Scaling removal in production wells is done by adding chemical inhibitors.

To maintain steam production, monitoring activity has been applied. The surveillance activity includes quantity of steam produced, the geochemistry of reservoir fluid, microgravity, seismicity, temperature (including logging pressure and temperature (PT) or pressure, temperature and spinner (PTS)), and tracer tests (radioactive tracers, fluorescent dyes, chemical tracers). After 30 years of production, in terms of power plant perspective, concerns have risen related to the improvement of power plant efficiency.

Salak Geothermal Field

The Salak field is a water dominated system with the reservoir temperature reaching more than 300ºC. Technical problems encountered are reservoir temperature decrease due to mixing of cooler recharge fluids and boiling, well production decline rate, low permeability of production wells, a large non condensable gas (NCG) percentage (east block), and decrease of turbine output caused by scaling in the turbine (ferrous iron particles and silica).

Exploring new productive zones of the reservoir by using geophysical and drilling works has been done to determine targets for some additional production wells to be drilled as make-up wells in order to maintain steam supply. To increase the production of lower production wells, the stimulation works of low permeable wells have been attempted by using massive water injection, thermally induced cracking, slow-acidizing, and coiled-tubing acidizing.

Since the Salak field is water dominated, it produces big amounts of waste water, and therefore more reinjection wells are needed; 21 reinjection wells existed in 2009. To reduce the reservoir temperature decrease due to mixing problems, a reformulating reinjection strategy was applied.

Scaling in the turbine is removed by the application of a non-oxygenated steam wash system and also a material improvement for the demister element holder and online steam. In terms of the sustainability of the field, especially from a power plant perspective, turbine output was increased from 330 MW_e in 1998 to 337 MW_e in 2012.

To maintain the steam supply, surveillance activities have been done since 1994, that is, quantity of steam produced, geochemistry of reservoir fluid, microgravity, seismicity, and temperature (by using PT, PTS, and geochemistry).

Lahendong Geothermal Field

The Lahendong field is a water dominated system, with temperatures reaching 320^{o}C, and is the first geothermal power plant on Sulawesi Island. The main technical problems in the field are acid geothermal fluid, high chloride content, and high sulphate content in a big productive well. Surveillance activities include quantity of steam produced and short-term micro seismic monitoring.

Dieng Geothermal Field

The Dieng field is located in Central Java, a water dominated system, with capacity of 60 MW_e, and beginning production in 1998. After that production had been unstable, declining rapidly, and the unit was shut down until 2002, but production then dropped below 30 MW_e in 2010–2011. Technical problems observed were unstable power generation and declining rapidly due to problems in the steam production process, power plant performance, silica scaling in the reinjection well and pipeline, sulphide scale in the production well, and the presence of pitting corrosion, dent, erosion, and a crack in the turbine. An increase in the steam production process, plant performance, and reliability, removal of scale by mechanical cleaning, reformulating the reinjection scheme were conducted to increase power production. After several attempts to overcome the problems, the maximum plant load reached approximately 52.56 MW_e in February 2014.

Darajat Geothermal Field

The Darajat field is a dry steam system, located close to Kamojang, with reservoir pressure of 28 bar on average, temperature around 240°C, and 49 active production wells. The technical problems of the Darajat field are similar to those of the Kamojang field and other systems: well production decline rate, pressure drop, and scaling (silica, and ammonium carbonate). Mechanical cleaning of the well to clean the obstruction in the wellbore and improve the deliverability of the well is common practice. An enhanced geothermal system is now attempted in this field to increase the permeability of the low permeable wells. Another attempt to reduce the flow rate decline was done by optimising the pressure drop around the interface area, a surface facility engineering work. This work was dedicated to increase pressure, hence reduce number of make-up wells. Surveillance activities are of integrated control system, quantity of steam produced, geochemistry of reservoir fluid, microgravity, seismicity, and temperature logging measurement (PT, PTS) using 6 monitoring wells.

Wayang Windu Geothermal Field

The Wayang Windu field is a two-phase system, now producing 227 MW_e from two units, where Unit 1 has been operating since 2000. The main technical problems are reservoir pressure decline and erosion of the turbine. New production wells were needed since the pressure declined. To provide new productive zones, new zones were explored by applying geophysics and well drilling works. Another attempt to provide a greater steam rate was done by applying hydraulic fracturing using cold water (condensate) injection to stimulate more permeability. Output optimisation was also conducted by increasing turbine output from 110 MW_e to 117 MW_e. Monitoring or surveillance activity in the Wayang Windu field consists of an integrated control system, quantity of steam produced, the geochemistry of the reservoir fluid, microgravity, seismicity, and temperature measurement (logging PT, PTS).

Lessons learned

- The most common problems in geothermal power plants are scaling (in production wells, piping, reinjection, and turbines), corrosion (in particular in production wells), and water mixing.
- Chemical inhibitors and mechanical cleaning (workover) are the most common methods to overcome the mineral scaling problems.
- Make-up well is a common practice to maintain steam supply.
- Major surveillance activities are to monitor the quantity of steam produced, the geochemistry of the reservoir fluid, microgravity, induced seismicity, temperature, and chemical tracers.
- Silica sinter problem was reduced by new a production design (by pressure and temperature control).

Table 4.2-1. Summary of Case Study of Six Geothermal Power Plants in Indonesia

Field Name	Energy Efficiency	Fluid Production	Reinjection	Monitoring	Problem
Kamojang: Vapour dominated ~ 245°C	- Life time turbine analysis of Unit 1 (after 30 years production)	- Removing silica scale by using chemical inhibitor - Reserve well and make-up wells to maintain steam supply - Exploring new productive zones (geophysics and well drilling) for expansion of production	- Reinjection well - Reformulating reinjection strategy due to mixing problem	Surveillance activities - Quantity of steam produced - Geochemistry of reservoir fluid - Microgravity - Seismicity - Temperature: PT, PTS - Tracer test: Radioactive tracers, fluorescent dyes, chemical tracers	- Well production decline rate 3–4% per year; - Reservoir temperature decrease: mixing of cooler recharge fluids - Scaling (silica) steam pipeline, gathering pipe and production wells, and turbine - Pressure drop
Salak: Water dominated 240–310°C ;	- Increase turbine output from 330 MW_e in 1998 to 337 MW_e in 2012. - Resolve decrease of turbine output caused by scaling problems: application of a non-oxygenated steam wash system, material improvement for the demister element holder and online steam	- Number of wells: 69 wells used for production in 2009, now some additional well - make-up wells to maintain steam supply - Exploring new productive zones (geophysics and well drilling) for expansion of production - Stimulation of low permeable wells: massive water injection, thermally-	- 21 wells in 2009 - Reformulating reinjection strategy due to mixing problem	Surveillance activities since 1994: - Quantity of steam produced Geochemistry of reservoir fluid - microgravity - seismicity - Temperature: PT, PTS, geochemistry	- Reservoir temperature decrease: mixing of cooler recharge fluids; boiling. - Well production decline rate - A number of wells (10 add wells added 2004–2009) have low permeability; - A large NCG percentage (east block) - Decrease of turbine output scaling in

		induced, slow-acidizing, and coiled-tubing acidizing; - Scale removal: application of a non-oxygenated steam wash system, material improvement			turbine (ferrous iron particles, silica)
Lahendong: Two phase 280–320°C			- Reinjection well	Surveillance activities: - Quantity of steam produced - Short-term micro-seismic	- Acid fluid, high chloride, high sulphate in a big productive well.
Wayang Windu: Two-phase system 227 MW_e, unit 1 operating since 2000	- Increase turbine output	- Exploring new productive zones (geophysics and well drilling) for expansion of production - Permeability stimulation: hydraulic fracturing by using cold water (condensate) injection	- Reinjection well	Surveillance activities: - Integrated control system - Quantity of steam produced - Geochemistry of reservoir fluid - Microgravity - Seismicity - Temperature: PT, PTS	- Reservoir pressure decline - erosion of turbine problem
Dieng: water dominated installed capacity of 60 MW_e	- Steam production process, - Plant performance and reliability	- Production wells productivity - Well workovers were performed using mechanical cleaning combined with a jet pulsation	- Reinjection well - Brine injection scheme - Well workovers were performed using mechanical cleaning combined with a jet pulsation	Surveillance activities - Quantity of steam produced - Scaling rate	- Power generation not stable and has declined relatively rapidly - Performance of steam production process, power plant - Silica scaling in well

					and pipeline as a major problem - sulphide scale in production well, silica scale in reinjection well - Presence of pitting corrosion, dent, erosion, and crack in turbine
Darajat: Dry steam; 28 bar in average; around 240°C 49 active production wells	- Optimisation of the pressure drop around the interface area	- Clean obstructions in the wellbore and improve the deliverability of the well - Enhanced Geothermal System to increase permeability	- One active injection well	Surveillance activities: - Integrated control system - Quantity of steam produced - Geochemistry of reservoir fluid - Microgravity - Seismicity - Temperature: PT, PTS - 6 monitoring wells	- Well production decline rate of ~12.1% per year - Pressure drop - Silica scale in the wellbore - Stopped producing completely due to ammonium carbonate (NH4CO3) scale build up near its wellhead - 20 years of continuous operation, the decline rate is about 9.3%

Source: Compiled by authors.

4.3 Japan: Cold Injection to Superheated Steam Zones

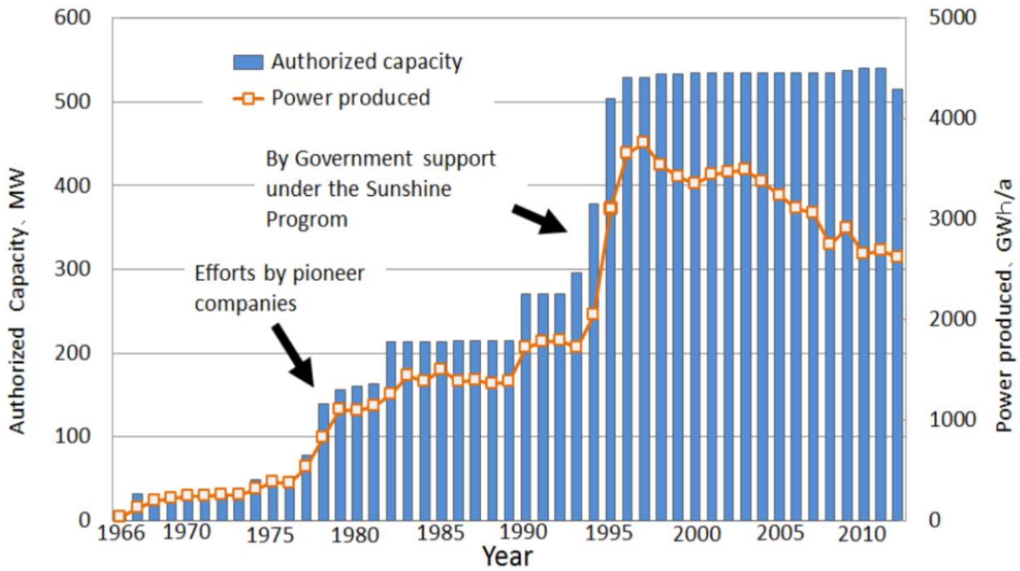
4.3.1. Status of Japan's geothermal power plants

The authorised capacity of geothermal power plants in Japan is about 520MW_e and has been almost the same since 1996. However, the annual power production is gradually decreasing.

The rate of production decrease depends on the site. Several geothermal power plants have rapidly decreased, while others have not. The reasons for decreasing production are mainly as follows:

1) Decreasing pressure or volume of reservoir due to over production rather than suitable production rate.
2) Scaling in production wells or injection wells and decreasing flow rate. In this case, the solution has been to remove scale from wells or drill new wells.

Figure 4.3-1. Geothermal Power Production and Authorised Capacity in Japan

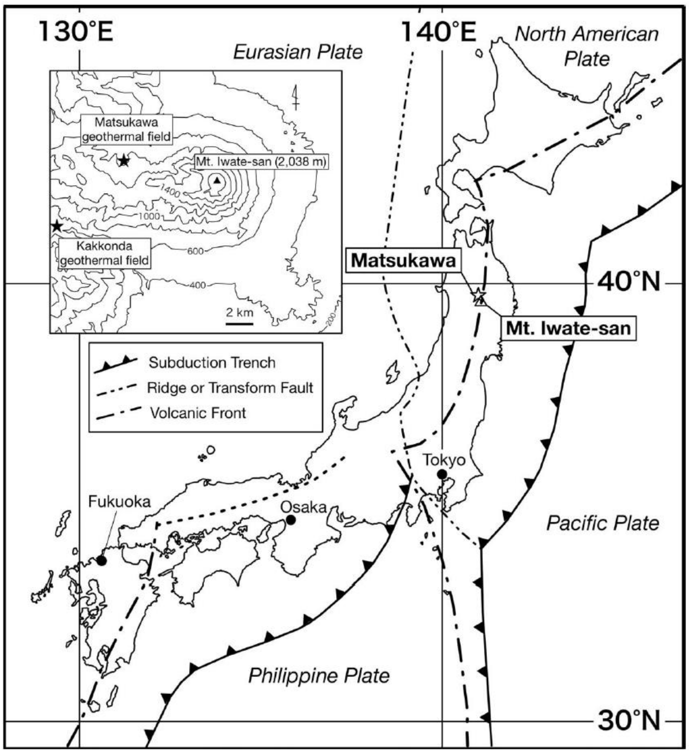


Source: Edited by authors based on TENPES (2014).

4.3.2. Review of injection test at Matsukawa Geothermal Field

The Matsukawa Geothermal Power Station is located near an active volcano Mt. Iwatesan in the Hachimantai volcanic area, northeast Japan (**Figure 4.3-2**). Its operation began in October 1966 with an installed capacity of 9.5 MW_e as the first commercial geothermal power station in Japan. Its capacity was increased gradually up to 23.5 MW_e by June 1993. Matsukawa is known as the only vapour dominated reservoir in Japan.

Figure 4.3-2. Site of Matsukawa Geothermal Power Station

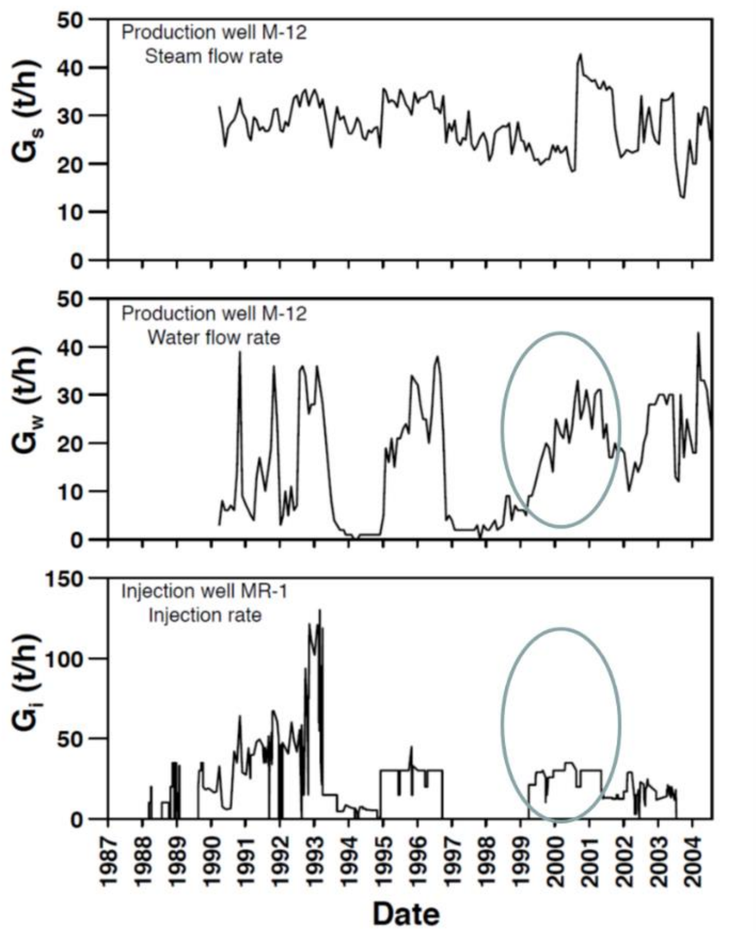


Source: Fukuda et al. (2006).

This geothermal field is situated in a valley and the production wells are distributed along a stream (**Figure 4.3-3**). Since it is a vapour dominated reservoir, no reinjection has been conducted. However, injection of river water was experimentally conducted from 1988 to 2003, aiming at recovery of the reservoir pressure (**Figure 4.3-3**). Although most of the production wells had been producing superheated steam, two of them started producing saturated steam following water injection.

In the Matsukawa geothermal field, the effect of injection to production rate and connectivity between injection well and production well were analysed (Fukuda, et al., 2013). **Figure 4.3-3** shows the relationship between the injection at MR-1 and production at M-12 from 1987 to 2004. In **Figure 4.3-4**, G_s and G_w represent the steam and water production rate of Well M-12, respectively, while G_i represents the injection rate of well MR-1.

Figure 4.3-3. Production History of Well M-12 and Injection History of Well MR-1

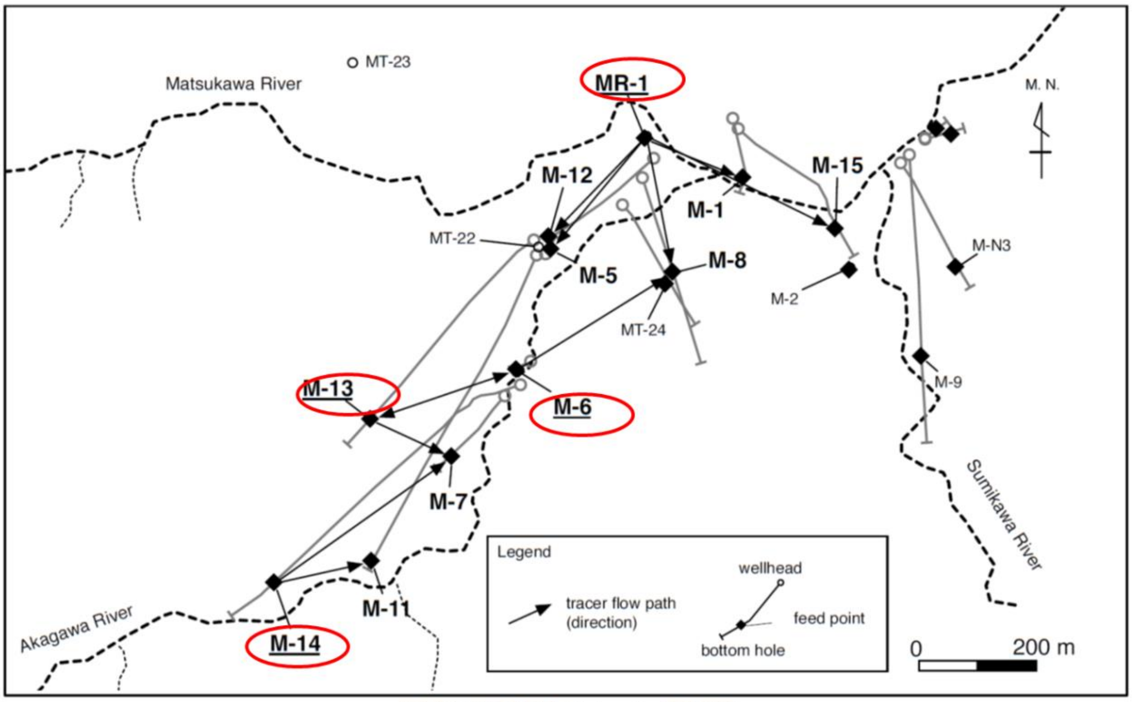


Source: Fukuda et al. (2013).

The increase of production rate at M-12 seems to be synchronising with injection rate of MR-1. The increasing rate of water production is higher than that of steam production. Since tracer return from MR-1 to M-12 is identified (**Figure 4.3-4**) with a return ratio of about 25 percent, the increasing production is recognized as the response of injection.

As for other wells, **Figure 4.3-5** show the relationship between injection well M-6 and production wells M-8 and M-13. In the Matsukawa geothermal field, the steam tends to be overheated steam. In the case of M-8 and M-13, the saturation temperature is around 145°C for the wellhead pressures around 0.45 MPa. The steam temperature of M-8 and M-13 was about 180°C before injection to M-6 and this means that M-8 and M-13 produced over-heated steam.

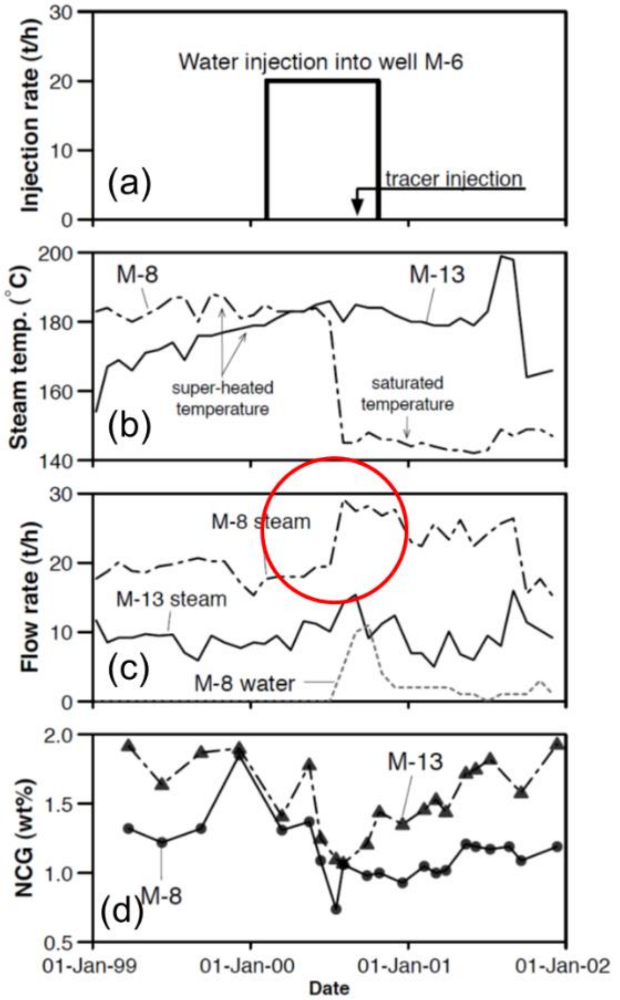
Figure 4.3-4. Tracer Flow Paths in the Matsukawa Geothermal Field



Notes: The arrows, connecting main outflow points of injection wells, and feed points of production wells, express tracer flow paths and directions.
Source: Fukuda, et al. (2013).

In this case, water injection from M-6 started in early 2000 and the injection rate is about 20 tonnes/hour. Six months after beginning of injection, the steam temperature rapidly decreased and the over-heated steam changed to saturated steam. With this change, the steam production increased about 10 tonne/hour with water production. The concentration of non-condensable gas (NCG) decreased 0.7 percent. The return ratio of tracer at M-8 is about 72 percent from M-6. These production rates and chemical components are the result of strong response of water injection. Therefore, after stopping water injection, the production status did not change to that of before injection. On the other hand, the status of production at M-13 did not change as that of M-8. The difference of the response is due to hydrological connection (water paths) between the wells identified by tracer return ratio.

Figure 4.3-5. Relationship Between Injection Well M-6 and Production Wells M-8 and M-13



Notes: (a) Injection History of Well M-6, (b) Steam Temperature, (c) Steam and Water Production Rates, and (d) Non-condensable Gas (NCG) Concentration of Wells M-8 and M-13.
Source: Fukuda, et al. (2013).

Lessons learned

- An over-heated vapour dominant reservoir, such as Matsukawa, showed increasing steam production with water injection.
- Tracer test is one important method for evaluating the production recovery.
- Other over-heated reservoirs and water dominant reservoirs should be checked, and the possibility of the EGS and water injection to maintain geothermal power generation should be discussed.

References

Fukuda, D., T. Akatsuka and M. Sarudate (2006), 'Characterization of Inter-Well Connectivity Using Alcohol Tracer and Steam Geochemistry in the Matsukawa Vapor-Dominated Geothermal Field, Northeast Japan', *Geothermal Resources Council Transaction*, 30, pp.797–801.

Fukuda, D., T. Kuwano, and R. Itoi (2013), 'Two-phase Tracer Tests Using Alcohols at the Matsukawa Vapour-dominated Geothermal Reservoir: Evaluation of Responses to Water Injection and Prediction of Production Interference', *J. Geotherm. Res. Soc. Japan,* 35(2), pp.69–81. (Japanese article with English abstract)

Thermal and Nuclear Power Engineering Society (TENPES) (2014), The Present Status and Trend of Geothermal Power Generation 2013 (in Japanese).

4.4. Philippines: Reservoir Management Case Studies of Two Philippine Geothermal Steam Fields for Sustainable Production and Reinjection

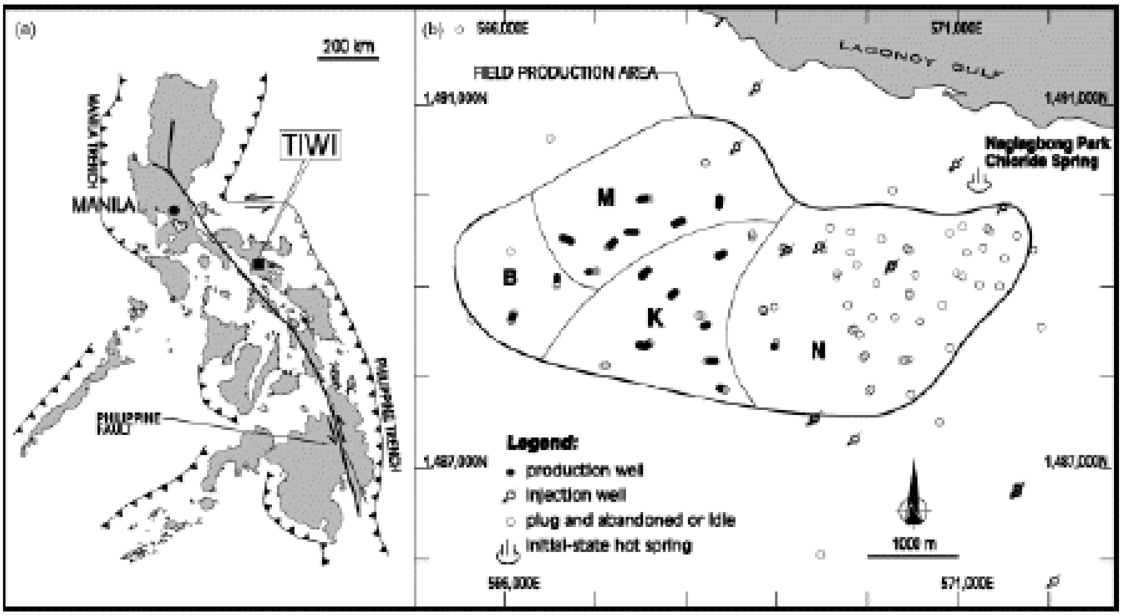
A. Case study on Tiwi Geothermal Field, Albay

(Condensed from Menzies et al. (2010)

4.4.A1. Background

The Tiwi geothermal field is located on the northeast flank of Mt. Malinao in Albay Province, the Philippines, approximately 350 km southeast of Manila (**Figure 4.4-A1**). Commercial operation began on 15 May 1979 with the start-up of the first National Power Corporation (NPC) 55 MW_e unit and over the next three years, the installed capacity was increased to 330 MW_e (Alcaraz, et al., 1989). After 30 years of operation, the total gross generation already reached 49.5 TWh, at an average of 157 MW_e per year. The turnover of NPC power plants to Aboitiz Power Renewables, Incorporated took place on 25 May 2009.

Figure 4.4-A1. Location of the Tiwi Geothermal Field



Notes: N = Naglagbong, K = Kapipihan, B = Barlis, M = Matalibong.
Source: Menzies et al. (2010).

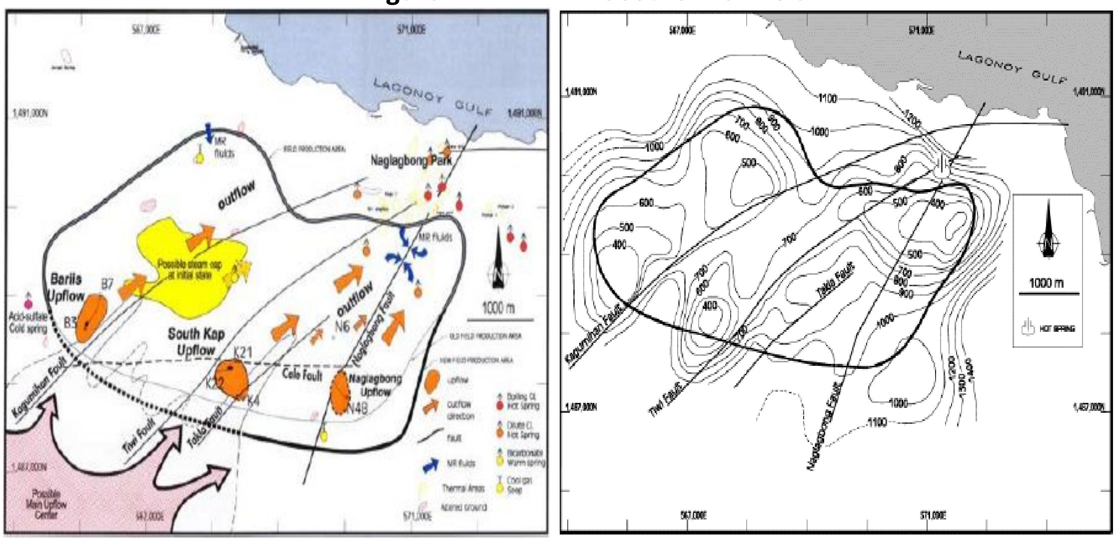
4.4.A2. The Tiwi Geothermal Field: From exploration to development

The commercial potential of the Tiwi field was established in the 1960s. Drilling of the first deep exploratory well, Naglagbong-1, in early 1972 proved the existence of a high temperature resource viable for commercial development, whilst drilling of the succeeding wells was successful in delineating a large reservoir.

4.4.A2.1. Conceptual model

The Tiwi field is divided into four distinct geographic sectors: Naglagbong (Nag), Kapipihan (Kap), Matalibong (Mat), and Barlis (Bar). Results of geochemical, geophysical, and early delineation drilling identified three different upflow zones in the Bar, South Kap, and Nag sectors (**Figure 4.4-A2**). The heat sources are believed to be related to intrusions underlying small dacitic to andesitic domes located south of the Kap and Bar sectors, as well as a broader heat source beneath Mt. Malinao. The Kagumihan and Tiwi faults (**Figure 4.4-A2**) and possibly the Naglagbong fault are main structural controls of fluid distribution. The cap rock overlying the productive reservoir is dominated by smectite clay. It is thinnest in the northeast of the Nag sector, where the reservoir top is shallowest (**Figure 4.4-A2**).

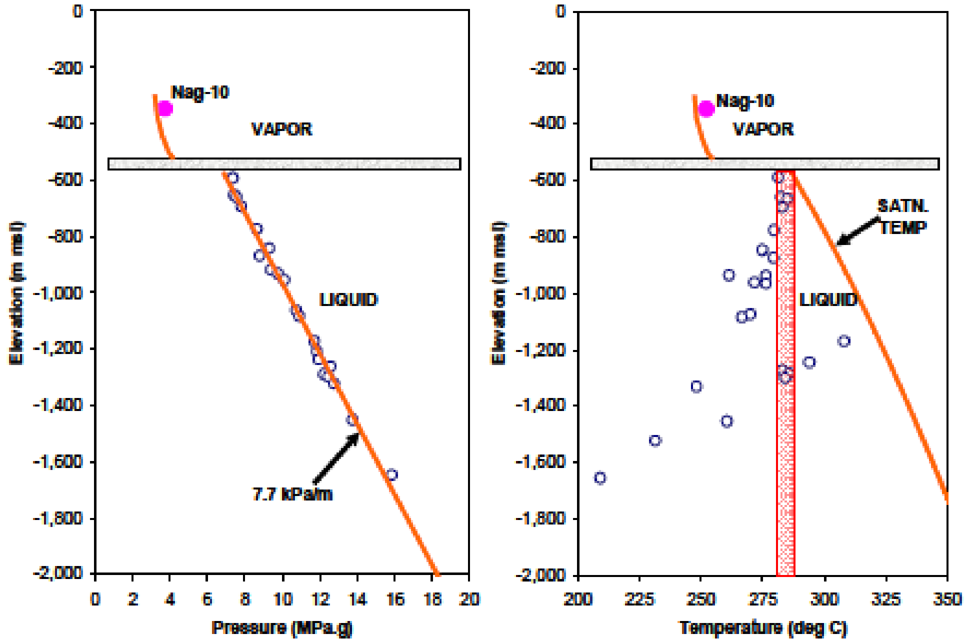
Figure 4.4-A2. Tiwi Geothermal Field



Notes: Initial state conceptual model of Tiwi (left); Reservoir top and major structures in Tiwi Geothermal Field (contours in metres below sea level) (right).
Source: Menzies et al. (2010).

The reservoir was initially an over-pressured (Strobel, 1982) and liquid dominated system (**Figure 4.4-A3**), with an average resource temperature of ~290°C (Sunio, et al., 2004). A shallow steam zone was present in the vicinity of Nag Park (**Figure 4.4-A3**) that was formed by leakage through the cap rock and subsequently expanded due to boiling associated with pressure decline. An extensive steam zone was also encountered in the west (**Figure 4.4-A2**) that was probably formed or expanded by pressure drawdown.

Figure 4.4-A3. Initial Pressures and Temperatures in Naglagbong Sector Wells



Source: Strobel (1982).

4.4.A2.2. Operational highlights

Figure 4.4-A4 shows generation performance from start-up in 1979 to the end of 2008 and steam production from the eastern (Nag) and western (Kap-Mat-Bar) areas of the field. Currently, the field has a baseload capacity of 234 MW_e, with Unit 3 designated as a stand-by plant. Out of the 156 wells drilled in the Tiwi area, 37 wells are presently used for production, whilst 20 wells are used for injection (12 hot and 8 cold). The operational highlights are summarised below:

1979–1984: Initial start-up of the power plants, with production mainly from the Nag area, reaching peak generation of 290 MW_e.

1985–1987: Decline in generation to 170 MW_e due to the impact of meteoric recharge

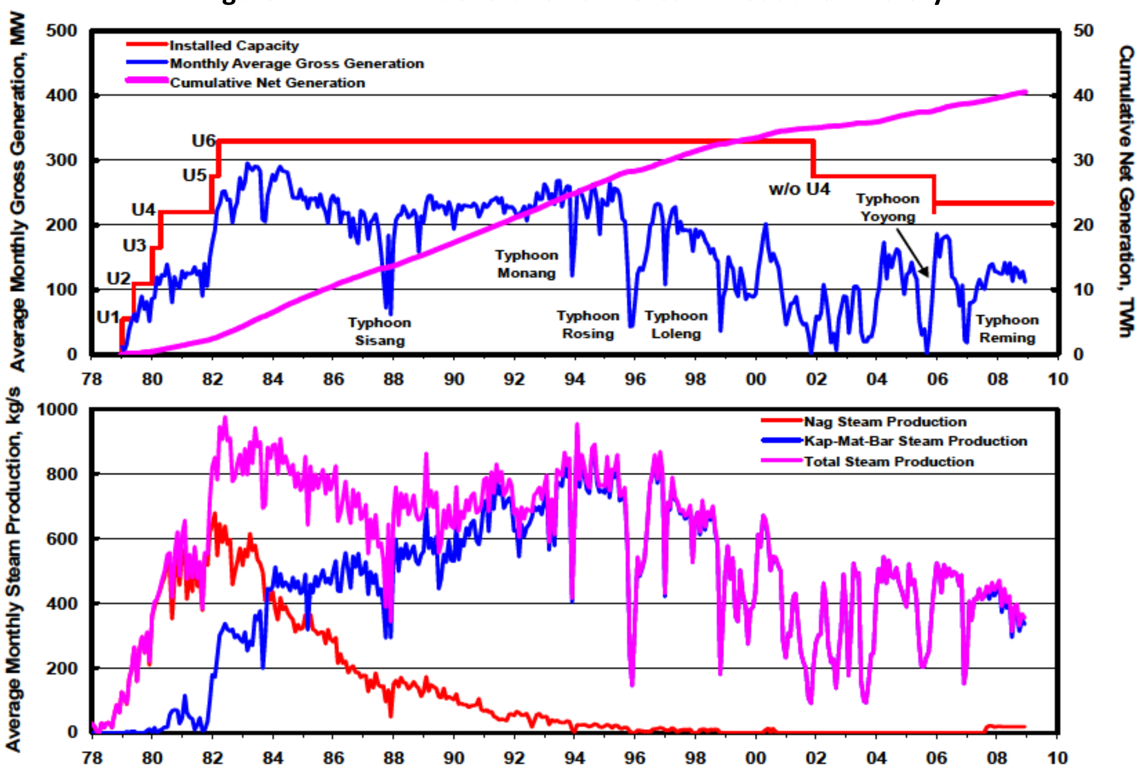
(MR) in the Nag area.

1988–1995: Recovery in generation to 270 MW_e due to continued drilling in the Kap, Mat, and Bar areas and improvements to surface facilities to optimise steam usage.

1996–2004: Low generation and steam production due to decline in base steam supply, lack of make-up well drilling, low steam efficiency due to deterioration of the power plants and plant shut-downs due to typhoon damage and rehabilitation activities.

2005–present: Improvement in steam efficiency as the rehabilitated plants came back on-line.

Figure 4.4-A4. Tiwi Generation and Steam Production History

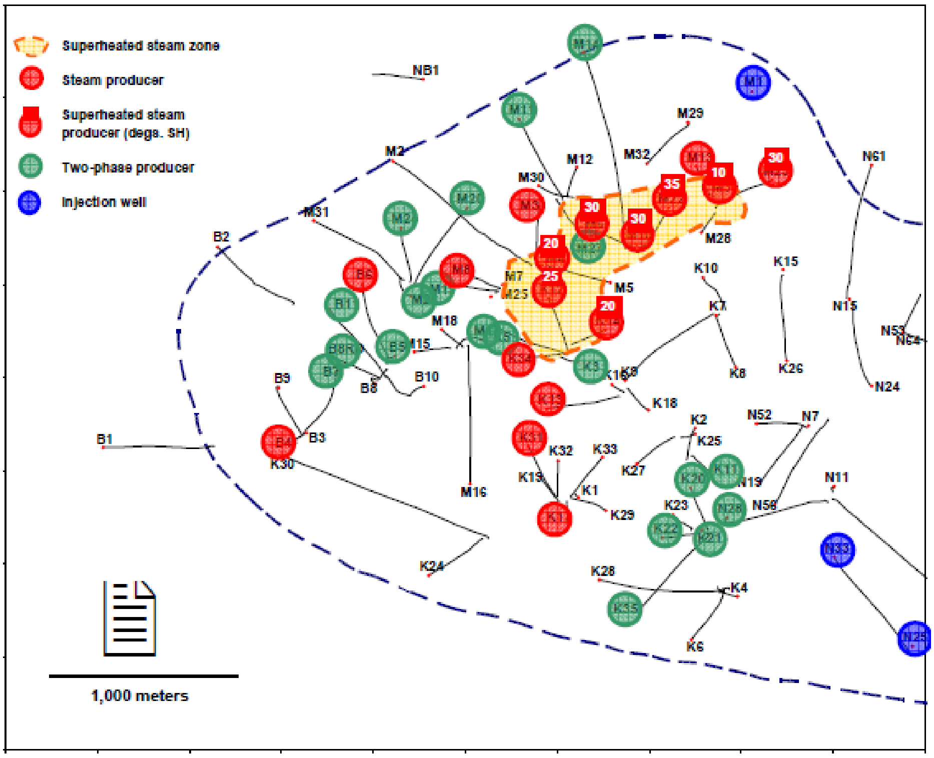


Source: Menzies et al. (2010).

In the initial development of the Tiwi field, the disposal of brine via a canal to Lagonoy Gulf (**Figure 4.4-A1**) caused high initial pressure drawdown. Injection in the Nag sector using existing acidic wells started in 1983 (Santos and Carandang-Racela, 1993) but this resulted in the cooling of nearby production wells. Shifting of injection location then took place, and by 1993 all brine and condensate were being injected at different parts of the field.

The present steam availability is estimated to be 450 kg/s from the 37 production wells (**Figure 4.4-A5**). This is equivalent to ~200 MWe, based on the design steam requirement of 2.25 kg/s-MWe for the rehabilitated power plants with their mechanical gas extraction systems operating. The discharge characteristics of the wells vary widely (**Figure 4.4-A5**) from liquid dominated producers, with enthalpies as low as 1,050 kJ/kg, to superheated steam wells with up to 35 °C of superheat.

Figure 4.4-A5. Tiwi Production Well Locations and Production Characteristics, December 2008



Source: Menzies et al. (2010).

4.4.A3. Current resource challenges

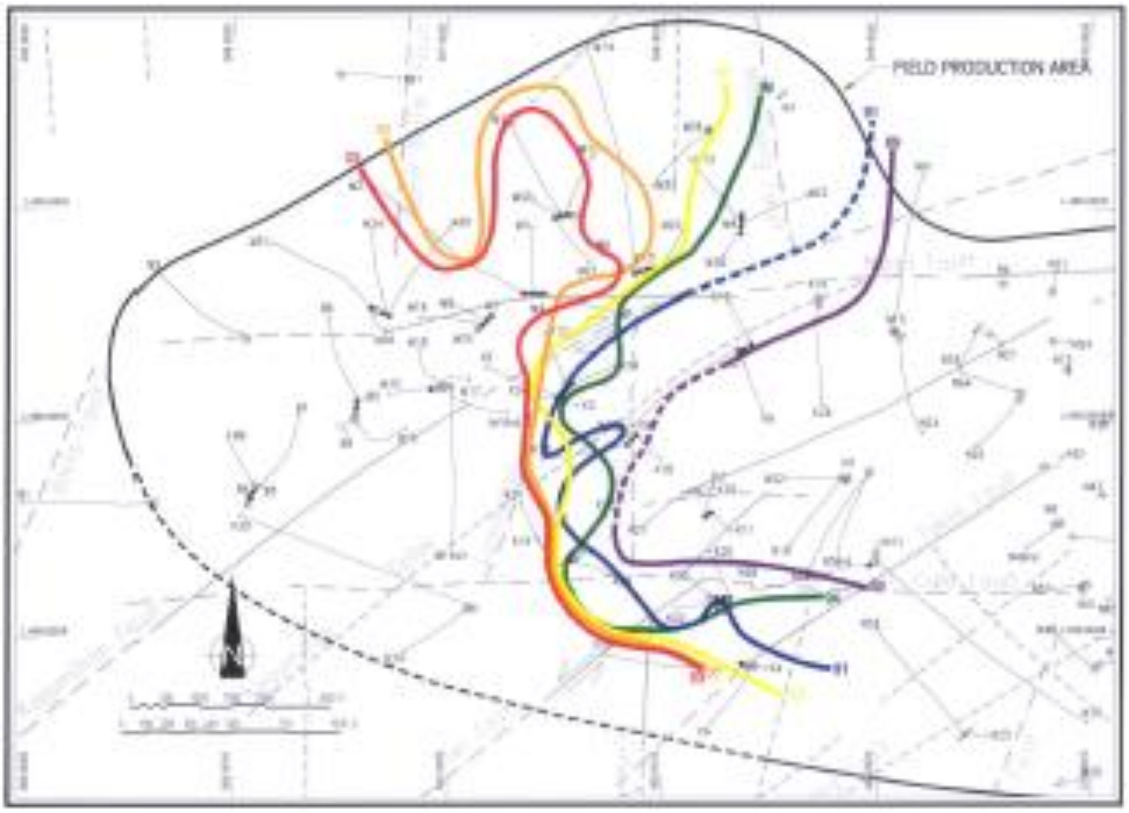
4.4.A3.1. Meteoric recharge

Intrusion of cooler, dilute groundwater in the Nag sector was inferred based on the decreasing Chloride (Cl) content of produced brine (Gambill and Beraquit, 1993) and results of tracer tests using tritium (**Figure 4.4-A6**). Induced by pressure drawdown, this rapid meteoric recharge encroachment caused calcite scaling both in wellbore and formation and resulted in significant reduction in steam supply. Later on, development shifted from Nag to Kap, Mat, and Bar sectors due to flooding with meteoric recharge of the shallow Nag reservoir.

Although a number of wells stopped producing due to the influx of cold meteoric recharge, it is believed that the increasing mass flow at constant enthalpy of some South Kap wells (Kap-20, 21, and 22) is associated with the pressure support coming from meteoric recharge (MR).

Repeat precision gravity surveys are becoming more helpful in tracking MR movement. The natural decline of tritium tracer concentration makes it impractical to use in studying the flow of fluids.

Figure 4.4-A6. Tritium Contours Showing Movement of MR 'Front' with Time



MR = meteoric recharge.
Source: Menzies et al. (2010)

4.4.A3.2. Production of acid-sulphate fluids

Wells drilled in the Bar and Kap sectors, situated in the southwest, and North Mat area were found to produce acid-sulphate fluids. These acidic wells are allowed to flow to the system as long as the discharge fluid pH is ≥ 4.0. The fluid's iron ion (Fe) concentration and potential hydrogen (pH) are carefully monitored as per set guidelines (Villaseñor et al., 1999) to ensure that corrosion is not occurring both within the well and in surface facilities.

Although the attempt to increase the discharge pH by injecting sodium hydroxide through capillary tubing was successful for 3 months (Bar-08), there was no other downhole mitigation system implemented due to the observed scaling in the wellbore and recovered corroded liner during workover.

The recent success of implementing a deep cemented liner strategy in two Bar wells proved that the shallow acid-sulphate zones can be isolated and that the south and southwest acidic areas can now be commercially exploited.

4.4.A3.3. Injection breakthrough

When injection started in 1983, cooling was quickly observed and injection was relocated to the southeast 'edgefield' and 'outfield' wells. Since then, there have not been any significant thermal breakthrough issues. But as a preventive measure, limits have been placed on the allowable injection rates in specific wells and production wells 'at risk' are carefully monitored.

In the Mat area of the field, some of the dry and superheated steam wells have turned two-phase over the past 5 years and there is a possibility this might be associated with injection.

In 2005, the volume of separated brine has increased significantly resulting to a lower overall flash fraction. Hence, there will be a continuing need to review the injection strategy and chemical monitoring, flow testing and tracer testing programmes and look for new injection sites in case of injection capacity shortfall.

4.4.A3.4. Matalibong 'superheated' steam zone

The increased extraction from the Mat area in the early 1990s caused extensive boiling to occur as the pressures declined, forming a reservoir zone that produces 'superheated' steam (Lim, 1997). Along with superheated steam, the wells produced volatile Cl (Sugiaman, et al., 2004), which formed very high, localised, concentrations of HCl that may promote accelerated corrosion in pipelines when condensation takes place. Scaling also occurred where the superheated steam mixed with two-phase fluids in the wellbores and pipelines.

To mitigate corrosion, the Mat-Ridge production system was redesigned to inject sufficient separated brine into the steam pipelines to prevent the high, localised HCl concentrations. This has been effective and with the increasing brine production in recent years, there is no longer a significant risk to the surface facilities.

Since 2001, the Mat superheated steam zone has lost 76kg/s of flow due to the water rising and 'flooding' zones that used to produce steam or superheated steam. The rise in water level is due to the combined effect of increasing deep reservoir pressure and declining steam zone pressure.

Both deep reservoir and shallow steam zone pressures are now being monitored to help develop a strategy to maintain production from the steam zone. If the effect of the increasing water level can be reduced, previously affected wells may be able to produce again. However, there will be a risk of MR influx from the field margins if the reservoir pressure becomes too low.

Summary and lessons learned

- The Tiwi Geothermal Field has been affected by a number of resource management challenges including meteoric-water influx, injection breakthrough, acid fluids utilisation, scaling and corrosion.
- The biggest challenge was the influx of MR in the Nag area, which necessitated the relocation of the entire production system. Repeat precision gravity survey is becoming useful for monitoring.
- To prevent detrimental effects of injection breakthrough, relocation of infield to edgefield and outfield injection was an effective strategy in the Nag area. Production wells at risk are carefully monitored and allowable injection rates are limited for specific injection wells to avoid cooling.
- As for mitigating corrosion attack from acidic fluids, the new well design with a cemented blank liner run to below –1,000 m msl was proven effective to case-off potential acid zones.
- For controlling superheated steam zones, pressure balance of shallow steam zone and deep reservoir is essential and pressure monitoring in these zones are important.
- The key to overcoming these challenges is to have a strong multi-disciplinary resource team in-place that understands the problems and can provide feasible solutions.

B. Case study on Tongonan Geothermal Field, Leyte

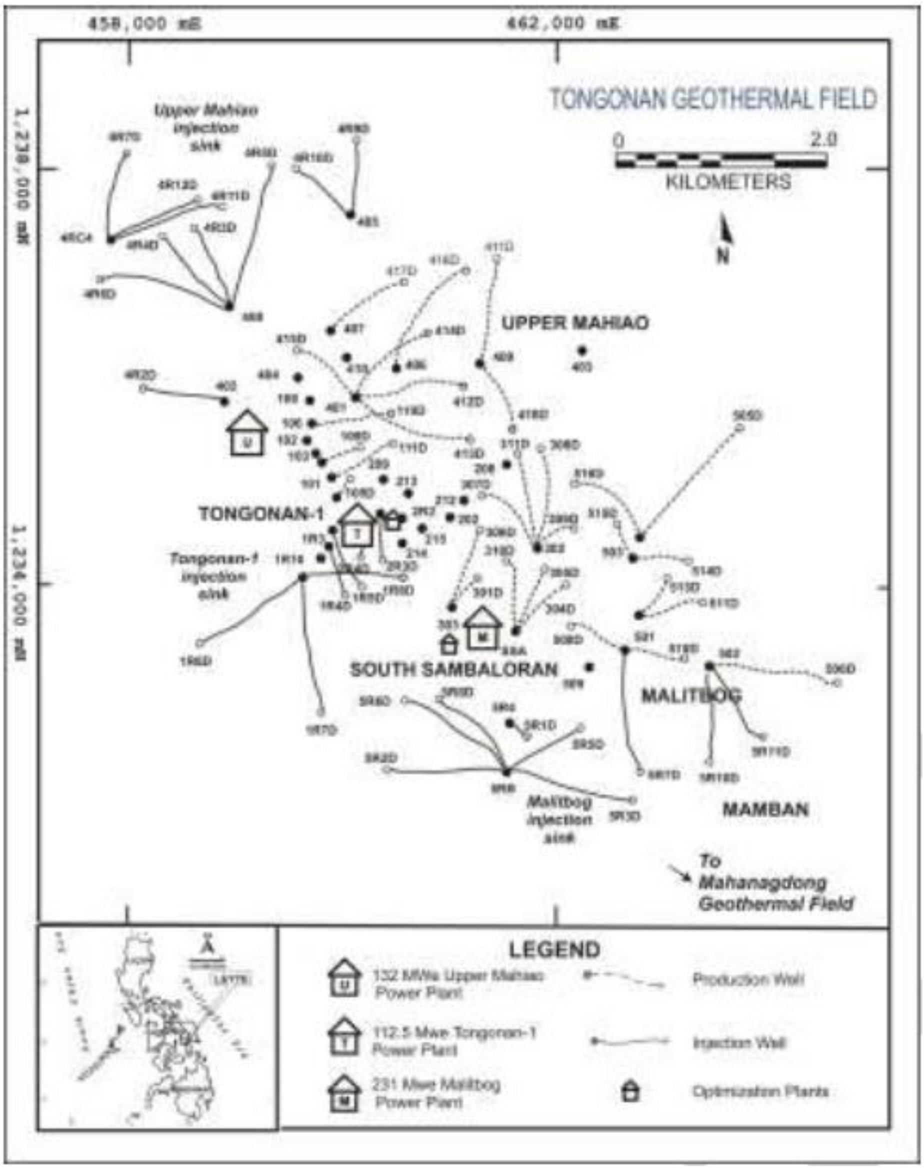
(Condensed from Dacillo et al., 2010)

4.4.B1. Background

The Tongonan Geothermal Field (TGF) in Leyte, Philippines has achieved 30 years of continued sustainable production. The TGF is one of the hydrothermal systems encompassed by the Leyte Geothermal Production Field (LGPF), one of the largest wet steam fields in the world. The LGPF is located along the northwest trending chain of Quaternary volcanoes that runs parallel to the Philippine trench and lies on a bifurcation of the Philippine Fault.

The developed production area of the LGPF draws from two distinct hydrothermal systems—the TGF and Mahanagdong, which are separated by the low permeability Mamban block. The TGF itself is divided into four production sectors—Upper Mahiao, Tongonan-1, Malitbog, and South Sambaloran—supplying steam to three power plants (**Figure 4.4-B1**). The oldest of the plants is the 112.5 MW_e Tongonan-1 Power Plant, which came online in 1983. From 1995 to 1996, the Upper Mahiao and Malitbog plants came online with installed capacities of 132 and 231 MW_e, respectively. By 1998, optimisation plants in the form of an 18 MW_e topping cycle plant in Tongonan-1 and a 15 MW_e bottoming cycle plant Malitbog were installed, bringing the total installed capacity of TGF up to over 508 MW_e.

Figure 4.4-B1. Well-track Map of the Tongonan Geothermal Field

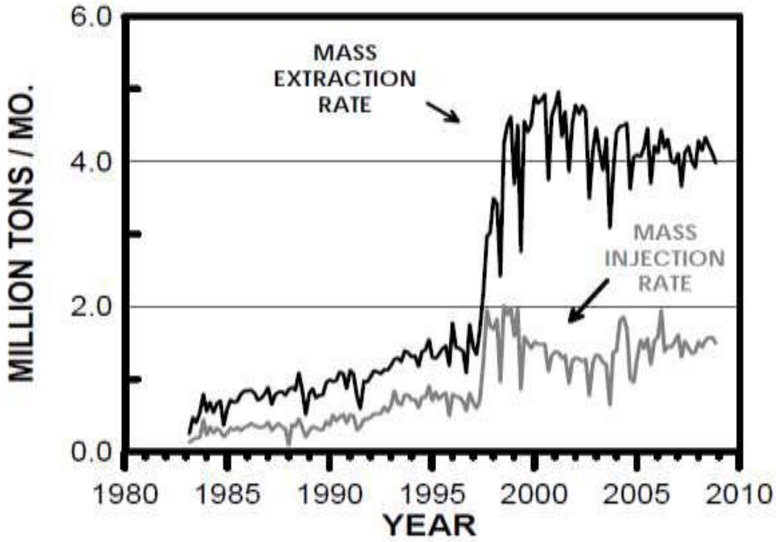


Source: Dacillo, et al. (2010).

4.4.B2. Effect of extraction and reservoir management strategies

From the commissioning of Tongonan-1 in 1983 until right before production was expanded in 1996, the TGF experienced a total pressure drawdown of 0.5 to 1.5 MPa. The increase in production caused a subsequent increase in the rate of pressure drawdown. Being a wet steam field and with the zero effluent disposal policy of the Philippine government, the increase in mass extraction also meant an increase in the rate of brine and condensate reinjection (**Figure 4.4-B2**). The combination of these led to reservoir processes that had a direct impact on steam production.

Figure 4.4-B2. Monthly Total Mass Extraction and Injection (in million tonnes per month)

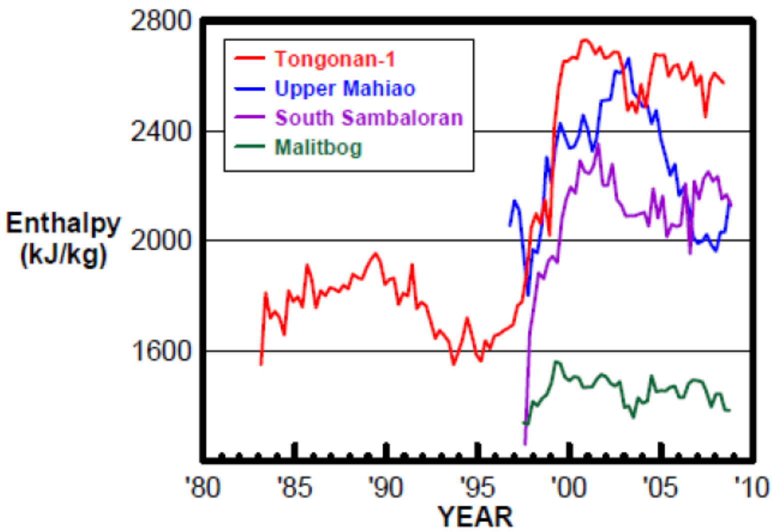


Source: Dacillo, et al. (2010).

4.4.B2.1. Pressure drawdown and boiling

With pressure drawdown came boiling and expansion of the two-phase zone in the reservoir, which brought about an increase in the enthalpy of most wells (**Figure 4.4-B3**). The phenomenon was also observed during flowing surveys and as shifts in the gas equilibria. While boiling led to an increase in overall steam available, it also brought about the problem of increased solids discharge that contributed to erosion of the casings.

Figure 4.4-B3. Average Enthalpy of the Different Sectors of the Tongonan Geothermal Field



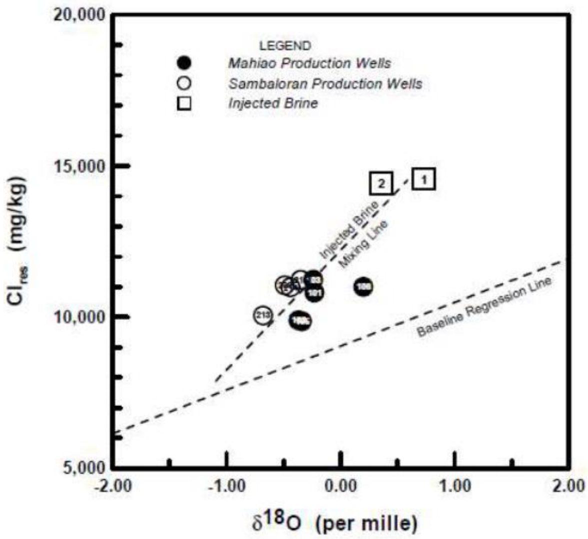
Source: Dacillo, et al. (2010).

Despite the increase in enthalpy in most of the production wells, a number of other wells did not show evidences of boiling or manifested declining enthalpy. As the depressurisation of the main production area and its surroundings resulted in boiling, it also created a pressure sink that draws fluids from the relatively higher pressure peripheral areas and injection sectors. Effects of injection returns and cooler fluid inflow were observed in a number of wells in the field.

4.4.B2.2. Injection returns

A decrease in the gas concentration and an increase in salinity of the discharge of wells are evidence of the production fluids mixing with the degassed and highly saline injected brine returns. Enrichment of the fluids in both chloride and ^{18}O isotope provided an estimate of how much injected brine mixed with in-situ fluids. Naphthalene disulfonate (NDS) tracer tests confirmed the connection of these wells with the brine injection sectors (**Figure 4.4-B4**).

Figure 4.4-B4. ^{18}O and Cl Enrichment in Production Wells due to Incursion of Injected Brine from Tongonan-1 Injection Sink

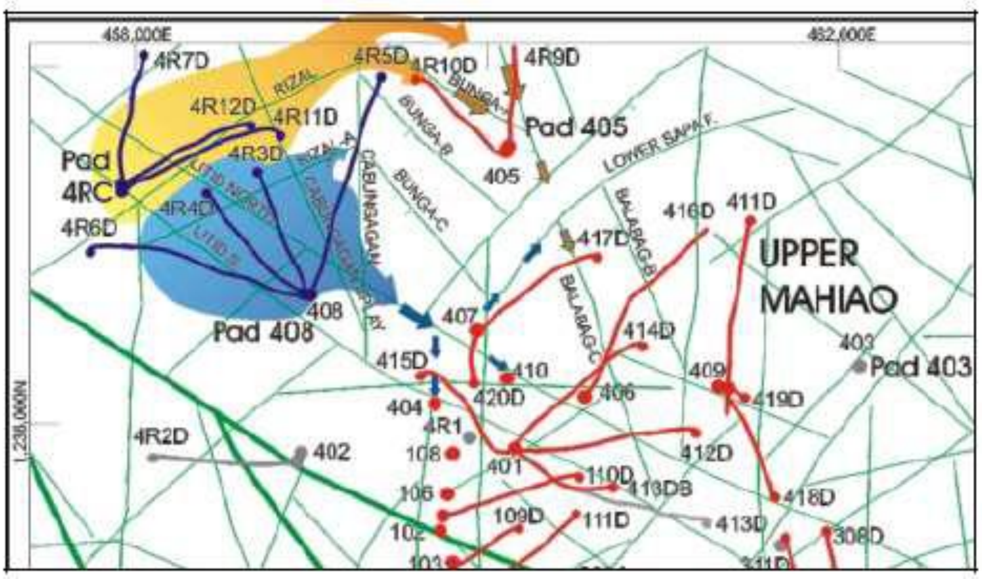


Note: The regression line represents the baseline distribution of oxygen eighteen (^{18}O) and Chloride (Cl) among the Tongonan-1 production wells prior to entry of the injected brine.
Source: Dacillo, et al. (2010).

The identification of brine returns affected wells and results of tracer tests led to changes in reinjection strategies. Transferring RI load away from the main production area to more peripheral areas allowed for the recovery of the affected wells. For example, when most of the injection load of Sambaloran wells was transferred to the Mahiao injection wells in September 1995, the increasing salinity and decreasing gas concentration of affected wells began to revert to in-situ levels by October 1995. Another method is to reinject deeper so as to sufficiently reheat the injected brine in the deeper part of the reservoir. A case of this is the transfer of brine injection from 1R8D to the nearby deeper 1R9D.

It should be noted that the impact of injection returns is not all detrimental to production. Injection provides mass recharge to the highly two-phase reservoir and the additional liquid component helps mitigate the erosive effects of solids discharge in steam-dominated flow. The mass recharge from injection returns can also prevent the influx of cooler fluids such as condensate injection by creating a thermal and pressure barrier. This principle was used to manage the effects of condensate returns on Pad 405 wells through controlled injection in Pad 408 (**Figure 4.4-B5**).

Figure 4.4-B5. Flow Model of Condensate from Pad 4RC and of Injected Brine from Pad 408 based on Tracer Studies and Geochemical Data



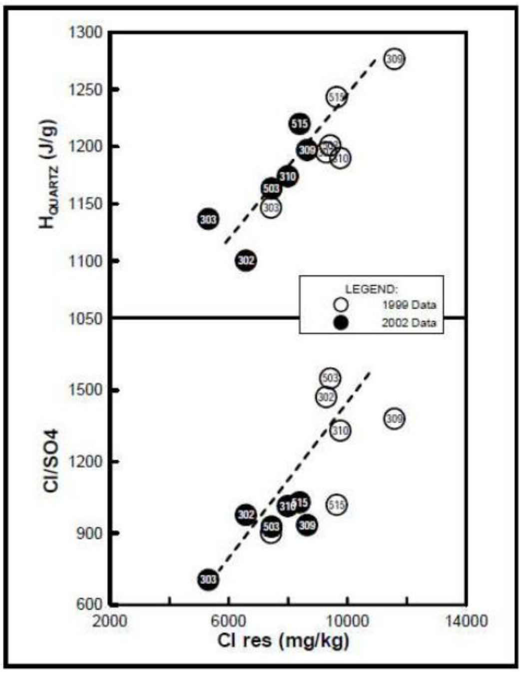
Notes: Pad 4RC = yellow area, yellow arrows; Injected Brine from Pad 408 = blue area, blue arrows
Source: Dacillo, et al. (2010).

4.4.B2.3. Cooler fluid inflow from peripheral areas

The cooler fluids from the peripheries of the field are dilute, sulphate-rich, and slightly more acidic than the in-situ fluid of the production wells. The wells affected by cooler fluid inflow therefore discharge lower enthalpy, less saline, and lower Cl/SO_4 ratio fluids (**Figure 4.4-B6**).

The effects of cold inflow were mitigated with the use of sacrificial wells. Sacrificial wells are strategically located wells that can preferentially draw in these cooler fluids when discharged. Sacrificial wells are continuously discharged to silencers. The discharge of sacrificial wells brought about significant enthalpy and steam flow recovery in cold inflow affected production wells. Though the enthalpies of affected wells were not fully recovered, they have stabilised.

Figure 4.4-B6. Plots Showing Dilution and Cooling of Production Wells due to Inflow of Cooler Peripheral Fluids



Source: Dacillo, et al. (2010).

4.4.B2.4. Mineral deposits

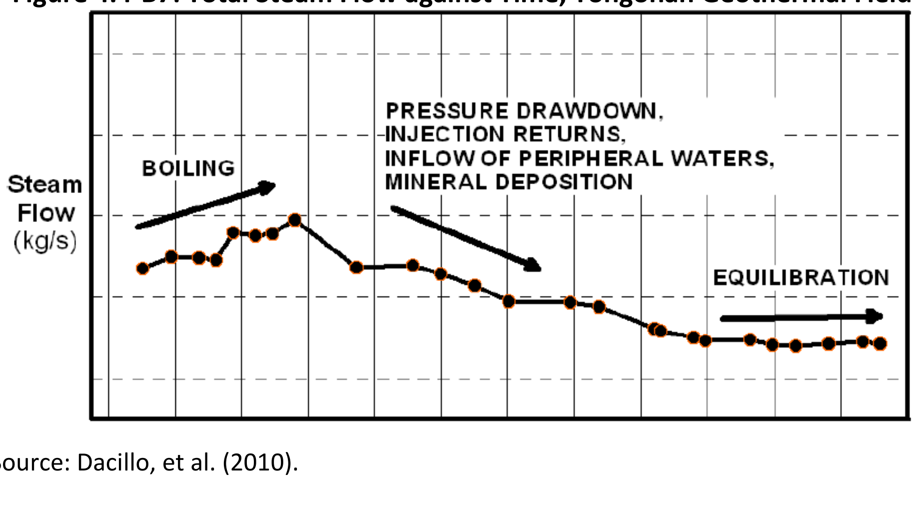
A phenomenon that derives from the encroachment of injection returns is mineral deposits in production wells affected by brine injection returns that are close to the areas with massive boiling. Since the chemistry of the injected brine has higher silica than the in situ geothermal fluid, it more easily becomes supersaturated in silica when boiled. It is postulated that as the silica-rich brine moves to the centre of the production field, it mixes with the two-phase fluids and begins to flash, increasing the silica saturation index. Production wells that are affected by mineral deposits have high output decline rates due to the constriction of the wellbore with silica scales. Silica scale ejecta recovered from the wells are evidence of this phenomenon.

Mechanical clearing workovers with rigs are usually performed to recover the output of wells with significant scaling. There are instances when a recovery of up to 4 MW_e can also be achieved by vertical clearing discharge from a high initial pressure. In this case, the force of the discharge is sufficient to dislodge the built-up scales. In the long term, deep injection ensures that injected brine mixes with the hotter, deep geothermal liquids. Mixing in the liquid state reduces the rate of further deposition.

4.4.B3. Results of resource management strategies

Negative effects on the production of reservoir processes due to massive extraction were eliminated or controlled through monitoring and good resource management strategies. The increase in steam supply due to massive boiling that was observed from 1999–2000 was soon offset by the effects of pressure drawdown, injection returns, inflow of peripheral waters, and mineral deposits. The combined effects of these reservoir processes resulted in the gradual decline in steam availability from 2000–2005. The mitigation measures implemented in the field have arrested this decline since 2006 (**Figure 4.4-B7**).

Figure 4.4-B7: Total Steam Flow against Time, Tongonan Geothermal Field



Source: Dacillo, et al. (2010).

Concluding remarks and lessons learned

- The experiences in TGF have shown that proper resource management and well intervention are effective in sustaining field generation.

- Though the effects of pressure drawdown due to extraction are inevitable, the negative impacts on steam flow production can be controlled.
- Some of the strategies used in TGF and described in this work are:
    - Optimisation of injection loading so that the benefits of mass recharge and pressure support are balanced against the drawbacks of cooling and mineral deposition;
    - Use of sacrificial wells to redirect cold natural recharge away from the depressurised production area; and
    - Well intervention techniques to address decline in production due to mineral deposition within wellbores.
- Careful monitoring of reservoir conditions through geochemical and reservoir engineering data were found to be useful in developing sound resource management strategies.
- As production continues, integration of the different data available will lead to continuous refinement of these strategies or even replacement with better methods.
- With sound resource management, TGF may be able to sustain production for another 25 years.

References

Alcaraz, A.P., B.J. Barker, R.T. Datuin, and T.S. Powell (1989), 'The Tiwi Field: A Case Study of Geothermal Development for the National Interest'. Presented at 10th New Zealand Geothermal Workshop and published in *Proceedings of the 11th New Zealand Geothermal Workshop*, pp.261–265.

Dacillo, D. B., M.H.B. Colo, R.P. Andrino, E.H. Alcober, F.X.M. Sta. Ana, and R.C.M. Malate (2010), 'Tongonan Geothermal Field: Conquering the Challenges of 25 Years of Production', *Proceedings of the World Geothermal Congress 2010.*

Gambill, D.T. and D.B. Beraquit (1993), 'Development History of the Tiwi Geothermal Field, Philippines'. *Geothermics*, 22(5/6), pp. 403–416.

Lim, W.Q. (1997), 'Superheating Wells in Tiwi', CGPHI Internal Report, MK-10,418.

Menzies, A.J., L.B. Villaseñor, and E.G. Sunio (2010), 'Tiwi Geothermal Field, Philippines: 30 Years of Commercial Operations'. *Proceedings of the World Geothermal Congress, 2010.*

Santos, S.L. and D.B. Carandang-Racela (1993), 'Injection History and Strategy Tiwi Geothermal Field, Philippines'. *Proceedings of the 15th New Zealand Geothermal Workshop,* pp.35–39.

Siega, F.L., R.S. Alincastre, and E.V. Parilla, Jr. (1998), 'Reservoir Response to Optimized Reinjection Scheme of Tongonan-1 Production Field, Leyte, Philippines', *Proceedings of the 9th Annual PNOC-EDC Geothermal Conference.*

Sta. Ana, F.X.M., V.S. Saw, P.O. Molina, E.T. Aleman, G.F. Cañete, C.S. Hingoyon, and Z.F. Sarmiento (1999), 'Increased Production Load in Tongonan Geothermal Field, Philippines: Reservoir Response and Field Management Strategies', *Proceedings* of the *24th Workshop on Geothermal Reservoir Engineering Stanford University, SGP-TF-162*.

Strobel, C.J. (1982), ‘Reservoir Engineering Studies of the Tiwi Hydrothermal System’. CGPHI Internal Report, MK-2,181.

Sugiaman, F.J., E.G. Sunio, P.A. Molling, and J.A. Stimac (2004), ‘Geochemical Response to Production of the Tiwi Geothermal Field, Philippines’, *Geothermics,* 33(1/2), pp.57–86.

Sunio, E.G., Z.P. Aunzo, D.B. Beraquit, J.S. Ching, Y.C. Ontoy, J.P. Protacio, G.P. Villafuerte, and L.B. Villaseñor (2004), ‘2004 Tiwi Conceptual Model Update, Part 1: Initial-State’, CGPHI Internal Report, MK-10,642.

Vasquez, N.C. and B.S. Tolentino (1972), ‘The Geology of the Tongonan Geothermal Field’, *The Comvol Letter* 6(3&4), pp.1–20.

Villaseñor, L.B., P.R. Joson, A.L. Balbin, and T.U. Calayag (1999), ‘Examples of Corrosion Monitoring at Tiwi Geothermal Field’, *Proceedings of the 20th PNOC-EDC Geothermal Conference,* pp.157–162.

Villaseñor, L.B. and R.O. Vicedo (2009), ‘Exclusion of Acid Sulfate Fluid in Wells at Tiwi Geothermal Field, Albay Province, Philippines’, *Proceedings of the 30th EDC Geothermal Conference.*

4.5. Thailand: Fang Binary Power Plant and Multi-purpose Use

Many geothermal hot springs in Thailand are located along the Thai-Malay plate, western part from North to South, and almost always associated with granitic rocks. It has been reported that hot springs can be used either directly or through electricity generation, depending on factors including characteristics of the springs, temperature, flow rate, reservoir size, and structure (Lund et al., 1999). Many sites of hot springs in Thailand are currently used for various purposes including recreation and tourism. The development of geothermal energy in the future will emphasise joint investment between the community and the private sector to promote sustainable development and participation of local residents. The total of 112 hot springs have been found in most regions of Thailand except the northeast. Water temperatures on the surface level range between 40–100^{o}C and most of the hot springs originate from granite, especially along the fault line, in the northern provinces such at Mae Jan in Chiang Rai and Fang in Chiang Mai.

Geothermal development in Thailand was formulated in 1981–1984 by a joint technical cooperation project between the Bureau de Recherches Geologiques et Minieres (BRGM) of France and the Electricity Generating Authority of Thailand (EGAT). The purposes were to model a geothermal reservoir and to appraise geothermal enthalpy targeting electricity generation. The first geothermal power plant in Thailand, using binary cycle, was installed and completed on December 1989 in Fang, Chiang Mai province. The inlet vaporiser temperature, after passing through an air released tank, varies between 115^{o}C to 120^{o}C and the temperature of the hot water released from the vaporiser outlet is approximately 80^{o}C. The thermal waters released from the power plant, since these are clean, are planned to be exploited downstream for non-electrical utilisation. This is a single-module 300 kW_e plant that has a water cooled condenser. Although the capacity of the plant is 300 kW_e, the net power output varies with the seasons from 150 to 250 kW_e (175 kW_e average). This is multipurpose, which in addition to electricity production, the geothermal fluid also provides hot water for refrigeration (cold storage), crop drying, and spa. The refrigeration and crop drying systems were running for 20 years (1989–2009) but have now stopped running due to operating and maintenance costs. The artesian well provides approximately 8.3 litter per second (L/s) of 116^{o}C water. The wells require mechanical cleaning to remove scale every six months. The estimated power cost is from 6.3 to 8.6 cents/kWh, which is competitive with 22 to 25 cents/ kWh diesel generate electricity engine. The operation and maintenance costs of the project was cheap and also has a longer durability. Electricity output from the plant is connected to the local distribution grid system of the Provincial Electricity Authority and provided 1.2 million kWh annually. The binary system was support by ORMAT International, Inc.

Lessons learned

- Mineral scaling problem is solved by chemical or mechanical cleaning to sustain system's operations.
- The operating cost of the geothermal project was three times cheaper than production from fossil fuel, with several times cheaper maintenance cost and longer durability, which may be an important factor for sustainable use in commercial sense.

Reference

Lund, J.W. (1999), 'Small Geothermal Power Project Examples Fang Geothermal Binary Power Plant', *GRC Bulletin,* June, pp.9–26.

4.6. Subsidence in New Zealand Fields

Extensive study has been done in New Zealand for the sustainable use of geothermal resources. Here a paper on subsidence is introduced. Although the environmental aspect is not a scope of our project, a study on subsidence is shown here because it is strongly related to reservoir management and is not included in case studies in former sections.

Subsidence anomalies in Wairakei and other geothermal fields in New Zealand are summarised in **Table 3.2.6-1**. It shows that the subsidence in these fields are gradually stabilising with time. According to Bromley, et al. (2015), the key factors of subsidence are shallow geology distribution, injection depth, and time. Note that injection into the steam cap caused more serious subsidence than that caused by shallow production.

Lessons learned

- Region of subsidence is strongly related to geology: clay in shallow subsurface.
- The initial subsidence was caused by mass production, but the major (ten times larger) subsidence was due to pressure drop by injection into steam zone.
- Subsidence rate was stabilised by deep injection (stop shallow injection), but slow subsidence is continuing due to creep phenomenon triggered by early injection.

Table 4.6-1. Summary of Subsidence Anomalies in New Zealand Geothermal Fields

Field and Bowl	Total (m)	Max rate (mm/yr)	Year max	Current rate (mm/yr)
Wairakei Valley	15	500	1974	50
Ohaaki West	6	400	1994	170
Tauhara – Spa Valley	3	110	2005	110
Tauhara – Crown Rd	1	60	2004	20
Kawerau	0.75	50	2012	50
Mokai (injection)	0.2	30	2009	10
Rotokawa (injection)	0.2	50	2007	10
Ngawha	0.03	3	2012	3

m = metre, mm/yr = millimetre per year.
Source: Bromley, et al. (2015).

References

Bromley, C.J., S. Currie, S. Jolly, and W. Mannington (2015), 'Subsidence : An Update on New Zealand Geothermal Deformation Observations and Mechanisms', *Proceedings of the World Geothermal Congress 2015.*

Chapter 5

Case Studies on Ground Source Heat Pumps

5.1. China: Investigation, Evaluation, and Monitoring

5.1.1. Introduction: Exponent increase of ground source heat pumps in China

Figure 5.1-1 shows growth of geothermal utilisation in the past 20 years in China. There are different speeds for three types of geothermal use. Geothermal power generation has very little growth only. Geothermal direct use has gentle growth. However, ground source heat pump (GSHP) has an exponential increase.

Figure 5.1-1. Growth of Geothermal Utilisation in China

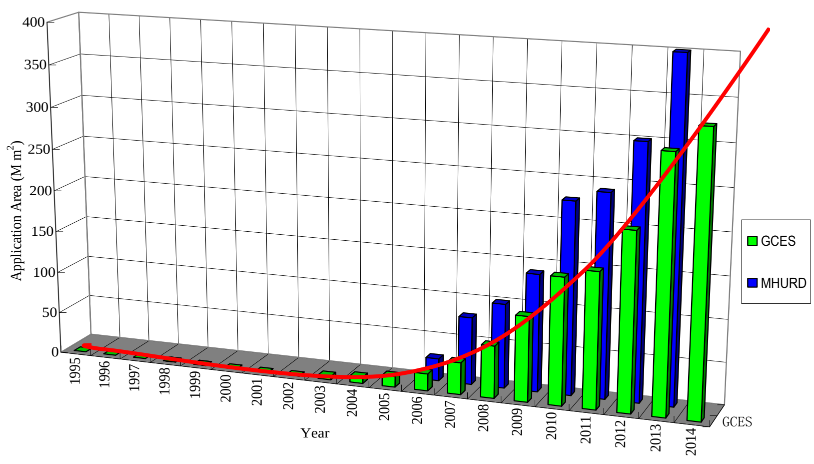
Source: Edited by authors based on statistics data of the Geothermal Council of China Energy Society.

GSHP has sprung up in China in the past 20 years. Even though the Chinese had studied heat pumps since 1960s, it was only in research by scholars in Tianjin University and Tsinghua University. Tests were carried out in the laboratory and at a few engineering sites. There was no condition for practical application due to the lack of electricity, even for public lighting at that time.

The first GSHP application project was the New Henderson Building in Beijing in 1995. It used the heat pump of the Carrier brand made in the United States. Ten groundwater wells were drilled for pumping-up and reinjection. Since project implementation, Tsinghua University, combining with Shandong Fuerda Co. Ltd., started to develop domestic heat pumps. It gained success in 1996 and then extended applications. In the later 1990s, a few demonstration projects also appeared in Liaoyang, Liaoning province and Jinan, Shandong province. At that time, several universities carried out experimental studies including theoretical modes and testing applications (Diao and Fang, 2006). At the end of 2000, GSHP reached 100 thousand m^2 of application. GSHP systems started high speed growth when entering the 21st century. The application was 7.67 million m^2 in 2004 and 100.7 million m^2 in 2009. During this period, Shenyang exceeded Beijing and became the first place in the country in 2007. It occupied 54 percent of total application numbers in China. Hereafter, Shenyang decreased its high-speed for partial adjustment but still kept the top position.

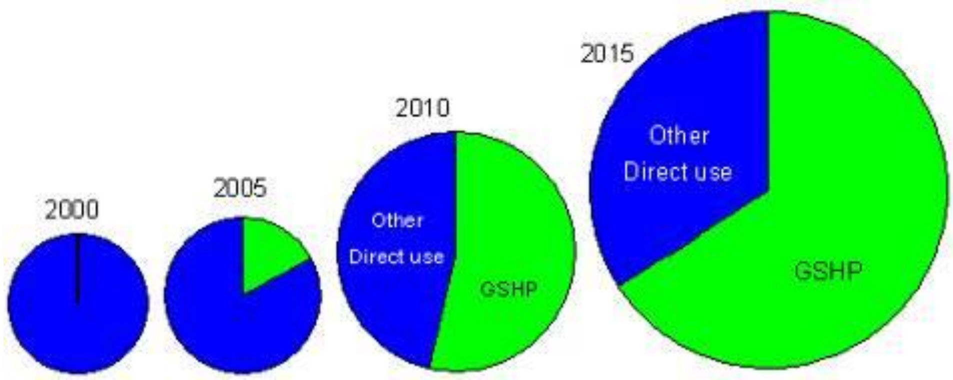
However, GSHP shows a positive and favourable progress in the first decade of the 21st century, probably due to the serious haze problem in eastern China. So GSHP application accelerated again. A new trend shows the most rapid growth appeared in the mid down-stream regions of the Yellow River and Yangtze River where there had been no winter space heating in the past. For example, in Jiangsu province there was no space heating under the planning economy. But with winter air temperatures lower than 5°C, it needs space heating. Developers have constructed new buildings including GSHP systems in recent years, which the public has welcomed. Another example is in Wuhan city. The local government has initiated the ‘warm in winter and cool in summer’ project. Therefore, all new buildings will use GSHPs for heating in winter and cooling in summer. Existing buildings will be remoulded by GSHPs progressively.

Figure 5.1-2. Growth of Ground Source Heat Pumps in China



GSHP = geothermal source heat pump.
Source: Keyan Zheng et al (2015).

Figure 5.1-3. 20 Years' Growth of Geothermal Direct Use and Proportion of Ground Source Heat Pumps in China



Notes: Area of circle = total direct use; green part = GSHP, GSHP = geothermal source heat pump.

Source: Edited by authors based on statistics data of the Geothermal Council of China Energy Society.

GSHP application reached 330 million m^2 in China in 2014. Its installed capacity will be 11.8 GWt with annual energy use of 110,311 terajoule per year (TJ/yr). GSHP application has a progressive annual increase rate of over 27 percent, higher than the rest of the world. **Figure 5.1-2** shows the process of GSHP growth in China. The long series shows the statistics from the Geothermal Council of China Energy Society (GCES); the short series shows the data from official website of the Ministry of Housing and Urban-Rural Development (MHURD), in which data consist of all heat pumps including industrial waste water and urban sewage.

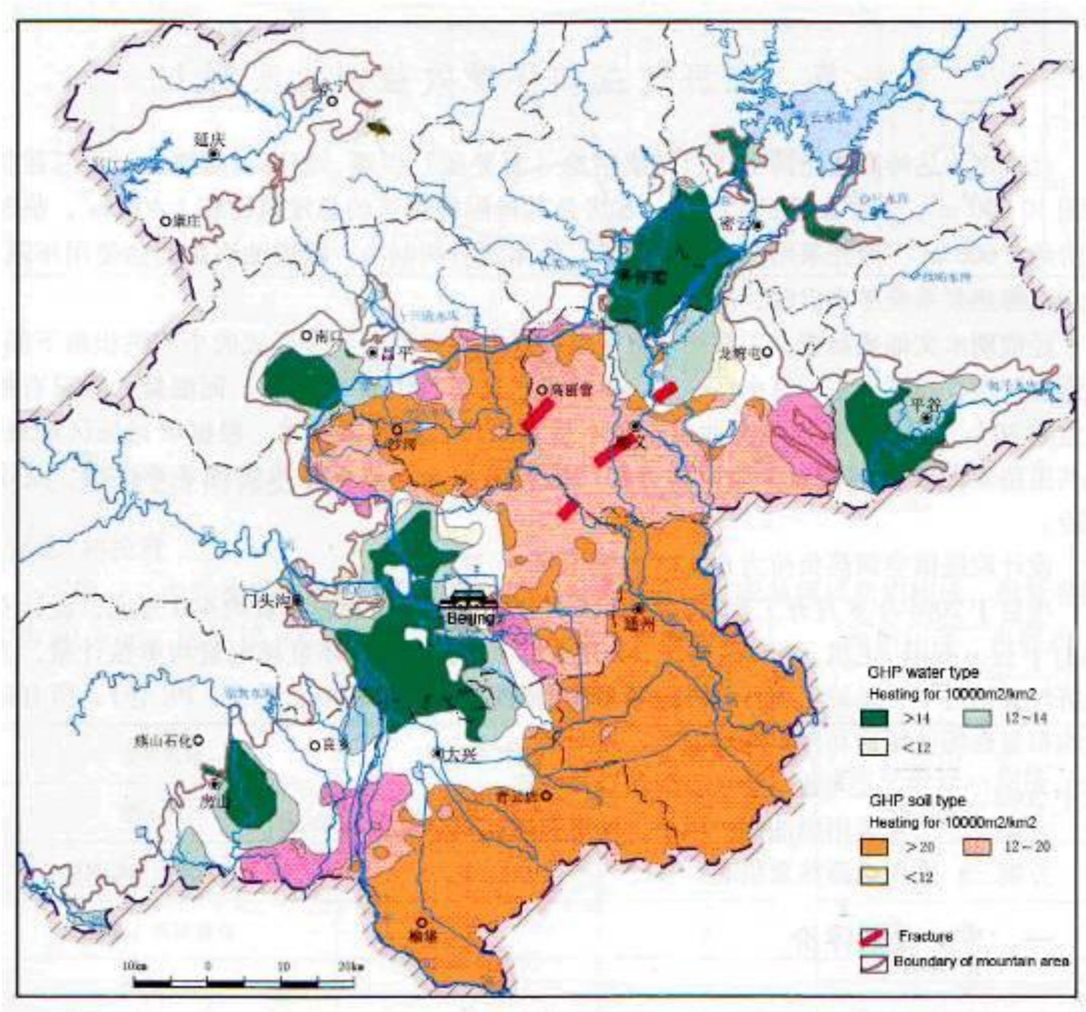
For such a rapid growth, the primary reason is policy support from the national and local governments. The first is the Law of Renewable Energy of P. R. China and then a series of government documents. The Ministry of Housing and Urban–Rural Development and the Ministry of Finance jointly supported a series of projects on energy saving for buildings, including demonstration projects on demonstration county and smart city, amongst others.

5.1.2. Case Study 1: Shallow geothermal energy investigation and evaluation

The GSHP application may contain risk in inappropriate locations. In order to reduce such risks, the Ministry of Land and Resources has supported a huge project for 287 prefecture-level cities for investigation and evaluation of shallow geothermal energy, which is mainly organised by each province (region, city), promoted by the cooperation of the province and the Ministry of Land and Resources. The fund has spent for over CNY100 million (about US$16 million). The first demonstration was in Tianjin city to carry out the pilot work, and make uniform the methods and techniques. Secondly, based on the experiences obtained from the pilot work in Tianjin, this work spread to other cities. Based on the identification of shallow geothermal energy storage condition, reports and maps show the suitable, basic-suitable, and unsuitable areas for GSHP development. These achievements have been provided to local governments for application in further GSHP projects. **Figure 5.3-4** shows such results from the Beijing achievement. It indicates the best, good, and poor conditions (divisions) for GSHP application of water type and soil type respectively.

The national project of investigation and evaluation of shallow geothermal energy has shown great potential. It provides heat capacity for GSHP use. The total potential is equivalent to 9.486 billion tonnes of standard coal (Wang, et al., 2013).

Figure 5.1-4. Map Showing Shallow Geothermal Energy Conditions in Beijing

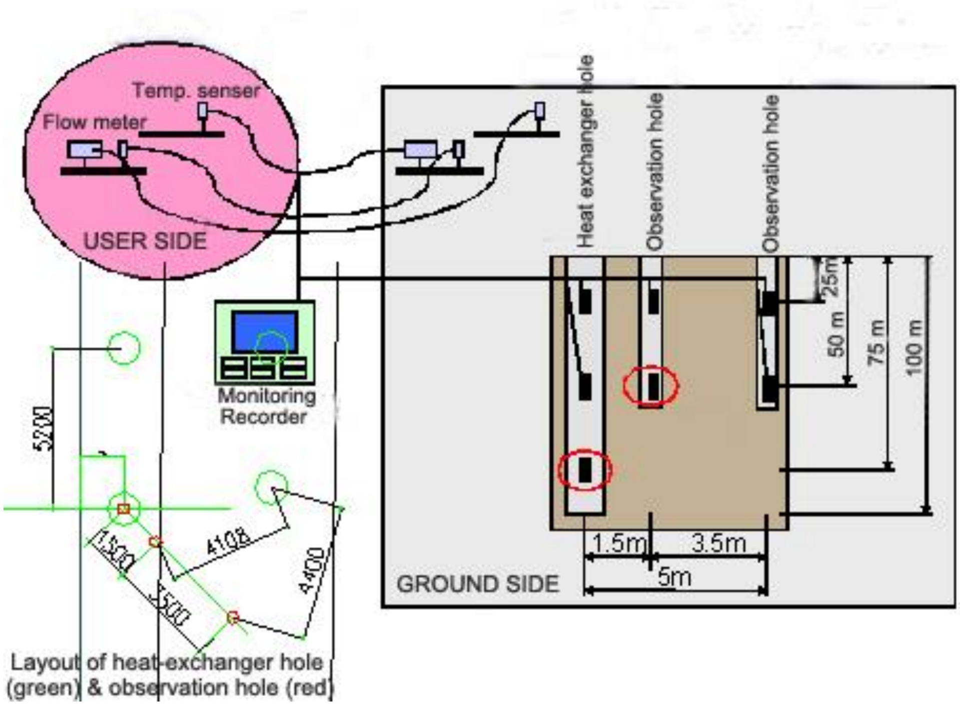


Source: Keyan Zheng et al. (2015).

5.1.3. Case study 2: Monitoring of ground temperature recovering

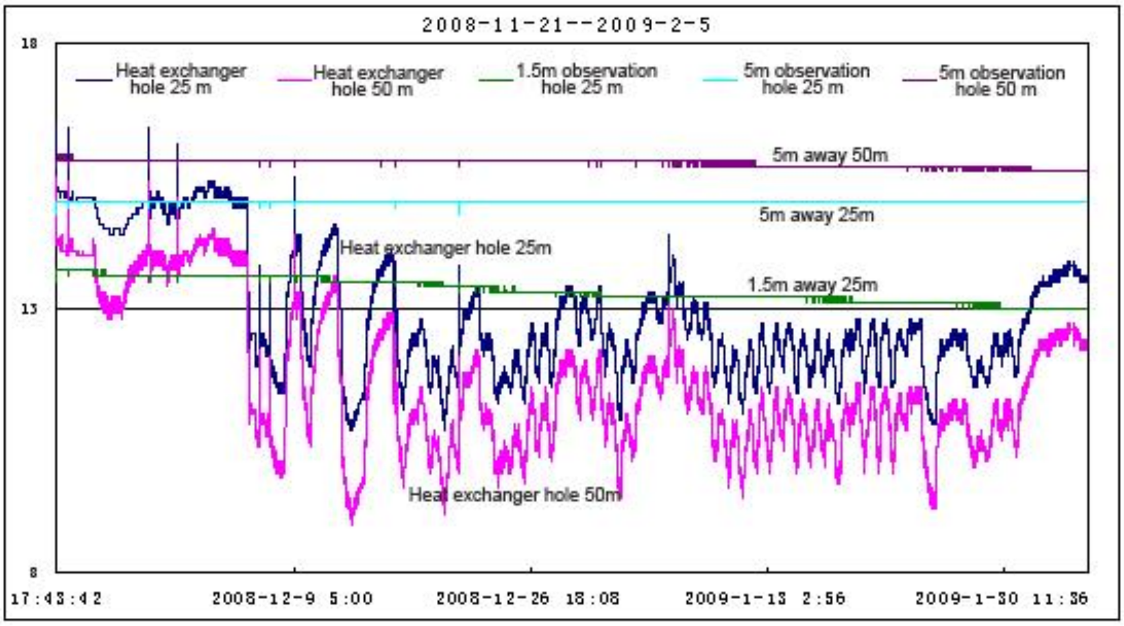
Construction designers worried about the balance of heating–cooling for GSHP application. Long-term monitoring has been carried out in typical projects for more than 10 years. By long-term monitoring of ground temperature and heat pump system, it has shown positive results. Similar results have come from 20 more projects in Beijing.

Figure 5.1-5. Installation of Monitoring Tools for Ground Source Heat Pump System



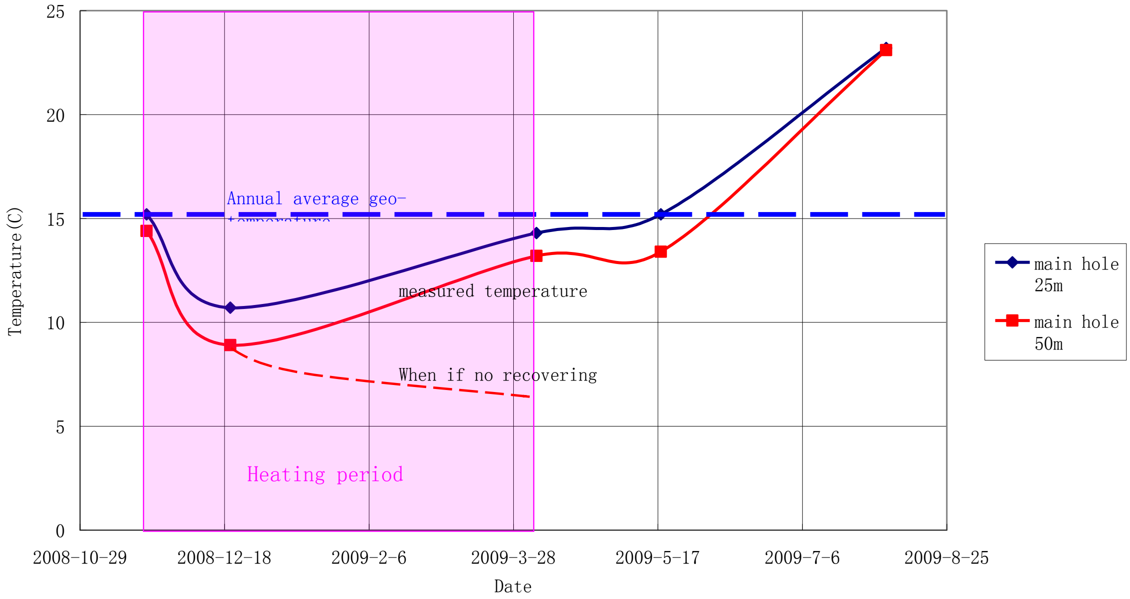
Source: Zhuang, Y. et al. (2010).

Figure 5.1-6. Temperature Curves Measured in Different Monitoring Holes



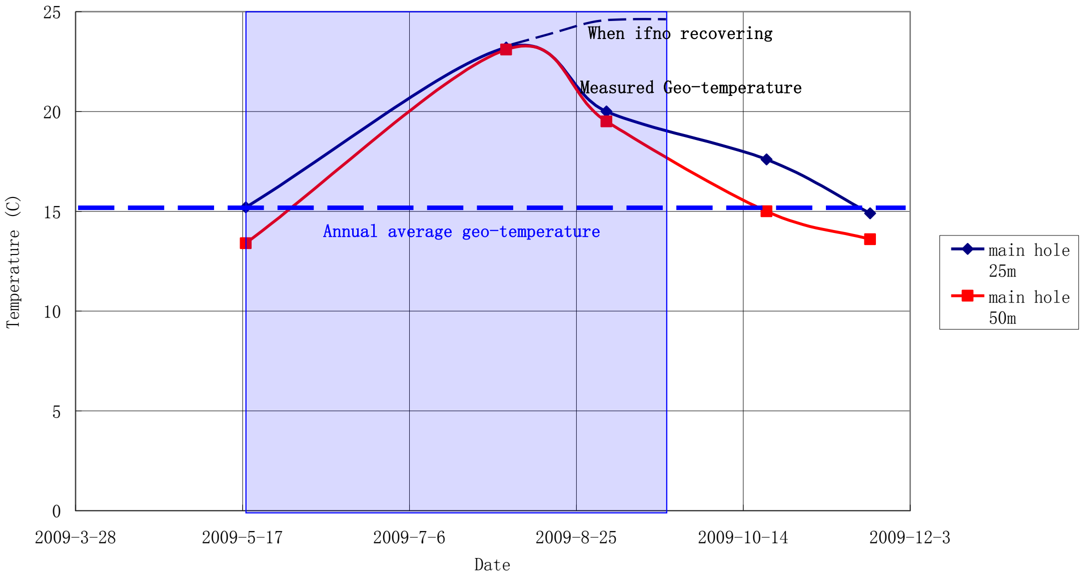
Source: Zhuang, Y, et al. (2010).

Figure 5.1-7. Geo-temperature Recovery During and After Heating Season



Source: Edited by authors based on monitoring data from Beijing Geothermal Engineering Institute.

Figure 5.1-8. Geo-temperature Recovery During and After Cooling Season



Source: edited by authors based on monitoring data from Beijing Geothermal Engineering Institute.

Lessons learned

- Mapping shallow geothermal energy conditions, such as water type and soil type, is important to perform proper design of GSHP systems.
- Monitoring of ground temperature is important to monitor thermal recovery of the ground and to assure the balance of heating and cooling.

References

Zheng. K., Y. Mo, L. Chen (2015), ‘Twenty Years of Geothermal Heat Pump in China,’ Proceedings of World Geothermal Congress 2015, 29025, p.4.

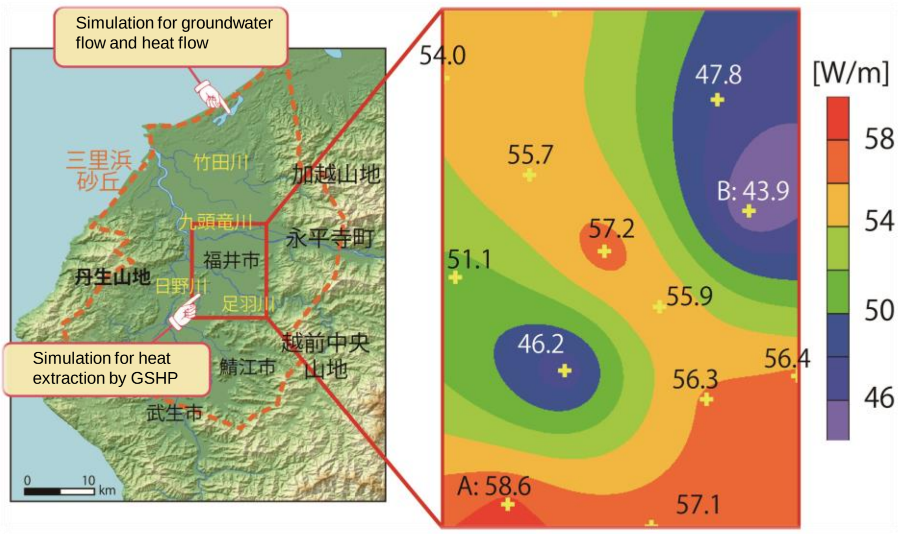
Zhuang, Y. et al. (2010), ‘Study on Ground Temperature Variation of Heat Exchange Area of GSHP,’ *Hydrogeology and Engineering Geology*, Vol.37, (6): 134–138 (in Chinese with English abstract).

5.2. Japan: Suitability Mapping for Both Closed Loop and Aquifer Thermal Energy Storage Systems

5.2.1. Suitability mapping for ground source heat pump application

Heat exchange rate and preferred drilling depth of a GSHP system varies with local hydrogeological settings in sedimentary basins and plains in monsoon Asia. Therefore, groundwater and geological surveys to perform numerical simulation on groundwater flow and local heat exchange are needed to compile suitability maps of GSHP systems (**Figure 5.2.1-1**). Design of the GSHP system can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.

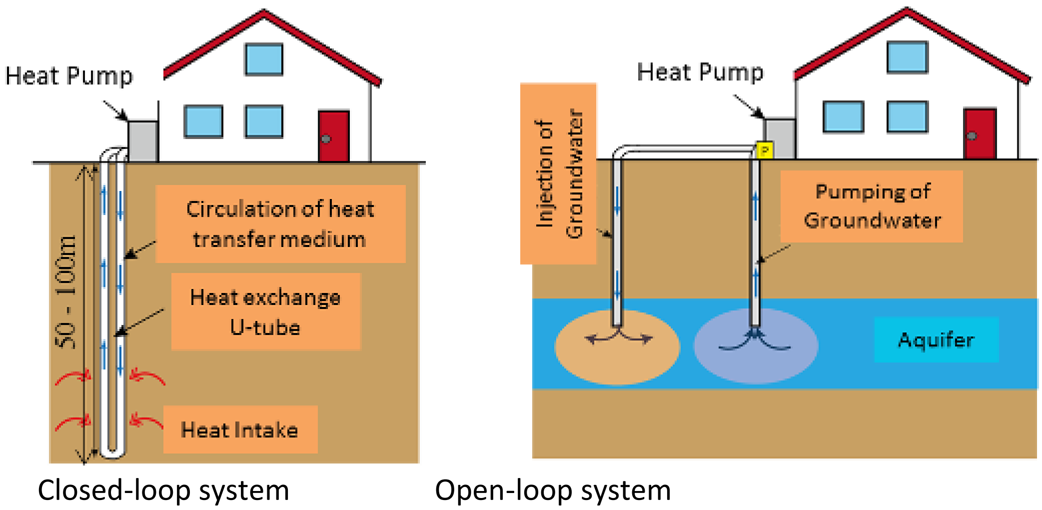
Figure 5.2.1-1. Potential Heat Exchange Rate in the Fukui Plain based on Simulation Results



Source: Yoshioka, et al. (2010).

In general, there are two types of GSHP systems, closed-loop and open-loop systems (**Figure 5.2.1-2**). In a closed-loop system, the ground heat exchanger (GHE) with U-tube is installed in bore hole and heat transfer medium (anti-freezing liquid) is circulated in order to exchange heat with the subsurface. In an open-loop system, groundwater is directly used by pumping for heat exchange at ground surface and reinjected after heat exchange. It is said that the closed type can be used anywhere, while the use of the open type is limited to places where groundwater aquifer is present, preferably at shallow depth.

Figure 5.2.1-2. Types of Ground Source Heat Pump Systems



Source: Edited by the authors.

5.2.2. Case study 1: Suitability map for closed-loop GSHP system; development of suitability map for installation of GSHP system

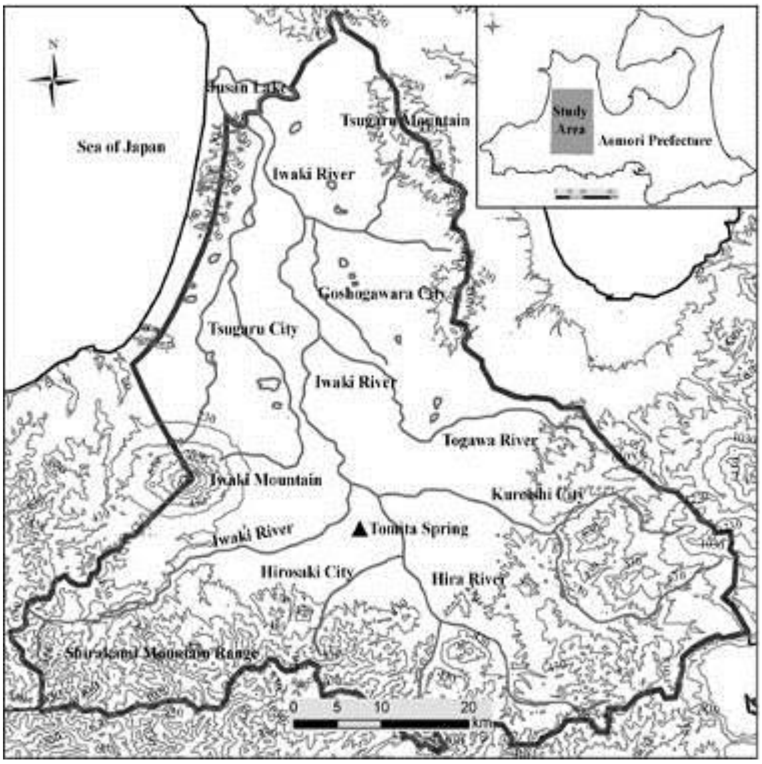
5.2.2.1. Introduction

The objective of this study is to assess the installation suitability of a closed-loop GSHP system by developing 'suitability' maps. The term suitability is mainly related to heat exchange with the subsurface, which depends on geology, groundwater flow system, and subsurface temperature distribution. Hence, suitability assessment should be done based on hydrogeological and thermal information. The study area is the Tsugaru Plain situated in the western part of Aomori Prefecture, Japan (**Figure 5.2.2-1**).

5.2.2.2. Regional scale analysis model

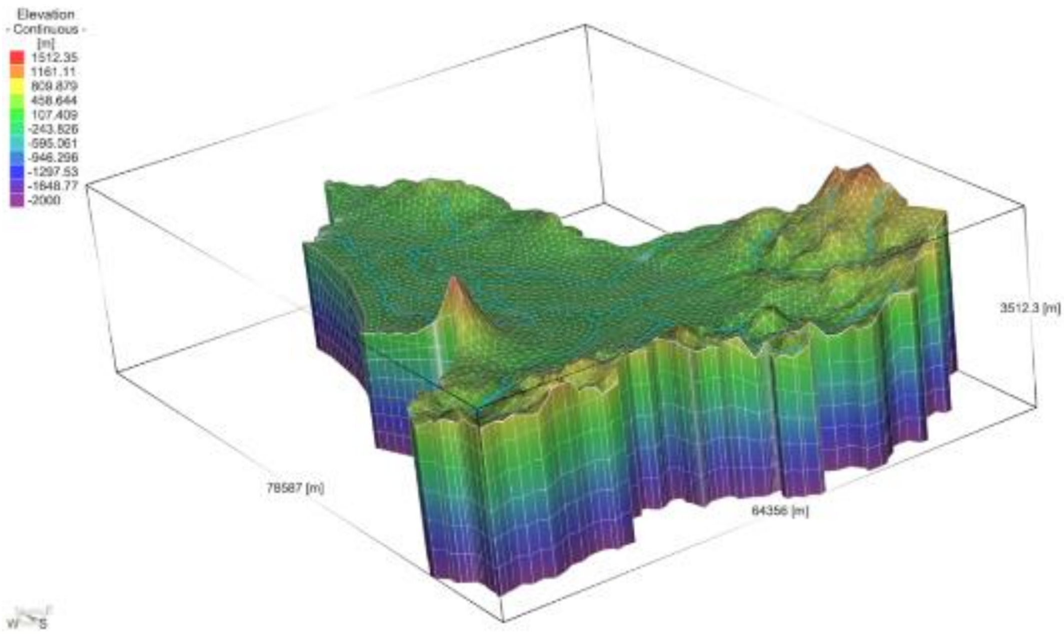
For the assessment of usage possibility of ground source heat energy, groundwater flow system, and subsurface temperature distribution must be understood. For this purpose, a regional scale analysis model (**Figure 5.2.2-2**) was prepared using finite element code FEFLOW (Diersch, 2005). Model boundary was defined along dividing ridges surrounding the plain.

Figure 5.2.2-1. Tsugaru Plain with Model Boundary



Source: Shrestha, et al. (2015).

Figure 5.2.2-2. Regional Scale Analysis Model of Tsugaru Plain



Source: Shrestha, et al. (2015).

Horizontal dimensions of the model were 64km and 78km in east-west and north-south directions respectively. In the model, layers 1 to 4 belonged to Quaternary System. Layers 5 to 7 belonged to Neogene and layers 8 to 12 belonged to Paleogene, both of which correspond to Tertiary System. Basal elevation of these geological layers were referred from Koshigai, et al. (2011). Quaternary System hosts the main aquifers of the Tsugaru Plain where groundwater flow primarily occurs.

Parameters adopted for the geological layers are shown in **Table 5.2.2-1**. Hydraulic conductivities of geological layers were determined by trial and error method based on the comparison of simulation results with the data of past studies and by confirming the path of simulated groundwater flow.

Regarding thermal conductivity, it was set by matching the results of single ground heat exchanger (GHE) model and thermal response test (TRT) which will be explained later.

Table 5.2.2-1. Model Parameters at Natural Springs and Lakes

	Quaternary System	**Tertiary System**	
		Neogene	Paleogene
Hydraulic Conductivity (m/s)	5×10^{-5}	3.4×10^{-6}	2.4×10^{-7}
Porosity (-)	0.4	0.1	0.1
Heat Capacity (J/m^3K)	2.6×10^{6}	2.6×10^{6}	2.6×10^{6}
Thermal Conductivity (W/mK)	1.2	1.5	1.5

Source: Shrestha, et al. (2015).

5.2.2.3. Groundwater flow and heat transport simulation

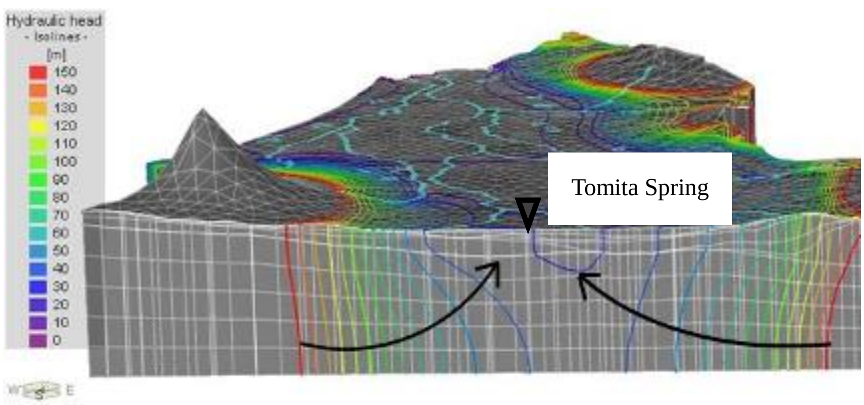
With this regional-scale analysis model, saturated steady state simulation of groundwater flow and heat transport was conducted. Regarding boundary conditions of the groundwater flow system, the top of the model was fixed by the water table that was determined as a function of surface elevation. The bottom of the model was treated as an impermeable boundary and the lateral sides were set as no flow boundaries. For boundary conditions of heat transport, the top and bottom of the model were fixed by time constant temperature boundaries, and lateral sides were set as adiabatic allowing heat transfer by groundwater convection only. The temperature distribution at the model top was estimated on the basis of the annual average temperature at Goshogawara City of

10.5°C and assuming a decrement rate in ambient temperature with elevation of 0.7°C/100m. The temperature distribution at the bottom was estimated based on the surface temperature distribution, using a geothermal gradient of 3°C/100m (GSJ, 2004).

In the absence of measured hydraulic heads of observation wells, computed results of the groundwater flow system were indirectly verified by comparing them with results of past studies and literature values. At Hirosaki City located in the southern part of the plain, the calculated hydraulic head was in the range of 30 m. The hydraulic head presented by Sakai (1960) in that city was also around 30 m. Similarly, at a high school in Kuroishi City located in the southeast part of the plain, the calculated hydraulic head was 47.1m. The hydraulic head measured by Machida and Yasukawa (2008) in the same area was 47 m, very close to the calculated value. The depth of the water table from the ground surface was found to be shallow in most areas of the plain. Machida and Yasukawa (2008) and Aomori Prefecture (2011) also showed similar results, implying the sustainable operation of GSHP systems in terms of groundwater availability and saturation of geological layers.

Natural water bodies such as springs, lakes, and ponds are generally formed by the upflow of groundwater. Simulation results were further validated by inspecting the path of simulated flow at natural water bodies, confirming if the groundwater was flowing in an upwards direction. At Tomita Spring located in Hirosaki City, the groundwater was found to be flowing in an upwards direction (**Figure 5.2.2-3**). Likewise, upflow was also found at other natural lakes and ponds. It can be said that the calculated results of the groundwater flow were consistent with the natural conditions and data of past studies.

Figure 5.2.2-3. Groundwater Upflow at Tomita Spring

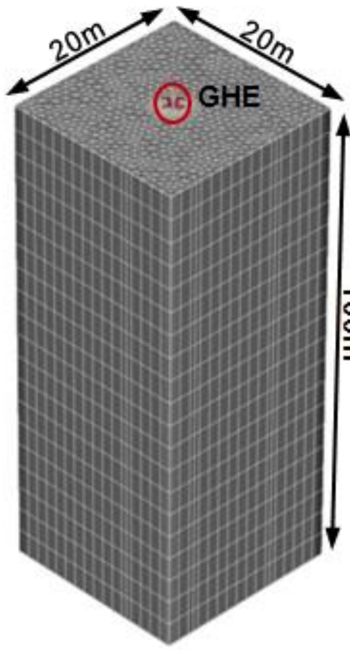


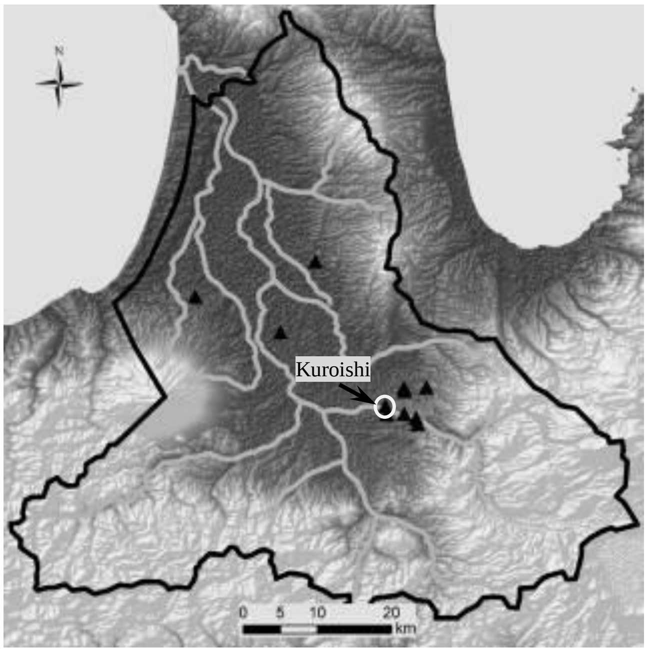
Source: Shrestha, et al. (2015).

5.2.2.4. Single ground heat exchanger model

Subsurface temperature distribution computed from the regional-scale analysis model could not be verified with measured vertical temperature profiles because observation wells were lacking. Hence, to verify the analysis model and its results, single GHE models were constructed at eleven locations (**Figure 5.2.2-4**), where TRT had been conducted. Single GHE models of dimensions 20 m x 20 m x 100 m were developed using the finite element software FEFLOW. Data related to TRT were referred from Aomori Prefecture (2011) and Kuroishi City (2011). Thermal conductivities of geological layers were determined by matching the results of GHE models with those of TRT.

Figure 5.2.2-4. Single Ground Heat Exchanger Model and Locations of Thermal Response Tests





Notes: Single ground heat exchanger model (left) and locations of thermal response tests and single ground heat exchanger models (right).
Source: Shrestha, et al. (2015).

In TRT, 50 m deep GHE was used which contained single U-tube of outer diameter 0.034 m. TRT was conducted by applying heat load of 3 kW to heat transfer medium (water), which was circulated for about 2 days at the rate of 20 litter per minute (L/min). Geological data and hydrological parameters assigned to each GHE model were adopted from their corresponding locations in the analysis model. At the center of GHE model, 50 m deep GHE was installed (**Figure 5.2.2-4**).

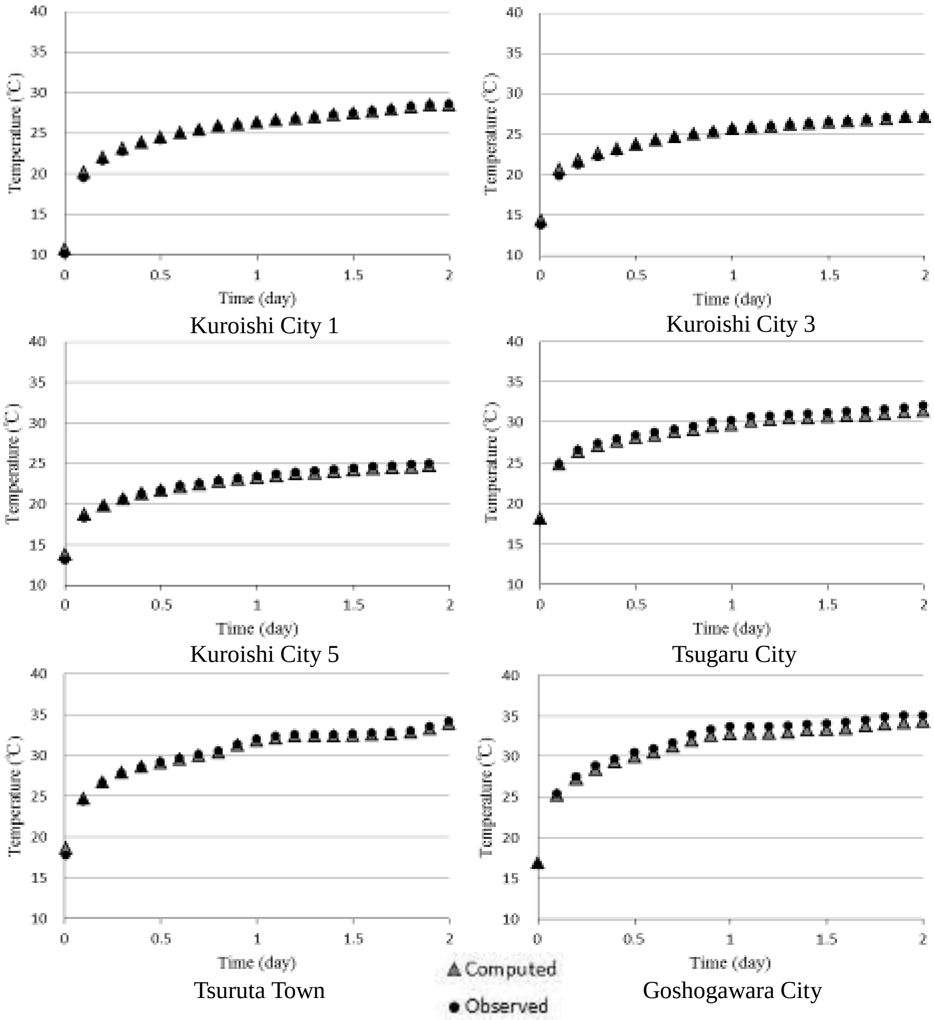
Regarding boundary conditions of groundwater flow system, top and bottom of the GHE model were set as no flow boundaries. Lateral sides were fixed with hydraulic heads to reproduce groundwater velocity, which was resulted in the analysis model at the corresponding location. For boundary conditions of heat transfer, constant temperature boundary condition was applied to the top and bottom of the model. At the top, the same value as assigned in the analysis model was set, while the bottom was fixed with temperature distribution obtained from the analysis model. At the upstream lateral side from where groundwater flowed, a constant background temperature was assumed. Remaining lateral sides were set as adiabatic, allowing heat transfer by groundwater convection only.

For heat exchange simulation, temperature of the heat transfer medium at the inlet of GHE and its flow rate observed during TRT were taken as input parameters. As an output, temperature of the heat transfer medium at the outlet of GHE resulted from the simulation. Then, computed outlet temperature distribution with time was compared with the real time result of TRT to find whether they matched with each other (**Figure 5.2.2-5**). **Figure 5.2.2-5** shows that computed profiles of outlet temperature of the heat transfer medium were almost consistent with those observed during TRT. At other locations also, there was satisfactory agreement between computed and observed outlet temperature of the medium. In this way, the thermal conductivities of geological layers were determined and the constructed 3D regional-scale analysis model was verified.

5.2.2.5. Development of suitability maps for GSHP system

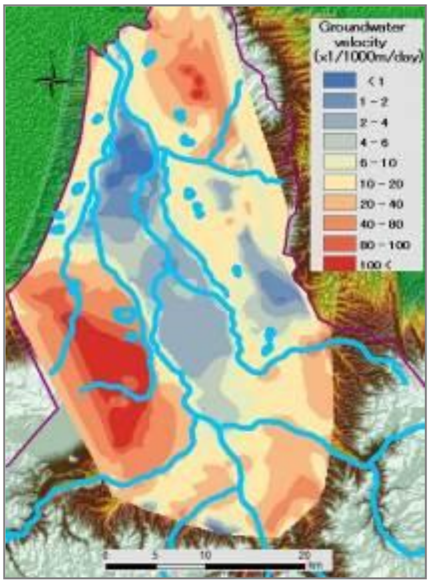
Groundwater flow and geological condition strongly affects heat exchange rate of GHE. Hence, suitability maps should be prepared based on hydrogeological and thermal information. For this purpose, thematic maps of groundwater velocity, subsurface temperature, water table depth, and sand-gravel ratio in geological layers were prepared using the Geographic Information System (GIS) (**Figure 5.2.2-6**). Groundwater flow velocity, subsurface temperature, and sand-gravel ratio were taken as average value up to 50 m depth from the surface.

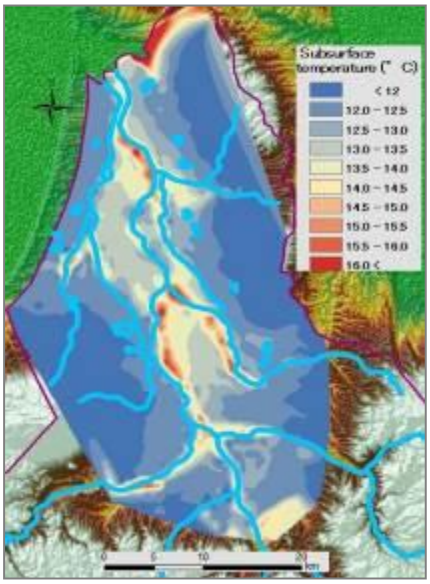
Figure 5.2.2-5. Comparison of Computed and Observed Outlet Temperature of Heat Transfer Medium



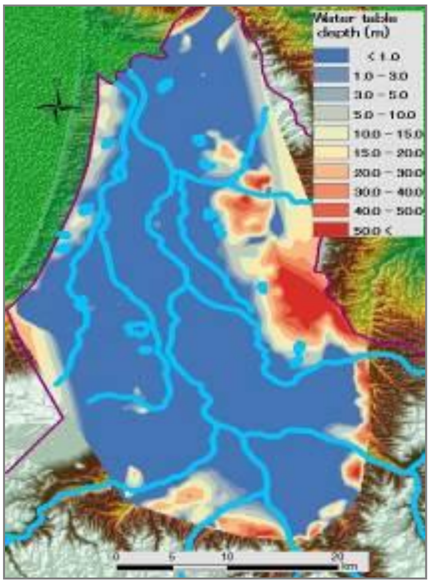
Source: Shrestha, et al. (2015).

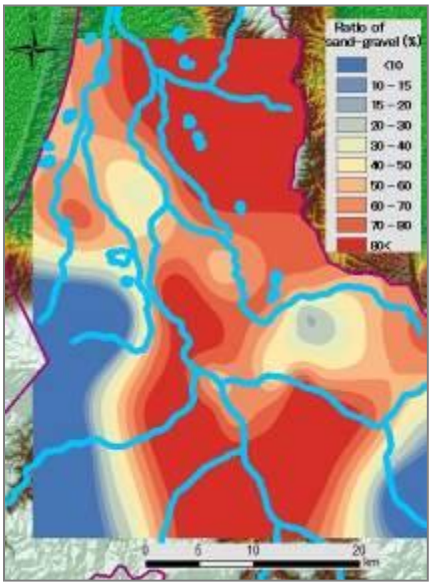
Figure 5.2.2-6. Thematic Maps of Tsugaru Plain





(a) Groundwater velocity (b) Subsurface temperature





(c) Water table depth (d) Sand-gravel ratio

Source: Shrestha, et al. (2014)

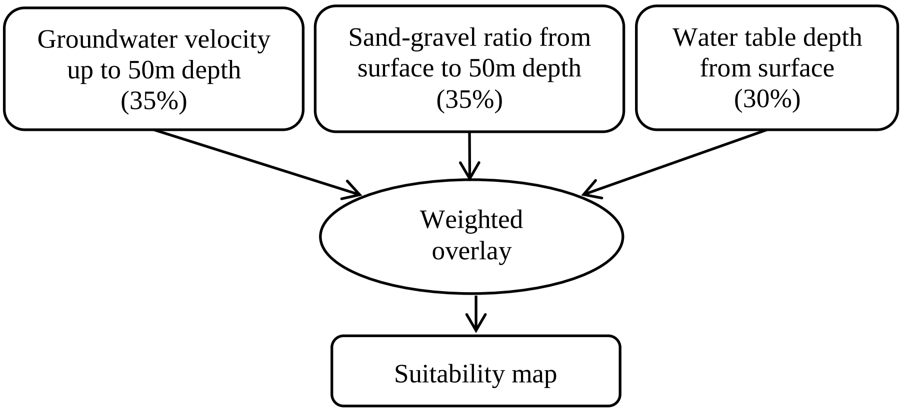
Table 5.2.2-2. Reclassification of Thematic Maps

Groundwater velocity Index class (x 10^{-3}m/day)	Sand-gravel ratio Index class (%)	Water table depth from surface Index class (m)	Grade
< 1	<10	50 <	1
1 – 2	10 – 15	40 - 50	2
2 – 4	15 – 20	30 - 40	3
4 – 6	20 – 30	20 - 30	4
6 – 10	30 – 40	15 - 20	5
10 – 20	40 – 50	10 - 15	6
20 – 40	50 – 60	5 - 10	7
40 – 80	60 – 70	3 - 5	8
80 – 100	70 – 80	1 - 3	9
100 <	80 <	< 1	10

Source: Shrestha, et al. (2014).

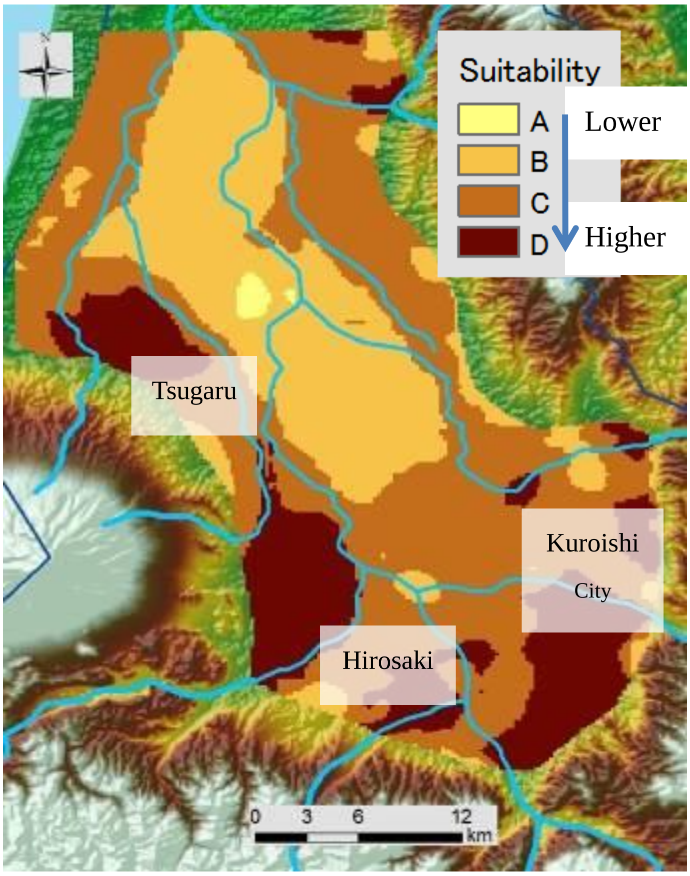
In this study, a suitability map for space-heating and space-cooling purposes was prepared by overlaying the thematic maps in GIS using an overlay model (**Figure 5.2.2-7**). For overlaying, the parameter of each map was reclassified into index classes and each index class was assigned a grade ranging from minimum 1 to maximum 10 (**Table 5.2.2-2**). The higher the grade, the higher the suitability for the GSHP system. For space-heating and space-cooling, the subsurface temperature was not considered in the overlay model. The reason is higher and lower subsurface temperatures both are equally important for space-heating and space-cooling. Weightage was set for thematic maps, 35 percent for groundwater velocity, 35 percent for sand-gravel ratio, and 30 percent for water table depth. The weightage was set based on the variation of each parameter. Maps were overlaid based on grades applied to each cell and weightage assigned to each maps, resulting in the suitability map (**Figure 5.2.2-8**).

Figure 5.2.2-7. Overlay Model for Space-Heating and Space-Cooling



Source: Shrestha, et al. (2014).

Figure 5.2.2-8. Suitability Map of Tsugaru Plain



Source: Shrestha, et al. (2014).

In the legend of the suitability map, ranking A to D represent lower to higher suitability respectively for the installation of GSHP system. Suitability was found higher at the upstream and peripheral areas of the plain as compared to the central and downstream areas. Lower suitability does not mean that GSHP system cannot be installed.

It can be installed but longer length of GHE may be required and hence the higher cost. Major city areas such as Tsugaru City and Hirosaki City showed higher suitability with favourable geological and hydrological conditions. This kind of map that illustrates the variation of suitability is essential to adopt appropriate locations for the optimum design of the GSHP system.

5.2.2.6. Conclusion

The groundwater flow system and subsurface temperature distribution of Tsugaru Plain were comprehended by developing a regional scale analysis model. Hydrological and thermal data to the plain could not be measured as observation wells were lacking. However, the analysis model could be verified by constructing single GHE models and incorporating the results of TRT conducted in the field. Prepared thematic maps of groundwater velocity, subsurface temperature, water table depth, and sand-gravel ratio showing the variation of their respective parameters can be regarded as significant for the proper siting of the GSHP system. Suitability maps developed can be used to determine appropriate locations for space-heating and space-cooling purposes.

References

Aomori Prefecture (2011), 'Survey Report on Potential Use of Ground-coupled Heat Pump System and Hot Spring Temperature in Aomori Prefecture', Aomori, Japan.

Diersch, H.-J.G. (2005), *FEFLOW Reference Manual*. Berlin, Germany: WASY GmbH Institute for Water Resources Planning and Systems Research.

Geological Survey of Japan (2004), 'Geothermal Gradient and Heat Flow Data in and around Japan, Digital Geoscience Map P-5', AIST, Japan (CD-ROM version).

Koshigai, M., A. Marui, N. Ito, T. Yoshizawa (2011), 'Development of Three Dimensional Hydrogeological Model and Estimation of Groundwater Storage in Japanese Islands', *Journal of Japanese Association of Groundwater Hydrology,* 53(4), pp.357–377 (in Japanese with English abstract).

Machida, I., and K. Yasukawa (2008), 'Regional Groundwater Survey for the Use of Ground-coupled Heat Pump System in Aomori Prefecture', in *Aomori Prefecture, Vision for the Promotion of Ground-coupled Heat Pump System in Aomori Prefecture, Aomori, Japan*, pp.91–126 (in Japanese).

Sakai, G. (1960), Study on Hydrogeology and Groundwater of Hirosaki City (I). Hirosaki City, Japan, (in Japanese).

Shrestha, G., Y. Uchida, M. Yoshioka, H. Fujii, and S. Ioka (2014), 'Estimation of Suitable Locations for Ground-source Heat Energy Use in Regional Scale', 2014 Annual Meeting, Geothermal Research Society of Japan, Abstracts with Programs, Akita, Japan.

Shrestha, G., Y. Uchida, M. Yoshioka, H. Fujii, and S. Ioka (2015), 'Assessment of

Development Potential of Ground-coupled Heat Pump System in Tsugaru Plain, Japan. *Renewable Energy,* 76, pp.249–257.

Yoshioka, M., Y. Uchida, Y. Yoda, H. Fujii, and S. Miyamoto, S. (2010), ‘Adoption of Suitability Area for Ground-coupled Heat Pump System 2nd Paper, Development of Heat Exchange Rate Maps using Groundwater Flow/Heat Transport Modeling’, *J. Geotherm. Res. Soc. Japan,* 32(4), pp.241–251 (in Japanese with English abstract).

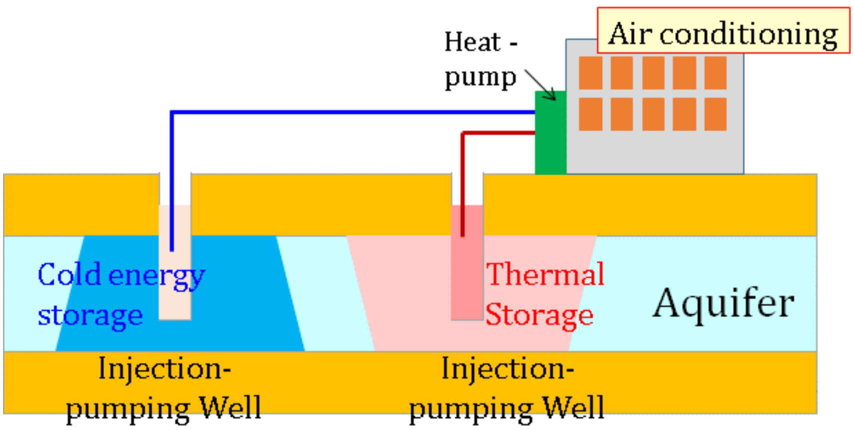
5.2.3. Case study 2: Suitability map for open loop GSHP system; Groundwater flow and heat transport modelling to estimate the area suitable for aquifer thermal energy storage

5.2.3.1. Introduction

An aquifer thermal energy storage (ATES) system is one of the most energy-saving heating and cooling systems that utilises open-loop shallow geothermal technology (**Figure 5.2.3-1**). Development of this system is still limited in Japan because of the complex hydrogeological conditions. For promotion and sustainable utilisation of an ATES system, it is important to evaluate areas suitable for the system, especially in terms of hydrogeology. The purpose of this study is to estimate the area suitable for an ATES system using large-scale groundwater flow and heat transfer modelling.

The study area is Yamagata Basin (**Figure 5.2.3-2**) located in the central region of Yamagata Prefecture, Japan. It extends about 35 kilometres (km) from north to south and 15 km from east to west.

Figure 5.2.3-1. Aquifer Thermal Energy Storage System

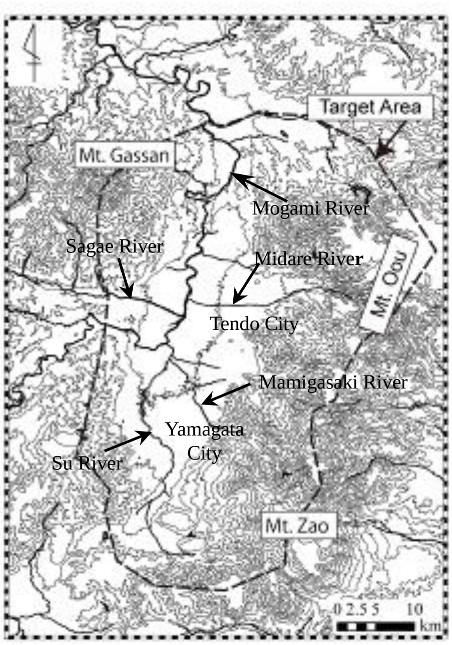


Source: Edited by authors.

5.2.3.2. Regional-scale groundwater flow and heat transport modelling

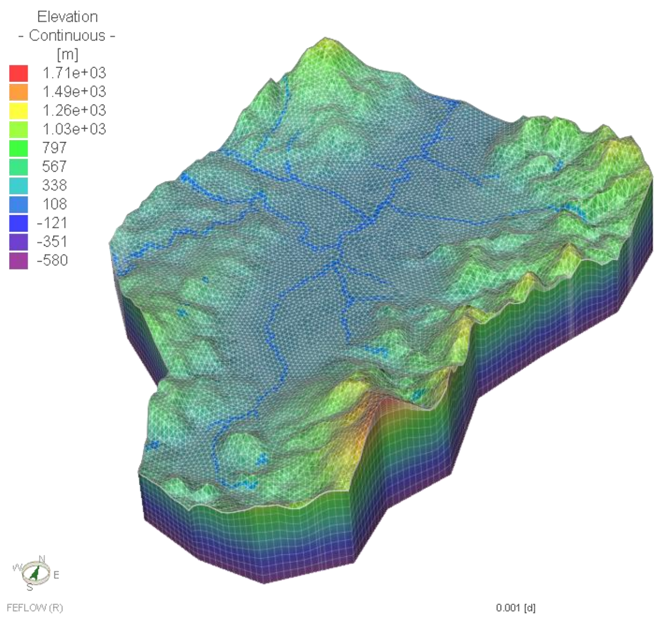
3D groundwater flow and heat transport modelling of Yamagata Basin was conducted using FEFLOW. The model boundary is shown in **Figure 5.2.3-2**. Southern and eastern boundaries of the target area were defined along dividing ridges. Northern and western boundaries were decided by considering the local geography because there were no dividing ridges. 3D analysis model (**Figure 5.2.3-3**) consists of 7 layers in the Quaternary System and 11 layers in the Neogene System. The bottom elevation of Quaternary System was decided by using 'Basement of Quaternary maps in Japan' (Koshigai, et al., 2011). The hydraulic and thermal properties of geological layers are shown in **Table 5.2.3-1**.

Figure 5.2.3-2. Yamagata Basin with Model Boundary



Source: Yoshioka et al. (2012).

Figure 5.2.3-3. 3D Analysis Model of Yamagata Basin



Source: Yoshioka et al. (2012).

Table 5.2.3-1. Physical Properties Used in the Analysis Model

	Unit	Quaternary (1–7 layers)	Neogene (8–18 layers)
Hydraulic conductivity (k_x, k_y)	m/s	7.6e-5	2.2e-8
Hydraulic conductivity (k_z)	m/s	7.6e-6	2.2e-9
Porosity	-	0.2	0.1
Dispersion Length	m	Longitudinal: 100, Transverse: 10	
Heat Capacity	J/kgK	2.6e6	
Heat Conductivity	W/mK	2.0	1.5

m/s = metre per second, m = metre, J/kgK = joule per kilogram Kelvin, W/mK = watt per metre Kelvin.
Source: Yoshioka et al. (2012).

The hydraulic and thermal properties of geological layers are shown in **Table 5.2.3-1**. Hydraulic properties (for example, hydraulic conductivity and effective porosity, amongst others) were decided using the previous studies (GSJ, 2012; Tohoku Regional Office, 1994).

Regarding boundary conditions of groundwater flow, the lateral sides of the model were fixed with a time-constant hydraulic head, which was determined as a function of surface elevation. At the northern and western sides of the basin, it was difficult to select the model boundary along dividing ridges. Therefore, pre-calculation was done using larger scale groundwater flow modelling, which included most of Mogami River and surrounding mountains. Hydraulic heads resulting from the pre-calculation were used as the boundary conditions. The top of the model was also set as time-constant hydraulic head boundary and the bottom was set as no flow boundary. For heat transport, the top and bottom of the model were fixed with time-constant temperature boundaries, and the lateral sides were set as no heat flow boundaries. Temperature distribution at the model top was estimated based on the average air temperature of Yamagata City and assuming a decrement rate in ambient temperature with elevation of 0.65^{o}C/100m. Temperature distribution at the model bottom was estimated based on temperature distribution at the model top, using a geothermal gradient (GSJ, 2004).

5.2.3.3. Results of groundwater flow – heat transport model

Figure 5.2.3-4 shows the distribution of the calculated hydraulic head, measured groundwater level and their comparison. According to the previous studies in this basin, at the top of Mamigasaki River's alluvial fan, the elevation of groundwater level was about 200 m, at the southern edge it was about 150 m, and around the centre the elevation was about 90 m. It was determined that the calculated results were in agreement with measured values.

In order to verify the calculated subsurface temperature distribution, measured subsurface temperature profiles were used. Subsurface temperature profiles were measured at 20 points in Yamagata Basin (GSJ, 2012). A digital thermistor with 300 m cable was inserted into observation wells and groundwater temperature was measured at 2 m depth intervals. **Figure 5.2.3-5** shows the distributions of measured and calculated subsurface temperature at 50 m depth from surface.

Figure 5.2.3-4. Distribution of (a) Calculated Hydraulic Head, (b) Measured Groundwater Level, and (c) Comparison of Calculated and Measured Values

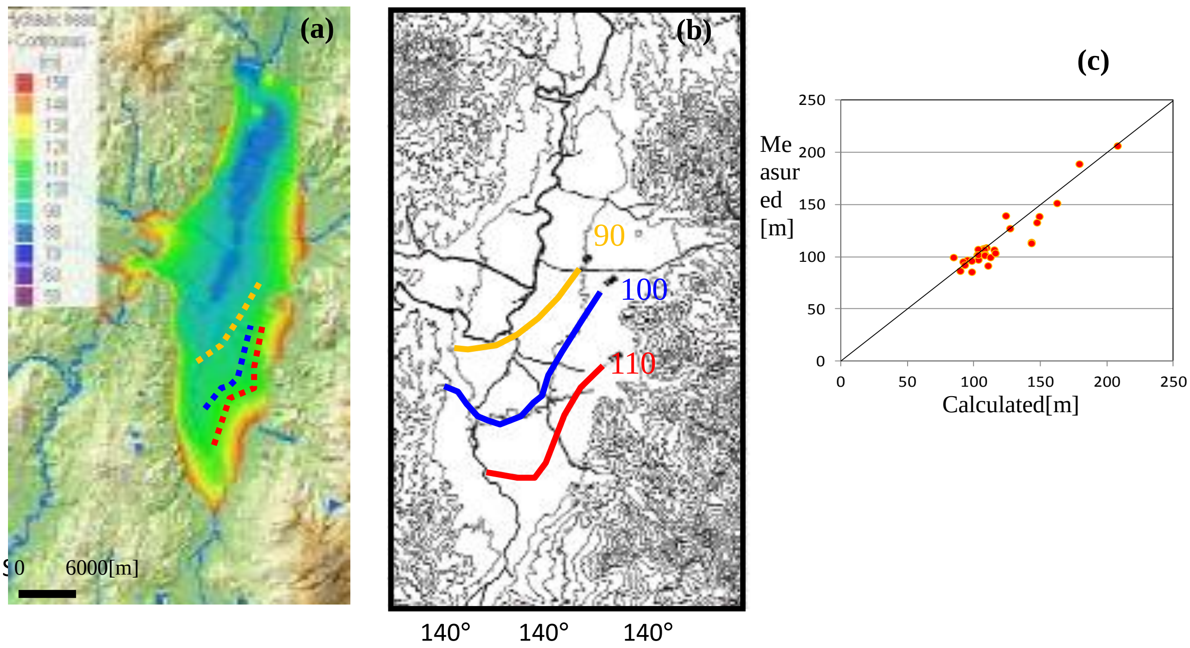
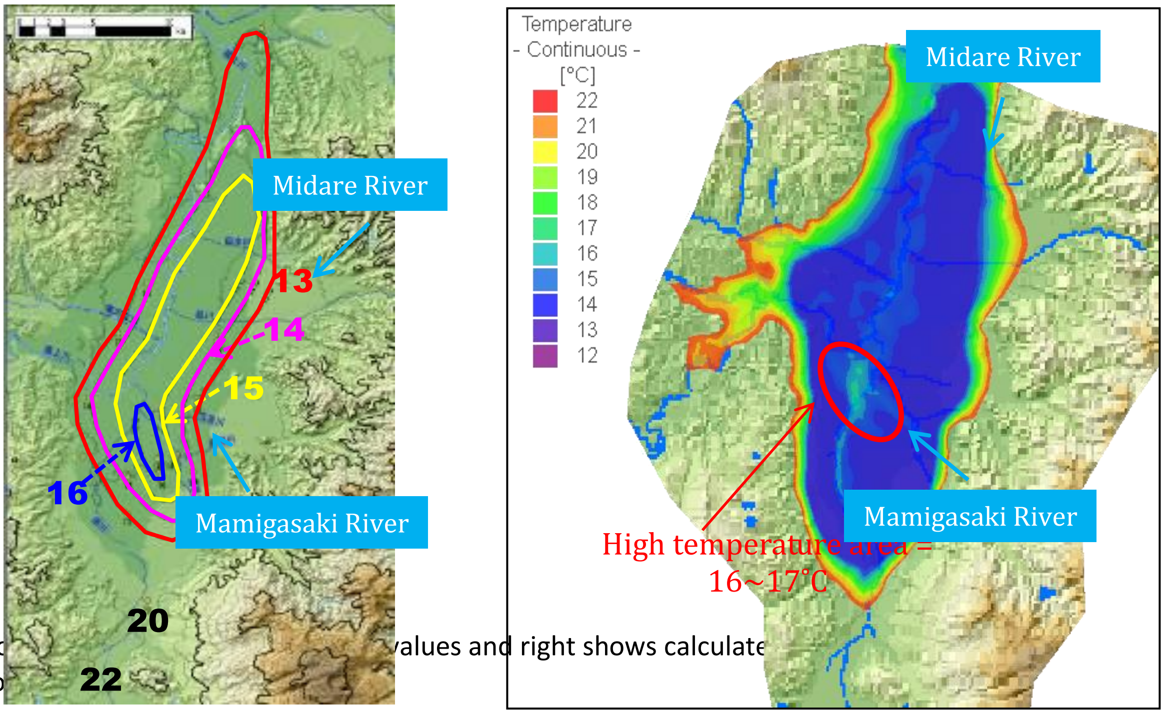


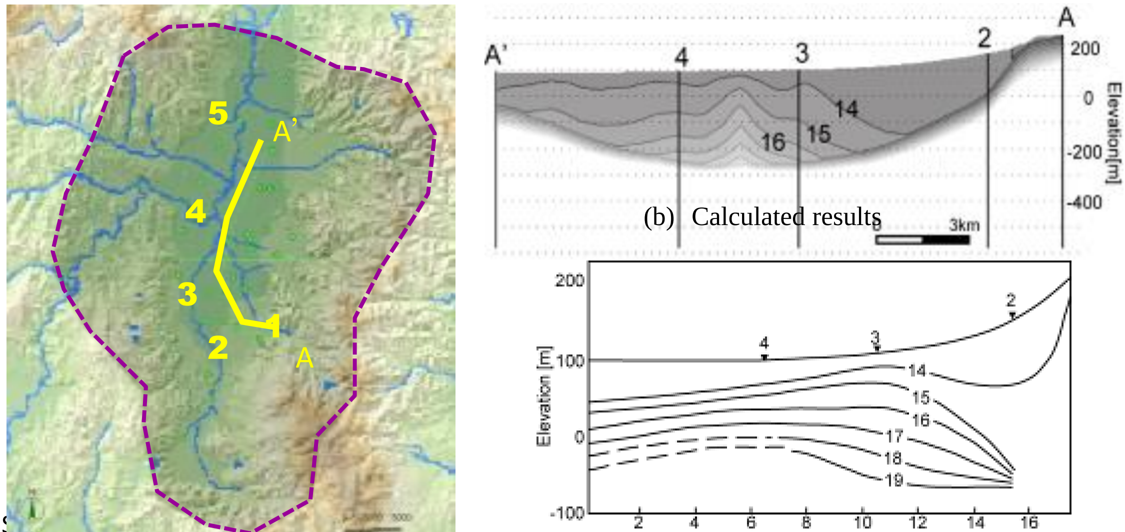
Figure 5.2.3-5. Distribution of Subsurface Temperature at a Depth of 50 Metres



No … values and right shows calculate…
So…

In both figures, the similar tendency of temperature distribution was found, that is, the temperature at the centre of the basin is higher than surroundings and the higher temperature zone elongates from the centre to the north along the Mogami River. The subsurface temperature is influenced not only by heat flux from the deep underground, but also advection due to groundwater flow. In general, the subsurface temperature in the recharge area is lower and that in the discharge area is higher at the same depth (Domenico and Palciauskas, 1973). The measured and calculated subsurface temperature cross-section views are shown in **Figure 5.2.3-6**. The convex form of the temperature profile can be seen in both figures and this area corresponds to the discharge area.

Figure 5.2.3-6. Subsurface Temperatures along Cross-section A-A’



(a) Measured values (modified after Uchida et al., 1993)

5.2.3.4. Indicative parameters for the suitability analysis of ATES system

Areas suitable for the ATES system depend on hydrogeological conditions. For example, pumping capacity is regulated by groundwater availability and hydraulic conductivity, whereas the ability of thermal storage depends on groundwater flow. In this study, parameters that can influence the system performance (called ‘indicative parameters’ hereafter) are adopted. Their values were obtained from the results of the regional-scale modelling and used for the evaluation of areas suitable for the ATES system in the Yamagata Basin. Indicative parameters considered are as follows.

- Horizontal groundwater flow:

It is most important for the ATES system to evaluate the horizontal groundwater flow velocity because the stored thermal energy in an aquifer may be transferred by groundwater flow in faster groundwater flow regions.

- Vertical groundwater flow:

Downward flow of groundwater occurs in recharge areas, which is considered to be applicable for an ATES system. On the other hand, upward flow occurs in discharge areas, which is a drawback for the system because the pumped groundwater cannot be reinjected in these areas.

- Geological setting:

The availability of groundwater and the effect of pumping to the surrounding environment (for example, land subsidence) are controlled by hydrogeological parameters, especially hydraulic conductivity. The higher the hydraulic conductivity, the higher the amount of groundwater can be pumped in general. However, it is site specific.

Hydraulic conductivity varies with the geology. Hence, the geological setting was considered as an indicative parameter in this study.

The groundwater level was found to be higher throughout the basin. For groundwater quality, there were no experimental results. Regarding the subsurface temperature, both low and high temperatures are important for the system. With these reasons, the above mentioned three parameters were taken as indicative parameters in this study. For each of these parameters, weightage was assigned to assess the suitable area for the system.

Weightage of geological setting (W_g):

The weightage of the Quaternary System was assumed to be 1 and that of the Neogene System as 0. This is because the hydraulic conductivity of the Quaternary System is higher than that of the Neogene System by about 3 order. The permeable layer makes it easier to pump up groundwater.

Weightage of horizontal groundwater velocity (W_h):

The weightage of horizontal groundwater velocity (v_{xy}) was assumed as the following.

v_{xy}>0.1m/d W_h =0
0.1m/d > v_{xy} > 0.07m/d W_h =1
0.07m/d > v_{xy} > 0.04m/d W_h =2
v_{xy} < 0.04m/d W_h =3

These threshold values were determined by numerical calculations.

Weightage of vertical groundwater velocity (W_z):

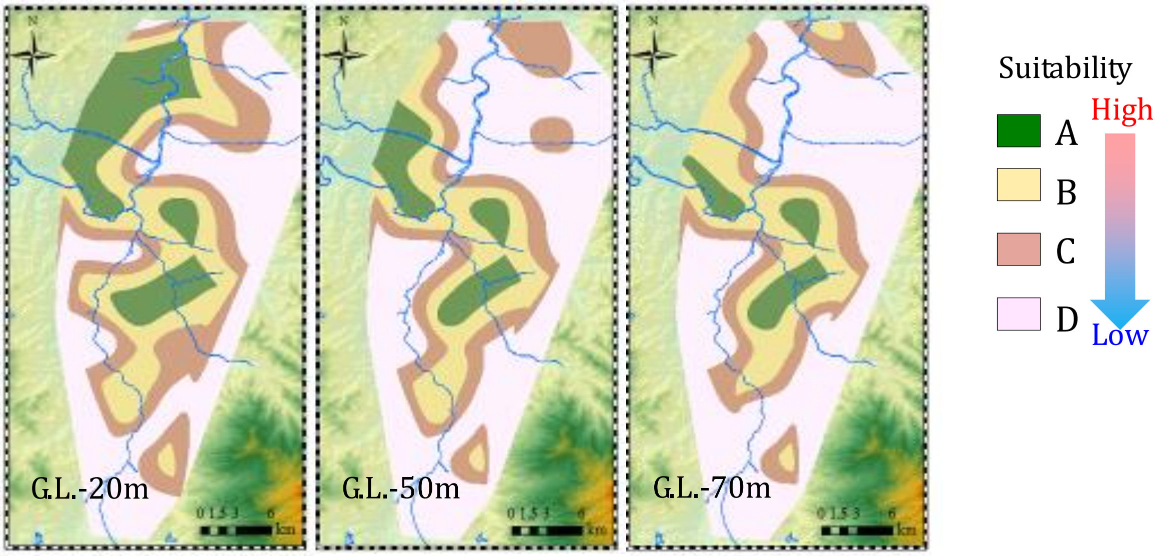
Vertical groundwater flow influences groundwater injection and installing the system in up-flow (discharge) areas is difficult. Hence, weightage in up-flow areas (v_z>0) was assumed as 0 and that in down-flow areas ($v_z \leq 0$) as 1.

Suitability for the ATES system (P) was estimated by using the following expression.

$$P = (W_g + W_h) \times W_z$$

Suitability maps based on above discussion at 20 m, 50 m, and 70 m depths from the surface are shown in **Figure 5.2.3-7**.

Figure 5.2.3-7. Estimated Areas Suitable for ATES System



Notes

Source: Yoshioka et al. (2012).

In the legend of **Figure 5.2.3-7**, the suitability rankings A to D represent high to low suitability respectively. The north-western area and central part of the Yamagata Basin were found to have higher suitability. At the north-eastern area, suitability was estimated to be lower. For areas like this, a closed-type GSHP system may be better than an ATES system.

5.2.3.5. Conclusion

In order to evaluate areas suitable for an ATES system in Yamagata Basin, groundwater flow–heat transfer modelling was performed. Computed results were in agreement with both measured groundwater level and subsurface temperature. Some indicative parameters were proposed and applied to the Yamagata Basin, especially horizontal and vertical groundwater flows and geological setting were used. As a result, the area suitable for the system appeared at the central and northwest of the basin. As a future study, results of the field experiment performed in the basin for ATES system will be incorporated in the suitability evaluation.

References

Domenico, P.A. and V.V. Palciauskas (1973), 'Theoretical Analysis of Forced Convective Heat Transfer in Regional Ground-Water Flow', *Geological Survey of America Bulletin*, 84, pp.3803–3814.

Geological Survey of Japan (GSJ) (2004), 'Geothermal Gradient and Heat Flow Data in and around Japan. Geological Survey of Japan', AIST, CD-ROM. (in Japanese with English abstract)

Geological Survey of Japan (GSJ) (2012), 'Water Environment Map No.6 Yamagata Basin. Geological Survey of Japan', AIST, CD-ROM. (in Japanese with English abstract)

Koshigai, M., A. Marui, N. Ito, and T. Yoshizawa (2011), 'Development of Three Dimensional Hydrogeological Model and Estimation of Groundwater Storage in Japanese Islands', *Journal of Japanese Association of Groundwater Hydrology,* 53(4), pp.357–377 (in Japanese with English abstract).

Uchida, Y., Y. Sakura, and T. Arakawa (1993), 'Groundwater Flow Estimated from the Distribution of Subsurface Temperature in Yamagata Basin', *Hydrology*, 23(4), pp.169–179 (in Japanese with English abstract).

Yoshioka, M., Y. Uchida, H. Fujii, and M. Yamaya (2012), 'Groundwater Flow and Heat Transfer Modeling to Estimate the Area Suitable for ATES System,' 3rd International FEFLOW User Conference, p.8.

Lessons learned

- For sustainable use of GSHP systems, system design suitable for the subsurface condition of the location as well as GSHP application purpose is needed.
- Heat exchange rate and preferred drilling depth of a GSHP system varies with local subsurface conditions.
- In this context, a hydrogeological survey is very important for places in sedimentary basins and plains, while only rock properties are important for places with near surface hard rocks.
- To compile suitability maps of GSHP systems for sedimentary regions, groundwater and geological surveys are needed to perform numerical simulations on groundwater flow and local heat exchange rate.
- The design of a GSHP system can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.
- A suitability map can be made in the following order of procedures:

1. Groundwater and geological survey
2. Regional groundwater flow simulation
3. Heat exchange simulation of the site
4. Making suitability map
    - Weighted overlay method may be used for making suitability map.
    - For closed-loop system, groundwater velocity, sand-gravel ratio, and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used.
    - Space heating suitability map needs subsurface temperature data additionally.

5.3. South Korea: Importance of Monitoring and its Data Analysis

5.3.1. Case study 1: Sejong Metropolitan City

Among the active installations of GSHP according to the Renewable Mandatory Act for Public Buildings, there is a notable case in the new central government office building complex in Sejong Metropolitan City. The government building complex is divided into three zones and the total building area reaches 607,555 m^2. Total installed capacity of GSHP exceeds 20 MW_t and covers more than 38 percent of heating and cooling load of the buildings. 70 percent of geothermal energy extraction is from borehole heat exchangers (BHEs) through 1,190 boreholes of 200 m deep and total length of holes reached 238 km. 30 percent of heat exchangers are using ground water wells of around 400 m deep. Zone 1 of the building complex started operation in 2012, Zone 2 in 2013, and Zone 3 was completed in 2014. GSHP for other public buildings including City Hall and the Educational District Buildings in Sejong City are continuously being installed.

Figure 5.3-1. Bird's-eye View of Zones 1 and 2 of the Government Building Complex, Sejong Metropolitan City

Source: www.chungsa.go.kr

Figure 5.3-2. Ground Source Heat Pumps for the Government Building Complex, Sejong Metropolitan City

Note: From top, drilling of borehole for BHE, trench line of heat exchanger pipes into building, and heat pumps in the basement floor of building.
Source: Photo by TurboEnergy Co., Ltd.

The GSHP system in Sejong City is readily equipped with automated monitoring systems and the monitored data are automatically collected at each site. But there is no systematic regulation or organisation for checking and analysing the monitoring data. It is very important not only to monitor the geothermal system, but to analyse the data. Regulations or organisations are needed for making advice on the sustainable use of GSHP systems based on the analysis of results.

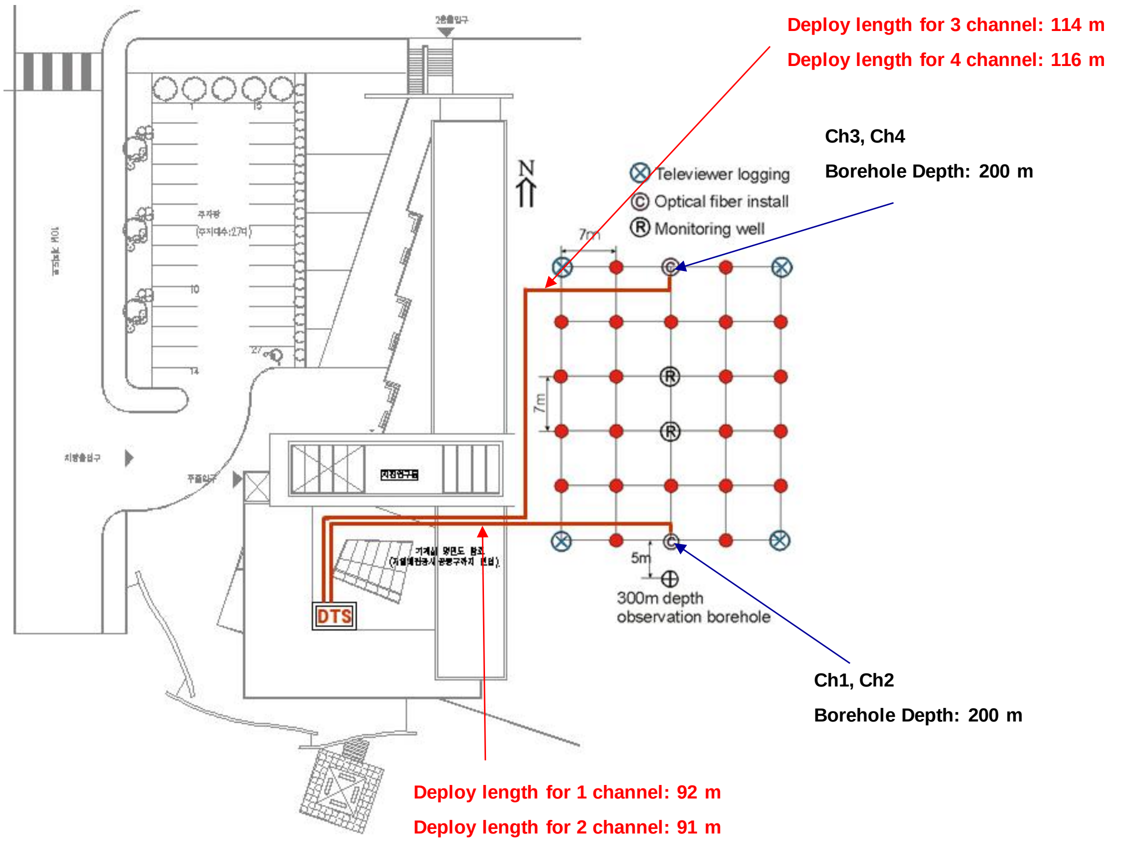
5.3.2. Case Study 2: Long-term temperature monitoring in Earthquake Research Center, KIGAM

A long-term monitoring case of ground temperature variation according to GSHP operation can be found at the Earthquake Research Center (ERC) building in South Korea's Institute of Geoscience and Mineral Resources (KIGAM). The building is three storeys high with an area of 700–900 m^2 each, 2,435.4 m^2 in total, and was constructed in 2005. The heating and cooling load is 400 kW. 28 boreholes with a diameter of 165 mm, a depth of 200 m, and 7 m apart were drilled to be installed with double U-tube type borehole heat exchangers (BHE). After installing the BHEs, the top of the BHE were covered with green grasses.

Figure 5.3-3 Earthquake Research Center in KIGAM

Note: During the installation of borehole heat exchangers (BHEs) (left) and after covering BHEs with green grasses (right).
Source: Photo by Tae Jong Lee.

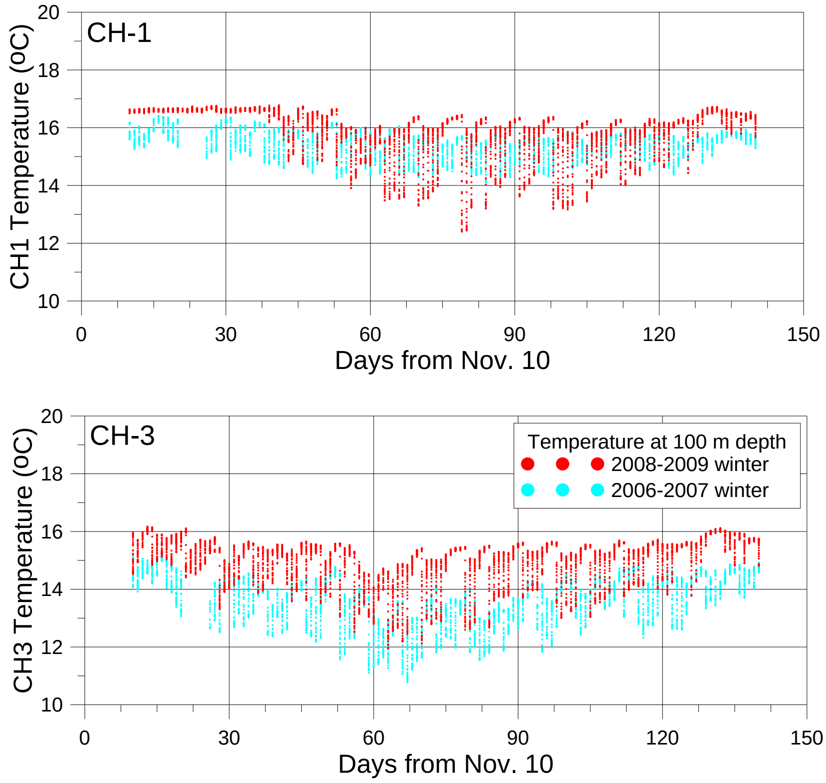
Figure 5.3-4. Layout of Borehole Heat Exchangers and the Monitoring System for the Earthquake Research Center Building at KIGAM



Source: Lee et al. (2010).

The monitoring of the inlet/outlet flow rate and temperature of the BHEs had been performed for about three and half years after the installation. Among 28 BHEs, in addition, fibre optic cables were attached to the outside of U-tubes of two BHEs to monitor the temperature variation with depth. The subsurface temperature beneath the borehole field was getting higher with the GSHP operations and we can see 0.5–1°C of temperature increase per year at 100 m depth (**Figure 5.3-5**). The increase of subsurface temperature was caused by unbalanced seasonal variation of load (actually cooling load is bigger than heating in the building), which may lead to performance degradation as GSHP operation continues year after year. This result is a good example showing that accurate monitoring of the subsurface is important for sustainable use of geothermal energy in heating and cooling applications.

Figure 5.3-5. Comparison of Temperature Variations at 100 Metre Depth Between the Winter Seasons of 2006–2007 and 2008–2009



Note: CH-1 and CH-3 denotes the borehole heat exchangers (BHEs) at different locations.
Source: Lee et al. (2010).

In South Korea, by law, all GSHP systems are subject to be monitored in terms of inlet and outlet temperature and flow rates during operation. All these data are collected by the authorised ministry. However, no analysis has been made for these data so that the actual coefficient of performance (COP) has not been calculated, although the COP is the key to understand the effectiveness of GSHP in terms of saving energy, heat extraction, and sustainability.

Lessons learned

- For long-term sustainability, monitoring of the system is important. The monitoring is mandated by law in case of South Korea, but the problem is that the monitoring data has not been properly analysed in many cases.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored.
- The flow rate and temperature of the primary and secondary fluids and electricity consumption of the heat pump and circulation pump should be monitored to calculate actual COP and long-term performance including extracted heat, amongst others.

Reference

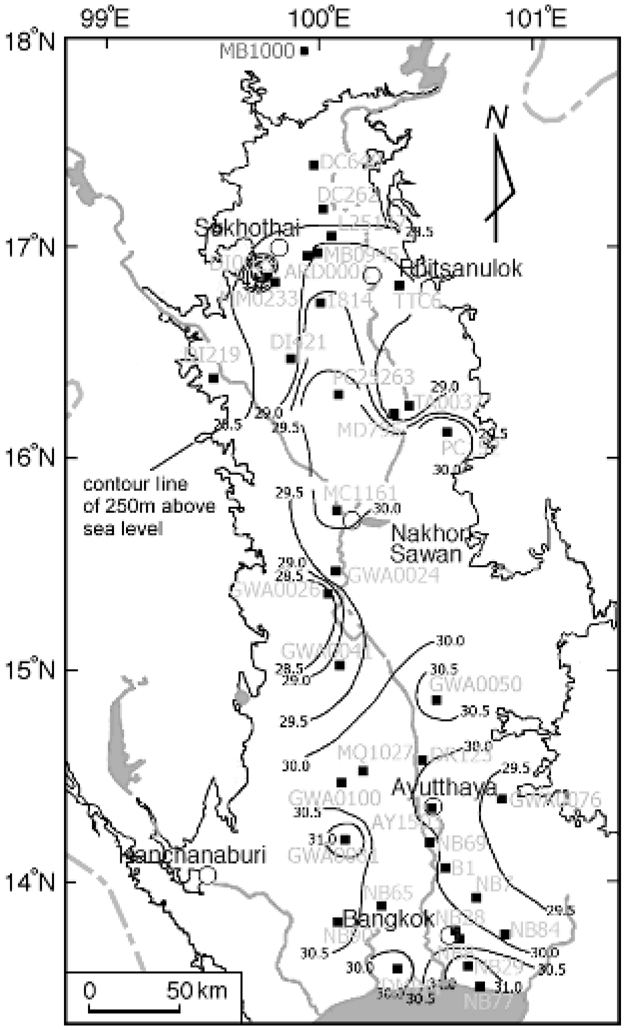
Lee, T. J., Shim, B. O., and Song, Y., 2010, Monitoring of subsurface temperature variation as geothermal utilization, *Journal of Korea Society of Geothermal Energy Engineers*, V. 6, pp. 29–36 (in Korean with English abstract).

5.4. Thailand: Comparison of Groundwater and Atmospheric Temperatures in the Chao-Phraya Plain

Groundwater temperature measurements were widely conducted in the Chao-Phraya Plain in a number of observation wells settled by the Department of Groundwater Resources (DGR), Thailand from 2003 to 2005 (Yasukawa, et al., 2009).

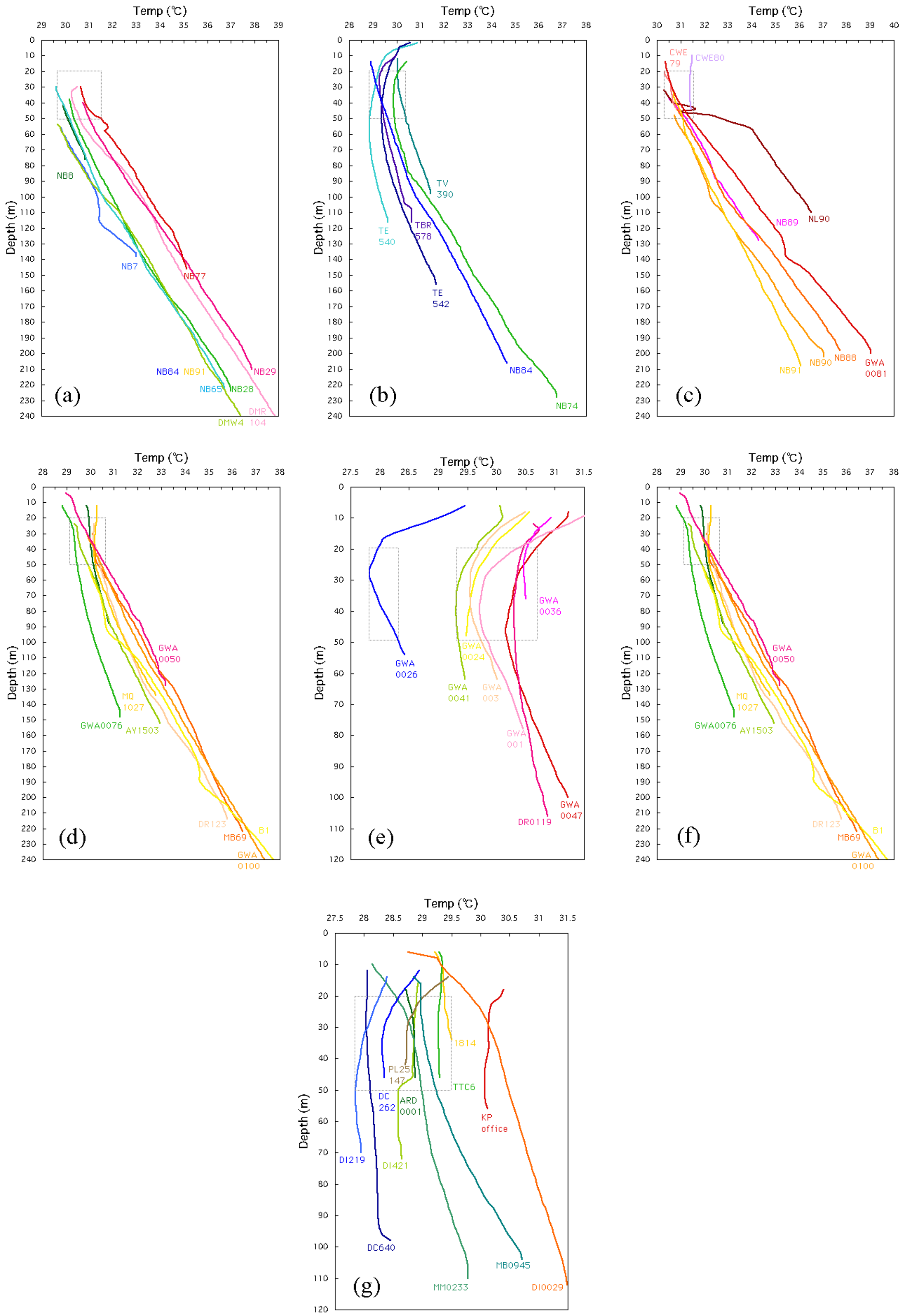
Topographically, the Chao-Phraya plain consists of the upper plain (north of Nakhon Sawan) and the lower plain (south of Nakhon Sawan) with a border around N15^{o}40’, which is also identified by separate shallow groundwater flows (Uchida, et al., 2009). Locations of observation wells are shown in **Figure5.4-1**.

Figure 5.4-1. Contour Map of Maximum Temperature at Depths of 20–50 m (°C)



Note: Location of observation wells are shown by black square.
Source: Yasukawa, et al. (2006a).

Figure 5.4-2. Temperature Profiles of Wells in Certain Areas in Thailand



Notes: (a) Bangkok, (b) Bangkok East, (c) Kanchanaburi, (d) Ayutthaya, (e) Nakhon Sawan south, (f) Nakhon Sawan north, and (g) Phitsanulok-Sukhothai areas.

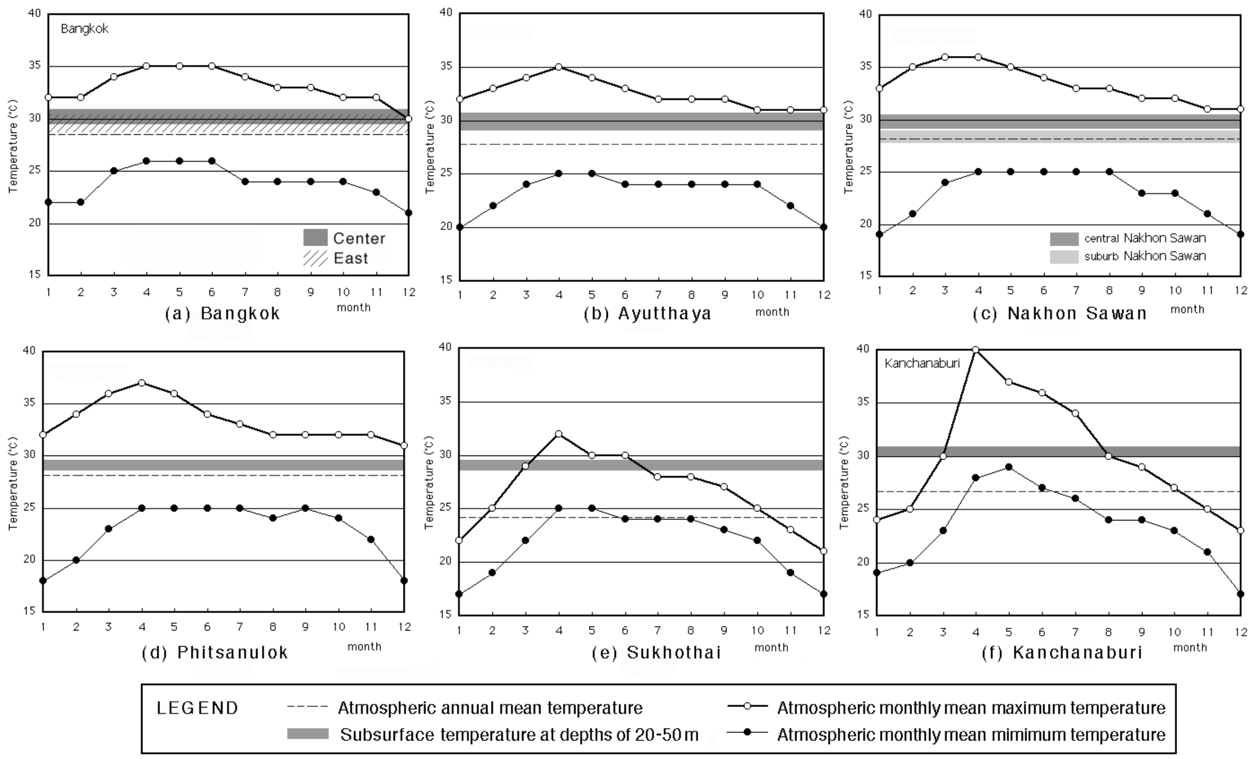
Temperature ranges at a depth from 20m to 50 m are indicated by grey rectangles.

Source: Yasukawa, et al. (2006b).

Figure 5.4-2 shows the observed temperature profiles in these wells. For GSHP systems for cooling, the proper depth of heat exchange wells may be around 50 m or less, since the subsurface temperature increases with depth and deep wells are not appropriate as a 'cool' heat source. Therefore the temperature range at depths between 20 to 50 m in each area is indicated in **Figure 5.4-2**. The temperature at depths shallower than 20 m is ignored because it may be affected by daily and seasonal changes so that the observed value may not represent the statistical mean. In the whole Chao Phraya plain, temperature at depths between 20 to 50 m ranges from 27.8^{o}C (GWA0026, DI219) to 31.5^{o}C (NB77, GWA0081).

Figure 5.4-1 shows a contour map of maximum temperature in these depths. Generally the wells in the upper basin have a lower subsurface temperature than those in the lower basin. However, GWA0041 (**Figure 5.4-2(c)**) and GWA0076 (**Figure 5.4-2(b)**) in the lower basin have rather low temperatures with profiles characteristic to the recharge zone. These wells are considered to be located in local recharge zones of the lower basin for shallow groundwater flow. Shallow local flows may exist in upper and lower basins, respectively.

Figure 5.4-3. Comparison of Atmospheric and Subsurface Temperature at Each Region



Source: Yasukawa, et al. (2006a).

Figure 5.4-3 compares atmospheric and subsurface temperatures in depths between 20 to 50 m at (a) Bangkok, (b) Ayutthaya, (c) Nakhon Sawan, (d) Phitsanulok, (e) Sukhothai, and (f) Kanchanaburi regions. The subsurface temperature data from wells NB29 and NB77, both located near the sea, with extremely high temperature, are eliminated for **Figure 5.4-3(a)**. Subsurface temperatures shown in **Figure 5.4-3(d)** and **Figure 5.4-3(e)** are identical because they are based on data from the same region, while the atmospheric temperatures are different.

At Pitsanulok and Nakhon Sawan, the subsurface temperature is lower than the monthly mean maximum atmospheric temperature (mmmax) through a year. Its difference is higher than 5 Kelvin (K) over four months. Also at Kanchanaburi, the subsurface temperature is lower for 5K or more over four months with a largest difference of 10K in April. A GSHP system may be used in these areas for space cooling especially in daytime. In Bangkok and Ayutthaya, the subsurface temperature is lower than mmmax for almost through a year, but the difference is 5K or less, so performance of a GSHP system may be lower in these regions. In Sukhothai, where the subsurface temperature is higher than mmmax for most of the year, underground may not be used as a ‘cold heat-source’.

Lessons learned

For GSHP application in tropical regions where only space cooling is needed, the underground temperature should be measured first to ensure the applicability of the GSHP system.

If the underground is cooler than atmosphere at least in daytime, GSHP may be effective.

Thus as results of the comparison of underground and atmospheric temperatures, applicability of a GSHP system is shown for many cities in Thailand.

References

Uchida, Y., K. Yasukawa, N. Tenma, Y. Taguchi, J. Suwanlert, and S. Buapeng (2009), ‘Subsurface Thermal Regime in the Chao-Phraya Plain’, Thailand. *Bulletin of Geological Survey Japan*, 60, pp.469–489.

Yasukawa, K., Y. Uchida, Y. Taguchi, N. Tenma, H. Muraoka, S. Buapeng, and T.H. Nguyen (2006a), ‘Possible Utilization of Ground-coupled Heat-pump System in Tropical Countries’, in *Proceedings of the 7th Asian Geothermal Symposium, 25–26 July, 2006, Qindao, China*, pp.159–164.

Yasukawa, K., Y. Uchida, Y. Taguchi, and S. Buapeng (2006b), ‘Possibility of GSHP Application in Thailand’, EIT-JAPAN-AIT Seminar on Geo-Risk Engineering-Monitoring and Geo-Exploration, 27 September 2006, Bangkok, Thailand.

Yasukawa, K., Y. Uchida, N. Tenma, Y. Taguchi. H. Muraoka, T. Ishii, J. Suwanlert, S. Buapeng, and T.H. Nguyen (2009), ‘Groundwater Temperature Survey for GSHP Application in Tropical Asia’, *Bull. Geol. Surv. Japan*, 60, pp.469–467.

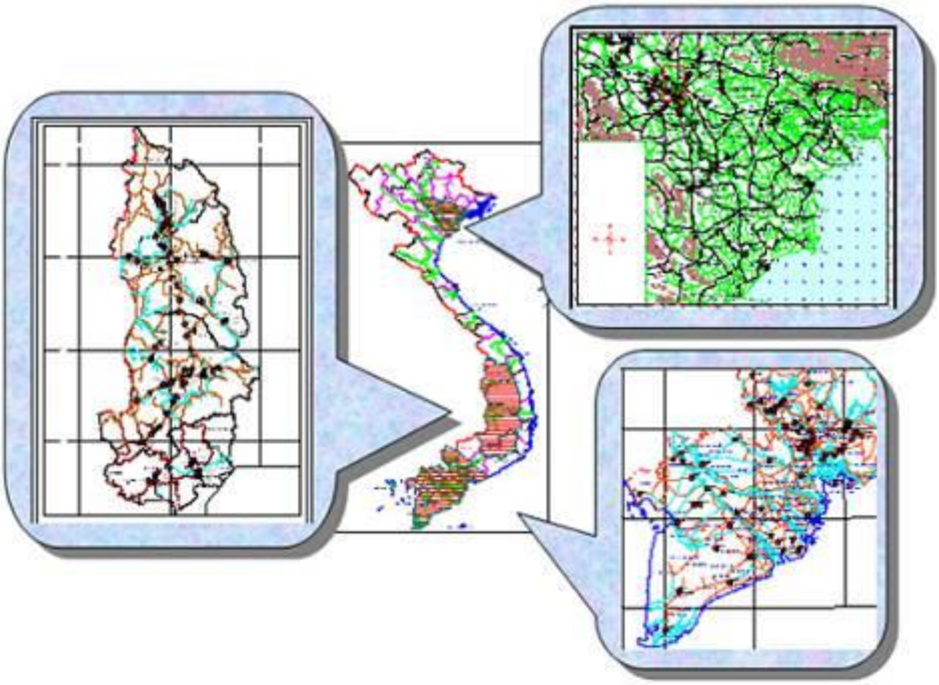
5.5. Viet Nam: Comparison of Groundwater and Atmospheric Temperature in the South Plain and the Red River Plain

5.5.1. Initial possibility evaluation to install GSHP in Southern Plain of Viet Nam

5.5.1.1. Introduction of the groundwater observation system in Viet Nam

The groundwater observation activities in Viet Nam have started in three main economic areas, the Southern Plain, the Northern Plain, and the Central Highlands, since 1990s with 259 observation places consisting of 515 observation wells (**Figure 5.5.1-1**). Recently, the system of groundwater observation places has been extended in the North Central Coastal areas and South Central Coastal areas with a total of 707 groundwater observation wells. Besides, some provinces have developed individual groundwater observation wells, which are not indicated in this report.

Figure 5.5.1-1. Three National Groundwater Observation Networks Developed Since 1995



Source: NDWRPI (2009).

Each groundwater observation network consists of many observation places. Some observation places have only one observation well but others have a cluster of wells that are quite close to each other (a few to tens metres). Each observation well is used for monitoring groundwater behaviour of a certain aquifer. The periodically observed parameters are water level, flow rate, flow velocity, temperatures, chemical composition, gas contents, and microbes.

Based on MONRE (2013) on stipulation of the groundwater observation technique, groundwater temperatures are measured manually or automatically in these wells. For a manually observed well that is not affected by tide, the temperature is measured soon after measuring the water level. For a manually observed well that is affected by tide, the temperature is measured once a day at 1300 hours. For an automatically observed well, the temperature is measured five times a month at inspection and maintenance time of the equipment. The measuring probe is placed at any position in the filter tube that is cased in the aquifer. Practically, most of the temperatures are measured when the measuring probe is submerged in the groundwater of the aquifer. The accuracy of measurement is 0.5K. From 2010 to now, most of the observation temperatures are automatically measured.

5.5.1.2. Introduction to the groundwater observation network in the Southern Plain

The Southern Plain, with an area of 57.000 km^2, is formed by the Me Kong and Dong Nai river deltas in the South of Viet Nam. The basement rock is friability Quaternary and Neogene with the thickness from 500-600 m lying on the Mesozoic–Paleozoic consolidated formations. The observation network is spread out 66 places with 189 wells.

The terrain of the Southern Plain is relatively flat and has some low hills in the north-western part that makes the boundary with Cambodian territory. The north-eastern part is the beginning of the central highlands, so the elevation is also increasing gradually. The coastal lines are surrounded on the east and the west sides. There are only some observation wells at an elevation of 70 m located in the north-east (Dong Nai and Binh Phuoc provinces). The rest of the observation wells are located mainly at the elevation of less than 20 m.

With the aim to evaluate the possibility of GSHP for cooling, a set of groundwater temperature observation data is used to analyse and interpret so that the initial evaluation on the capability to install the GSHP is introduced for the Southern Plain.

Because there are no temperature measurement data in detail for each observation well (for example, temperatures measured in 2 m interval), the statistic data of observation wells from NDWRPI (2011) are used. As many of those observation places have plural observation wells with different screen depth, places with at least two observation wells are selected for this study. Since the wells at one place are very close each other, all the temperature data from one place are considered as temperature data from deferent depths of one well.

From 66 observation places with 189 wells, 14 places with 50 wells have been selected in the areas of Ho Chi Minh, Tay Ninh, An Giang, Ca Mau, and Tra Vinh. The wellhead elevation of these wells varies from 1 m to 20 m (**Table 5.5.1-1**). The well locations are shown in **Figure 5.5.1-2**.

Among 50 observation wells, 23 wells are affected by tide. The wells in Tay Ninh province are not affected by tide and located at the highest elevation (from 4.8 to 19.8m) (**Table 5.5.1-1**), while the most of wells in Ca Mau and Tra Vinh provinces are affected by tide and located at the lowest elevation (from 1.15 to 2.54 m). The distances between the wells in one province varied from 1 km to 50 km.

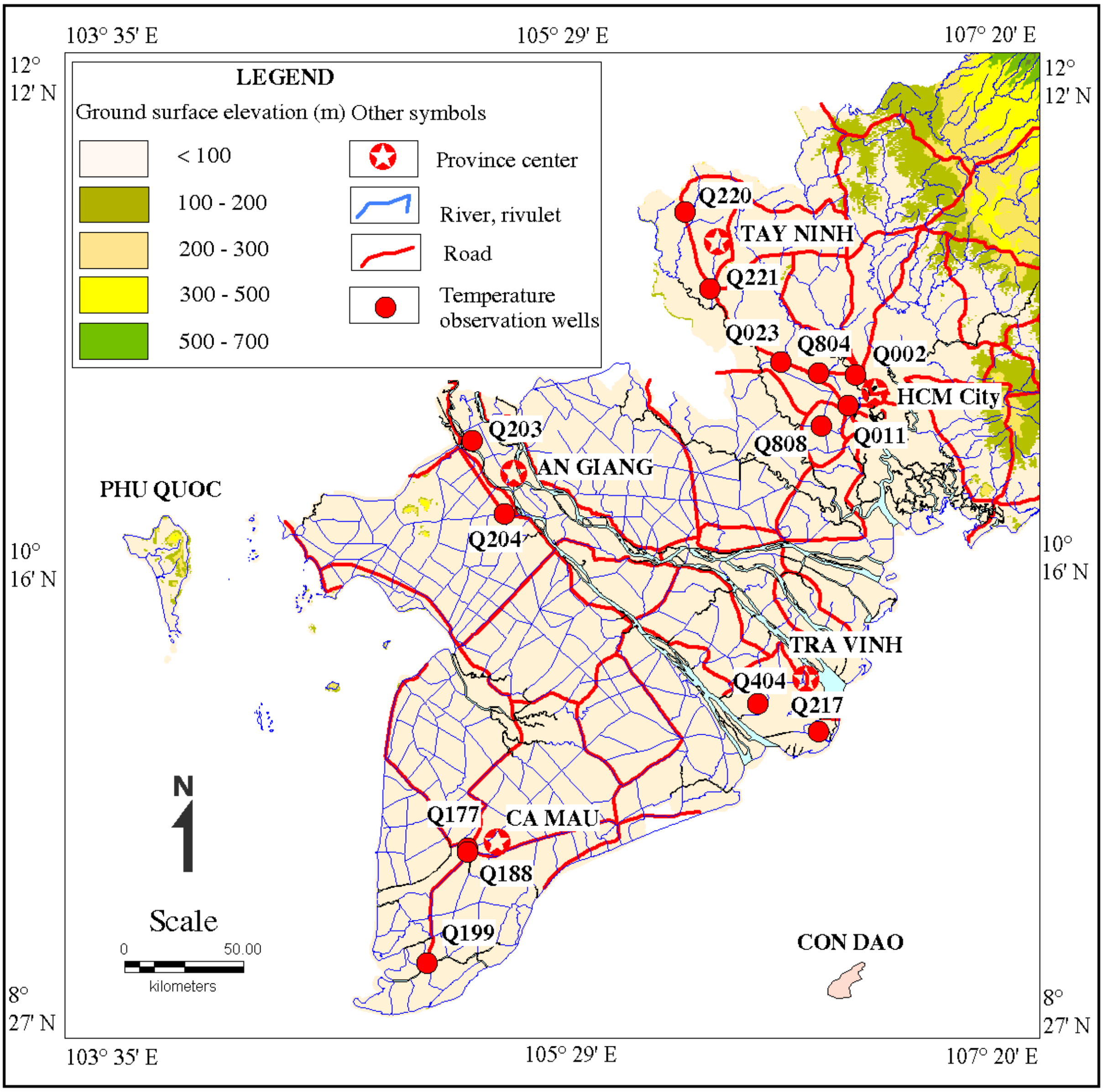
Table 5.5.1-1. Monthly Mean Temperatures of Groundwater at Deferent Aquifers in the Observation Wells in South Plain, Viet Nam

No.	Area	Observation place	Well	Aqu.	Depth (m)		Tid.	Location			Month											
					from	*to*		*x*	*y*	*z (m)*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	HCM City	Q808	Q808010	qh	20	29	y	1192962	665306	1.23	28.5	28.5	28.5	28.7	28.6	28.6	28	27.4	28	27.9	27.5	27
2			Q808020	qp_3	29	77	y	1192970	665306	1.36	28.6	28.4	28.5	28.8	28.6	28.6	28	27.4	28	27.9	27.5	27
3			Q808030 M1	qp_{2-3}	86.9	133.5	y	1192981	665317	1.24	28.5	28.4	28.5	28.5	28.6	28.6	28	27.4	28	27.9	27.5	27
4			Q808040	n_2^2	173.5	207.5	y	1192979	665312	1.4	28.5	28.6	28.3	28.5	28.6	28.6	28	27.4	28	28	27.5	27
5			Q808050 M1	n_1^3	257.5	313	y	1192974	665315	1.31	28.5	28.4	28.5	28.5	28.6	28.6	28	27.4	28	27.9	27.5	27
6		Q804	Q804020	qp_3	0	28	n	1215192	664143	10.2	29.5	29	29	29	29	30	30	30	30	30	30	30
7			Q80404T	n_2^2	64.8	119.6	n	1215189	664144	10.3	30	30	30	30	30.3	30.5	30.5	30.5	30.5	30.5	30.5	30.3
8			Q80404Z M1	n_2^1	124.6	179.5	n	1215188	664143	10.3	30	30	30	30	30.3	30.5	30.5	30.5	30.5	30.5	30.5	30.3
9		Q011	Q011020	qp_3	0	32	n	1201413	676370	7.91	28	28	28.3	29	29.3	27.6	27.5	27.5	27.5	26.8	27.3	25.9
10			Q011340	qp_{2-3}	48	70	n	1201404	676357	8.1	28	28	28	29	29.3	27.6	27.6	27.5	27.5	26.8	26.3	25.9
11			Q011040	n_2^2	130	174	n	1201398	676357	8.05	28	28	28.3	29	29	27.6	27.4	27.5	27.5	26.8	26.3	25.9
12		Q002	Q00202A	qp_{2-3}	25	49	y	1214361	679458	1.94	27.5	27.5	27.5	27.5	27.5	27.5	27	27	27	27	27	27
13			Q00204A	qp_1	50.9	75	y	1214361	679462	2.15	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27	27	27	27
14	Tay Ninh	Q221	Q221020	qp_3	0	23	n	1250383	618306	4.8	28	29	29	29	29	29	29	29	28	28	28	28.2
15			Q22104T	qp_1	37	77	n	1250381	618299	4.63	29	29	29	29	29	29	29	29	29	29	29	29
16			Q22104Z	n_2^2	81.4	141.5	n	1250381	618294	4.54	29	29	29	29	29	29	29	29	29	29	29	29
17		Q023	Q023020 M1	qp_3	8.5	15	n	1219729	648145	5.39	29	29	29	29	29	29	29	29	29	29	29	29
18			Q02304T M1	qp_1	41.5	54.5	n	1219729	648145	5.41	29	29	29	29	29	29	29	29	29.1	29	29	29
19			Q02304Z M1	n_2^1	93.2	114.7	n	1219729	648145	5.42	30	30	29.9	30	30	30	30	30	30	30	30	30
20			Q023050 M1	n_1^3	114.7	141.5	n	1219730	648146	5.41	30	30	29.9	30	30	30	30	30	30	30	30	30
21		Q220	Q22002T	qp_3	0	4.5	n	1282515	607651	19.9	29	29	29	29	29	29	29	29	29	29	29	29
22			Q22002Z	qp_{2-3}	4.5	32	n	1282520	607650	19.9	30	30	30	30	30	30	30	30	30	30	30	30
23			Q220040 M1	qp_1	38.8	77	n	1282535	607647	19.8	30	30.6	31	31	31	31	31	31	31	31	31	31
24			Q220050 M1	n_2^1	118	179.5	n	1282538	607647	19.8	30	30.6	31	31	31	31	31	31	31	31	31	31

25	An Giang	Q203	Q20302TM1	qh	15	38	n	1186763	518233	5.06	30	30	29	30	30	30	30	30	30	30	30	30
26			Q20302ZM1	qp_3	45	75	n	1186763	518233	5.06	30	30	29	30	30	30	30	30	30	30	30	30
27			Q203040M1	qp_{2-3}	77	93	n	1186763	518233	5.07	29	29	29	29	29	29	29	29	29	29	29	29
28		Q204	Q20400S	nm	0	0	n	1156229	531843	3.44	29	29	29	29	29	29	29	29	29	29	29	29
29			Q204010	qh	0	32.8	n	1156175	532012	3.4	29	29	29	29	29	29	29	29	29	29	29	29
30			Q20402T	qp_3	42	49	y	1156180	532016	3.4	29	29	29	29	29	29	29	29	29	29	29	29
31			Q20402Z	qp_{2-3}	76.2	130	y	1156182	532017	3.44	29	29	29	29	29	29	29	29	29	29	29	29
32			Q204040	n_2^2	162	182	y	1156184	532019	3.47	29	29	29	29	29	29	29	29	29	29	29	29
33	Ca Mau	Q177	Q17701T	qh	0	29.5	n	1016287	516372	1.16	27.1	27.3	27.5	27.5	27.3	27.2	27.7	28	28	27.4	27.9	28
34			Q17701ZM1	qp_3	43.5	58.1	n	1016292	516374	1.15	28	27.6	27.5	28	28.1	27.2	27.9	28.1	28	27.7	28	28.4
35			Q177020M1	qp_{2-3}	82	96.2	n	1016290	516372	1.21	29	29	29	29	29	28	29	29	29	28.7	29	29
36			Q17704TM1	n_2^2	165.5	236.6	y	1016287	516375	1.16	29	29	29	29	29	29	29	29	29	28.9	29	29
37			Q17704ZM1	n_2^1	260	273	y	1016291	516377	1.17	29	29	29	29	29	29	29	29	29	28.9	29	29
38		Q188	Q188020	qp_{2-3}	41.5	122	y	1014731	516404	1.73	29	29	29	29	29	29	29	29	29	28.8	29	29
39			Q188030	qp_1	122	185	n	1014730	516405	1.75	28.5	28.1	28.1	28.6	28.2	28.3	28.2	28.2	28.1	28.3	28.1	28.4
40		Q199	Q199010	qh	0	40	y	968465	499584	1.14	28	28	28	28	28	28	28	28	28	28	28	28
41			Q19904T	n_2^2	224.9	250.5	y	968461	499586	1.11	31	31	31	31	31	31	31	31	31	31	31	31
42			Q19904ZM1	n_2^1	294.5	322.4	y	968458	499551	1.03	31	31	31	31	31	31	31	31	31	31	31	31
43	Tra Vinh	Q217	Q217010	qh	0	26	n	1065368	663815	2.54	27.6	27.9	28	28	28	27.7	27.8	27.7	27.7	27.7	27.3	27.7
44			Q217020	qp_{2-3}	100	152	y	1065369	663817	2.39	27.5	27.5	28	28	28	28	28	27	27	27.5	27.5	27
45			Q217030	n_2^2	242.5	313	y	1065371	663821	2.45	27.5	27.5	28	28	28	28	28	27	28	28	28	28
46			Q217040	n_2^1	322	381	y	1065372	663824	2.49	27.5	27.5	28	28	28	28	29	29	27.5	29	29	29
47		Q404	Q404020	qp_3	27	128	y	1076961	638467	1.58	28	28	28	29	29	28	27	27.3	28	27.7	28.2	27.7
48			Q40403T	qp_{2-3}	128	174	y	1076985	638470	1.58	29	29	29	29	29	28.5	28	27.8	28.5	28.2	28.7	28
49			Q40403Z	n_2^2	237	285	y	1076958	638470	1.58	29	29	29	29	29	29	28.5	28.3	29	28.7	29.2	28.5
50			Q40404TM1	n_2^1	317	377	y	1076960	638473	1.74	30	30	30	30	30	29.5	27	28.8	29.5	29.2	29.7	29

Aqu. = aquifer layer; Tid. = aquifer is affected by tidal: y = yes or n = no; z = elevation of ground surface at observation well.
Source: NDWRPI (2011).

Figure 5.5.1-2. Groundwater Observation Places in Southern Plain



Source: NDWRPI (2011).

5.5.1.3. Climate characteristics in Southern Plain

The Southern Plain is situated in the typical monsoon tropical and subequatorial area with abundant humid heat-base, plentiful sunlight, long radiation time, and high temperature. The day and night temperature change among months of a year is low and moderate. Annual average humidity ranges from 80–82 percent. There are two seasons in a year: dry and rainy. The rainy season is from May to November and the dry season is from December to April. The highest and lowest temperatures of every month in Ho Chi Minh and Ca Mau areas are presented in **Tables 5.5.1-2** and **5.5.1-3**.

Table 5.5.1-2. Groundwater and Atmospheric Temperatures in Ho Chi Minh

Month / Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean maximum of air	32	32	33	34	35	34	33	32	33	33	32	33
Monthly mean of ground water	28	28	28	28	28	28	28	28	28	28	28	28
Monthly mean minimum of air	21	22	23	25	25	24	24	24	24	23	23	22

Source: Compiled by authors based on NCHMF (2015) and NDWRPI (2011).

Table 5.5.1-3. Groundwater and Atmospheric Temperatures in Ca Mau

Month / Temperature (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly mean maximum of air	25	26	33	35	35	33	33	33	33	33	32	30
Monthly mean of ground water	29	29	29	29	29	29	29	29	29	29	29	29
Monthly mean minimum of air	22	22	23	25	25	24	24	24	24	23	22	20

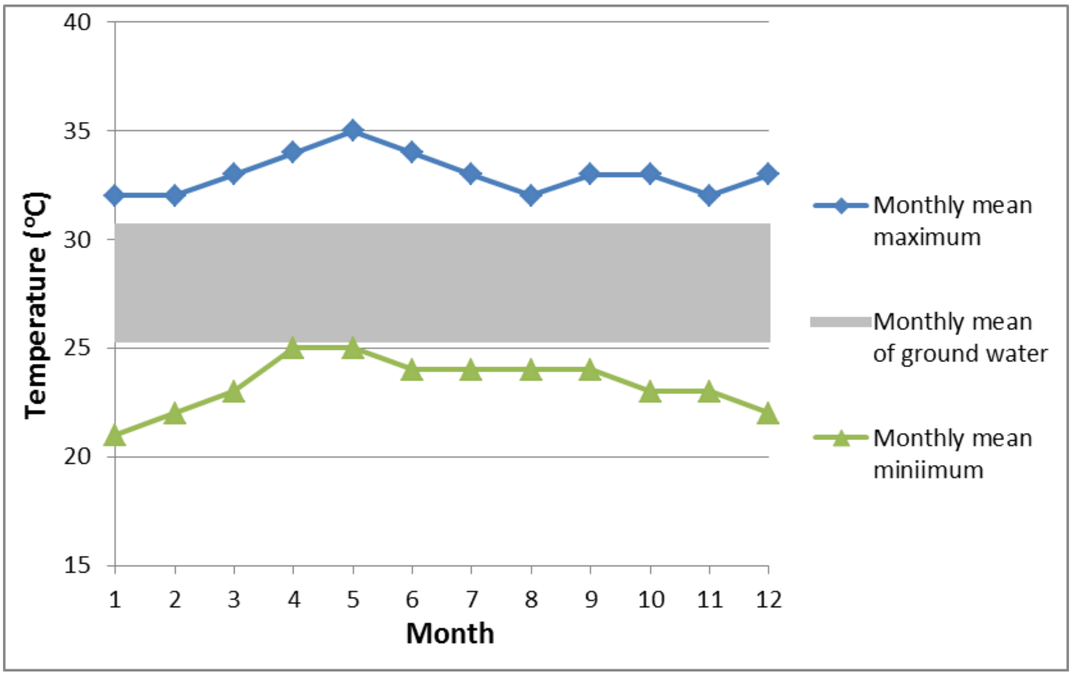
Source: Compiled by authors based on NCHMF (2015) and NDWRPI (2011).

5.5.1.4. Comparison of atmospheric and groundwater temperatures

Since most of the aquifers lie at depths of dozens to hundreds of metres, the temperatures are relatively stable through a year. The average values of groundwater temperature measured from January to December were used to compare with atmospheric temperature. The measuring points are few metres deeper than the water level in the wells (hydraulic head of the aquifer) because the measuring probe should be submerged into the water. Since temperatures at deeper levels are not available, these measured temperatures at slightly deeper than the water level of each well were used. The measured temperatures are about 27 to 30°C in Ho Chi Minh and 27 to 31°C in Ca Mau areas.

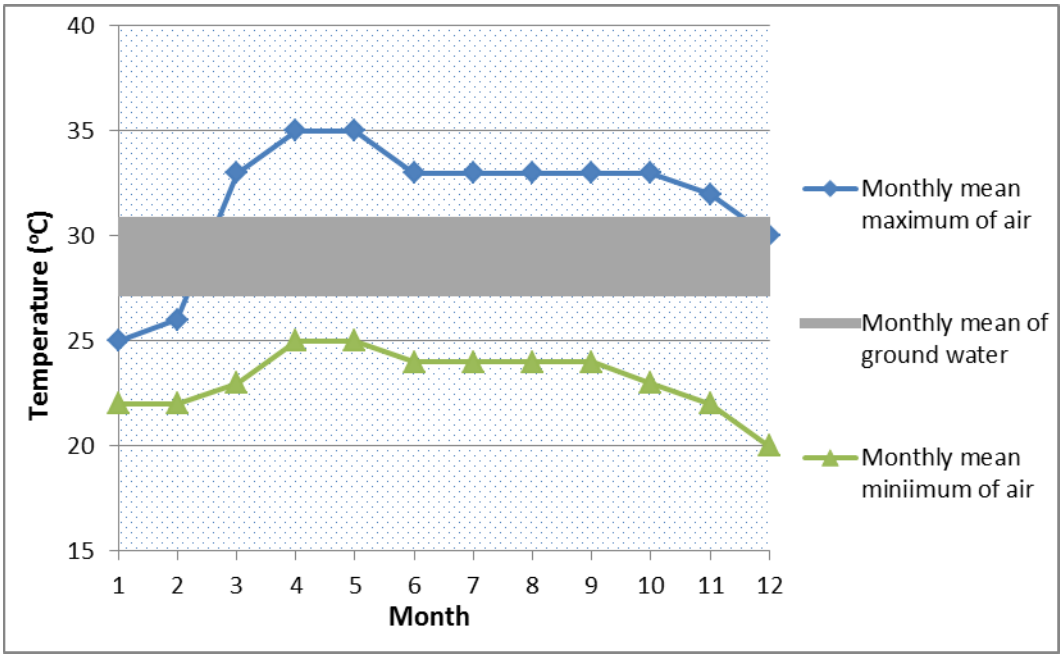
The minimum and maximum temperatures in each month and the range of subsurface temperatures in Ho Chi Minh and Ca Mau areas are presented in **Tables 5.5.1-2** and **5.5.1-3**. From these tables, the diagrams of subsurface and atmospheric temperature comparisons are made as shown in **Figs. 5.5.1-3** and **5.5.1-4.** These figures indicates that GSHP may be used for cooling in Ho Chi Minh area throughout the year while GSHP may be used for cooling in Ca Mau from March to November.

Figure 5.5.1-3. Comparison of Atmospheric and Groundwater Temperatures in Ho Chi Minh



Source: Edited by authors based on NCHMF (2015) and NDWRPI (2011).

Figure 5.5.1-4. Comparison of Atmospheric and Groundwater Temperatures in Ca Mau



Source: Edited by authors based on NCHMF (2015) and NDWRPI (2011).

Lessons learned and recommendations

- Monthly mean maximum atmospheric temperature in the Southern Plain is hot and sunny almost all year round so the GSHP may be installed for cooling.
- The variances between atmospheric and groundwater temperatures can help to initially predict the capability of installing the GSHP in many areas in the Southern Plain of Viet Nam.
- The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated in Viet Nam.
- To extract the suitable areas for GSHP systems, more detailed investigations including suitability mapping based on hydrogeological data should be conducted. As for areas where the GSHP can be applied, a pilot system installation and operation including subsurface temperature monitoring is recommended before distribution of the systems.

References

Ministry of Natural Resources and Environment. (MONRE) (2013), 'Circular on Stipulation of Groundwater Observation Technique', 19/2013/TT-BTNMT 18 July 2013.

National Division for Water Resources Planning and Investigation (NDWRPI) (2009), 'Introduction to Groundwater Observation Network', National Division for Water Resources Planning and Investigation, Ministry of Natural Resources and Environment of Vietnam.

NCHMF (2015) Website of the National Centre for Hydro-Meteorological Forecasting. Ministry of Natural Resources and Environment, Viet Nam.

NDWRPI (2011), *Year Book 2010. Groundwater Resource in Southern Plain of Vietnam,* National Division for Water Resources Planning and Investigation, Ministry of Natural Resources and Environment.

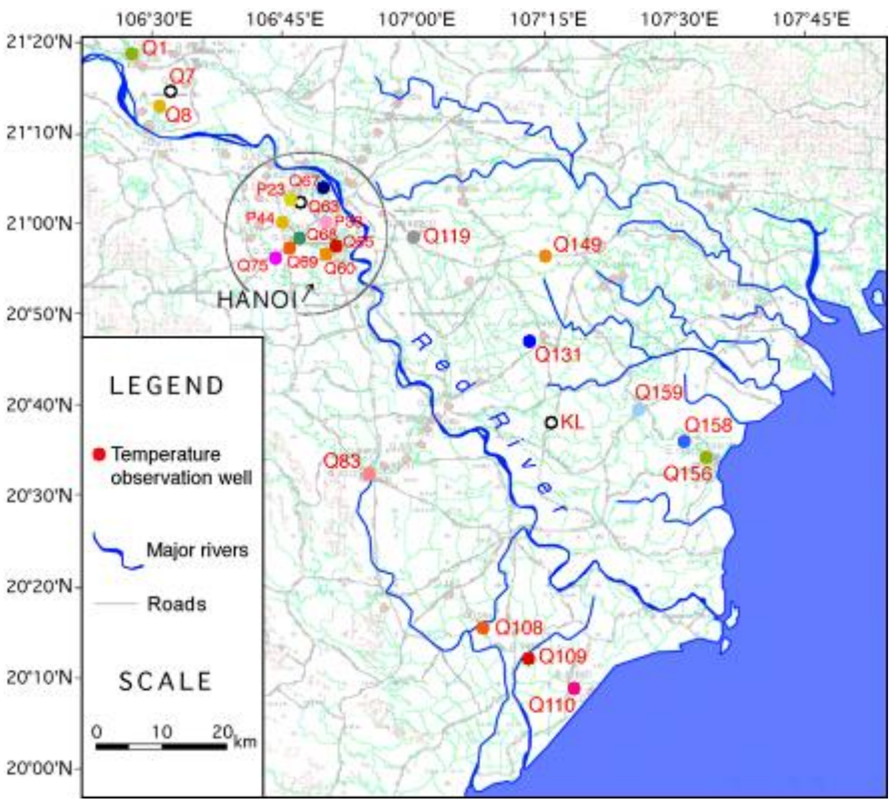
Yasukawa, K., Y. Uchida, N. Tenma, Y. Taguchi. H. Muraoka, T. Ishii, J. Suwanlert, S. Buapeng, and T. H. Nguyen 2009), 'Groundwater Temperature Survey for Geothermal Heat Pump Application in Tropical Asia', *Bulletin of the Geological Survey of Japan,* 60(9/10), pp.463–466.

5.5.2 Temperature survey at the Red River Plain, Viet Nam

A groundwater temperature survey was conducted in the Red River plain in observation wells operated by the Department of Geology and Minerals of Viet Nam (DGMV) in 2005 and 2006 (Yasukawa, et al., 2009). Although this region is not a tropical area, it is important to know the subsurface temperature distribution around this area in order to compare with the southern part of the country.

The location of observation wells in this area, for which temperature profiles are obtained, are shown in **Figure 5.5.2-1. Figure 5.5.2-2** shows the observed temperature profiles for these wells. The colour of each profile corresponds to that of wells in **Figure 5.5.2-1**.

Figure 5.5.2-1. Locations of Temperature Observation Wells in the Red River Plain

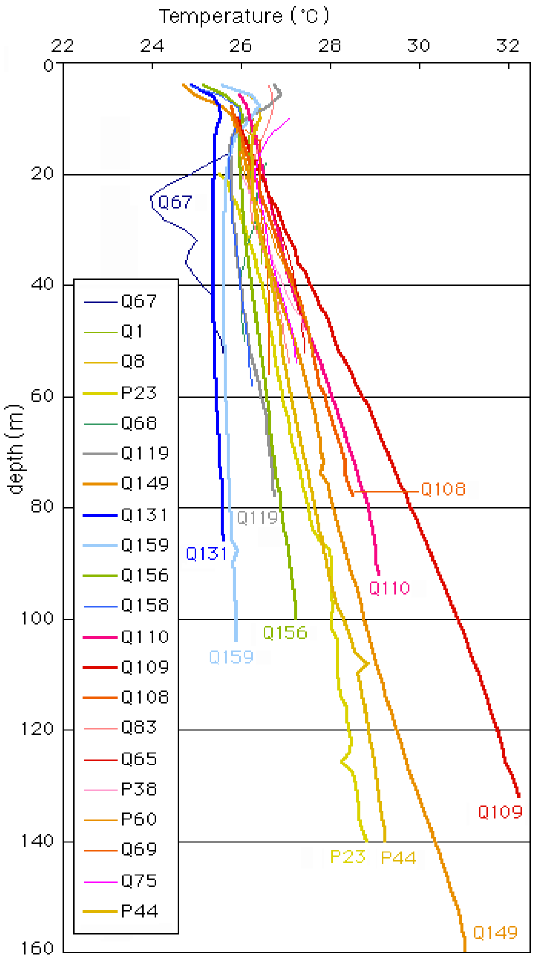


Source: Yasukawa, et al. (2006).

In the south of the Red River, the wells near the sea (Q108, Q109, Q110) show higher a temperature gradient than those at Ha Noi (inner land), indicating the difference of discharge and recharge zones as shown in **Figure 5.5.2-2**. However in the north of the

Red River, the wells near the sea (Q156, Q158, Q159, Q131, etc.) have lower a temperature gradient than those in Ha Noi. It suggests that the groundwater system in the north is different from that along the Red River. Amongst the ones in the north, wells near the sea have a higher temperature gradient.

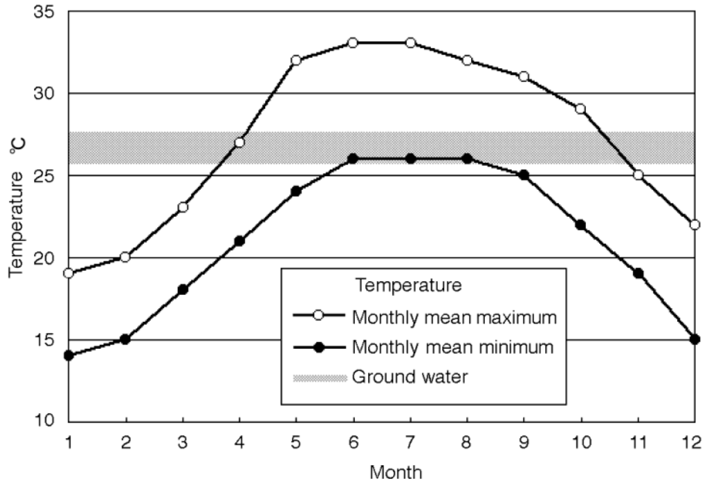
Figure 5.5.2-2. Temperature Profiles of the Wells around Ha Noi



Source: Yasukawa, et al. (2006).

Figure 5.5.2-3 shows monthly change of atmospheric temperature at Ha Noi and groundwater temperature at depths of 20–50m, observed at wells shown in a grey circle in **Figure 5.5.2-1**. In Ha Noi, the subsurface temperature is lower than the monthly mean maximum atmospheric temperature (mmax) from May to October for 5K or more. Therefore, underground may be used as a 'cold heat source' in the summer season. On the other hand, in the winter season, the underground temperature is higher than the atmospheric temperature and it can be used as a hot heat source. Although winter air temperature in Ha Noi is not very low, the humidity is so high that GSHP as a heating system would be useful for drying.

Figure 5.5.2-3. Comparison of Atmospheric and Subsurface Temperature Around Ha Noi



Source: Yasukawa, et al. (2006).

Lessons learned

For GSHP application in tropical regions, the ground temperature should be measured first to ensure the applicability of the GSHP system in terms of temperature advantage.

If the underground temperature is lower than the atmosphere at least in daytime, GSHP may be effective. Thus temperature survey results shows the applicability of a GSHP system in Ha Noi.

References

Yasukawa, K., Y. Uchida, Y. Taguchi, N. Tenma, H. Muraoka, S. Buapeng, and T.H. Nguyen (2006), 'Possible Utilization of Ground-coupled Heat-pump System in Tropical Countries', in *Proceedings of the 7th Asian Geothermal Symposium, 25–26 July 2006, Qindao, China*, pp.159–164.

Yasukawa, K., Y. Uchida, N. Tenma, Y. Taguchi. H. Muraoka, T. Ishii, J. Suwanlert, S. Buapeng, and T.H. Nguyen (2009), 'Groundwater Temperature Survey for GSHP Application in Tropical Asia', *Bulletin of Geological Survey Japan*, 60, pp.469–467.

Chapter 6

Compilation of Case Studies

6.1. Power Generation and Direct Heat Use

The lessons learned in Chapter 5 for high-enthalpy geothermal utilisations (power plant and direct heat use) are summarised below.

<u>China 1: Yangbajain (binary power plant)</u>

- Lack of systematic survey: 'Seeking heat from heat' type of exploration.
- Failure in implementing reinjection: Importance of injection was recognised at start of production but problems related to poor skills of drilling/operating crew and scaling in initial injection cools, prevented the successful full implementation of reinjection.
- No prevention of subsidence: Caused abolished well and dry-out of natural manifestation.
- Delay of strategy change in reservoir management: Although the shallow reservoir encountered pressure and temperature drop, they did not change the production zone into deep reservoir, that caused drastic production decline.

<u>China 2: Xiaotangshan (direct heat use from single liquid phase reservoir)</u>

- Successful reinjection in production scale may recover water level.
- Monitoring of water chemistry including geothermometry, water level, and water quantity is important.
- Resources management was achieved by water level control.

<u>Indonesia: Case study from six geothermal fields</u>

- Most common problems in geothermal power plant are scaling (in production wells, piping, reinjection, and turbine), corrosion (in particular in production wells), and water mixing.
- Chemical inhibitor and mechanical cleaning (workover) are the most common methods to overcome the mineral scaling problems.
- Make-up well is common practice in order to maintain steam supply.
- Major surveillance activities are to monitor the quantity of steam produced, the

geochemistry of reservoir fluid, microgravity, induced seismicity, temperature, and chemical tracers.

- Silica sinter problem was reduced by new production design (by pressure and temperature control)

Japan: Matsukawa (Steam dominated reservoir with super-heated zones)

- An over-heated vapour dominant reservoir, such as Matsukawa, showed an increasing stem production with water injection.
- Tracer test is one important method for evaluation of the production recovery.
- We have to check other over-heated reservoirs and water dominant reservoirs to discuss the possibility of EGS and water injection to maintain geothermal power generation.

Philippines 1: Tiwi geothermal field

- The Tiwi geothermal field has been affected by a number of resource management challenges including meteoric-water influx (MR), injection breakthrough, acid fluids utilisation, scaling, and corrosion.
- The biggest challenge was the influx of MR in the Nag area, which necessitated the relocation of the entire production system. Repeat precision gravity survey is becoming useful for monitoring.
- To prevent detrimental effects of injection breakthrough, the relocation of 'infield' to 'edgefield' and 'outfield' injection was an effective strategy in the Nag area.
- Production wells 'at risk' are carefully monitored and allowable injection rates are limited for specific injection wells to avoid cooling.
- As for mitigating corrosion attack from acidic fluids, the new well design with a cemented blank liner run to below –1000 m mean sea level (msl) was proven effective to case-off potential acid zones.
- For controlling superheated steam zone, pressure balance of shallow steam zone and deep reservoir is essential and pressure monitoring in these zones are important.
- The key to overcoming these challenges is to have a strong multi-disciplinary resource team in place that can understand the problems and provide feasible solutions.

Philippines 2: Tongonan geothermal field (TGF)

- The experiences in TGF have shown that proper resource management and well intervention are effective in sustaining field generation.

- Though the effects of pressure drawdown due to extraction are inevitable, the negative impacts on steam flow production can be controlled.
- Some of the strategies used in TGF and described in this work are:
  - optimisation of injection loading so that the benefits of mass recharge and pressure support are balanced against the drawbacks of cooling and mineral deposition;
  - use of sacrificial wells to redirect cold natural recharge away from the depressurised production area; and
  - well-intervention techniques to address decline in production due to mineral deposition within wellbores.
- Careful monitoring of reservoir conditions through geochemical and reservoir engineering data were found to be useful in developing sound resource management strategies.
- As production continues, integration of the different data available will lead to continuous refinement of these strategies or even replacement with better methods.
- With sound resource management, TGF may be able to sustain production for another 25 years.

Thailand: Fang binary plant (economical sustainability)

- Mineral scaling problem is solved by chemical or mechanical cleaning to sustain system's operations.
- The operating cost of the geothermal project was three times cheaper than production from fossil fuel, with several times cheaper maintenance cost and longer durability, which may be an important factor for sustainable use in commercial sense.

Example of other country: New Zealand fields (liquid dominated reservoirs)

- Region of subsidence is strongly related to geology: clay in shallow subsurface.
- The initial subsidence was caused by mass production, but the major (ten times larger) subsidence was due to pressure drop by injection into steam zone.
- Subsidence rate was stabilised by deep injection (stop shallow injection), but slow subsidence is continuing due to creep phenomenon triggered by early injection.

Tables 6.1 shows the summary of lessons learned for power plant and direct heat use in a matrix of problems and solution in each case study.

Table 6.1. Summary of Lessons Learned for Power Plant and Direct Heat Use

	Well and Reservoir Processes Monitoring	**Reservoir Drawdown**	**Brine and Condensate Reinjection**	**Super-Heated Steam and Erosion**	**Mineral Scaling (Sio2, Caco3, Caso4, etc.)**	**Corrosion**	**Others** -Subsidence -Turbine rundown -Poor permeability
China Yangbajain	Minimal monitoring for wells and reservoir.	Shallow reservoir has encountered pressure drawdown and temperature decline.	Carried out reinjection test several times, but reinjection was not successful.	No occurrence	CaCO3 and SiO2 scaling occurred with mechanical cleaning conducted daily.	No serious corrosion occurred in old wells.	Deep reservoir has been explored and assessed, but information was not used for reservoir management.
China Xiaotangshan **Direct Heat Use**	Monitoring has been carried out over time for 58 years.	Reservoir drawdown has been controlled basically by reinjection where water level had risen continuously over 3 years.	Reinjection has reached 40%–60% of production flow rate.	No occurrence	No scaling problem so far for the low-temperature geothermal fields.	Very little corrosion for low temperature fields.	No other problem
Indonesia Six fields	Major surveillance activities are to monitor quantity of steam produced, geochemistry of reservoir fluid, microgravity, induced seismicity, temperature, and chemical tracers.	Reservoir drawdown results to pressure drop which occurs mostly due to cooler water mixing other than over production. Additional wells are needed to	Problems related to reinjection are scaling and cooling due to brine water mixing with reservoir fluids. Reinjection strategy was reformulated to	Not a problem	Scaling mostly occur in production wells, pipelines, reinjection wells, and turbine leading to generation decline. Mechanical and chemical cleaning from scaling are	Corrosion occurs in production wells and also together with erosion in the turbine blades.	Low permeability wells are enhanced by stimulation using massive water injection, thermal cracking and

		maintain geothermal steam supply.	reduce effects of mixing problem.		practiced to maintain well production.		with acidizing.
Japan Matsukawa	Production recovery is monitored through tracer tests.	Effects of pressure drawdown is monitored by determining the relationship between production rate and injection rate.	Effects of reinjection is monitored by determining the relationship between production rate and injection rate.	A dominant super-heated steam reservoir such as Matsukawa, showed an increasing steam production with water injection.	(Not discussed in case studies)	(Not discussed in case studies)	(Not discussed in case studies)
Philippines Tiwi and Tongonan	Monitoring of geochemistry and reservoir engineering data is done to develop sound resource management strategies: 1) high-risk producers are monitored and injection rates are limited for specific injectors to avoid cooling, 2) wells with	Effects of pressure drawdown have negative impacts on steam flow production. This can be controlled through: 1) optimisation of injection loading, and 2) balancing mass recharge and pressure support against the drawbacks of	Influx of reinjection returns necessitates the: 1) dispersion farther outfield of the reinjection system or even relocation of the entire production system, 2) repeat precision gravity survey is becoming useful	In controlling superheated steam zone: 1) pressure balance of shallow steam zone and deep reservoir is essential, 2) pressure monitoring in these zones is important, and 3) erosional effects are	Intervention techniques to address decline in well performance production due to mineral deposition includes: 1) mechanical clearing by well workovers, 2) acidizing, 3) scale inhibitors, 4) higher separation pressures, and	Mitigation of corrosion attack from acidic fluids can be done through: 1) new well design with a cemented blank liner run to case-off potential acid zones, 2) use of corrosion-	The key to overcoming these challenges to sustaining production is to have a strong multi-disciplinary resource team in-place that can understand the problems and provide

	performance decline were stimulated to sustain field generation, 3) data integration leads to improved reservoir management strategies, and 4) sound resource management can sustain production beyond 25-year economic life.	cooling and mineral deposition.	for monitoring, and 3) use of sacrificial wells to redirect cold natural recharge away from the depressurised production area.	addressed with either wellhead washing or drilling of deeper M&R wells into liquid reservoir.	5) modification of discharge fluid chemistry through acid injection.	resistant alloys for casings/liners and wellhead cladding, 3) buffering with caustic soda downhole, and 3) corrosion inhibitors.	feasible solutions.
Thailand Fang	No continuous applications	No occurrence	No occurrence	No occurrence	Mineral scaling problem is solved by chemical or mechanical cleaning to sustain system's operations.	No occurrence	The project's operational cost is 3 times cheaper than from fossil fuel, also with cheaper maintenance with longer durability.

Source: Edited by authors.

6.2. Ground Source Heat Pump

The lessons learned in Chapter 5 for low-enthalpy geothermal utilisations (GSHP) are summarised below.

China

- Mapping shallow geothermal energy conditions, such as water type and soil type, is important to perform proper design of the GSHP systems.
- Monitoring of ground temperature is important to monitor thermal recovery of the ground and to assure the balance of heating and cooling.

Japan

- For sustainable use of GSHP systems, system design suitable for the subsurface condition of the place as well as GSHP application purpose is needed.
- Heat exchange rate and preferred drilling depth of a GSHP system varies with local subsurface conditions.
- In this context, a hydrogeological survey is very important for places in sedimentary basins and plains, while only rock properties are important for places with near surface hard rocks.
- To compile suitability maps of GSHP systems for sedimentary regions groundwater and geological surveys are needed to perform numerical simulation on groundwater flow and local heat exchange rate.
- Design of GSHP system can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.
- Suitability map can be made in the following order of procedures:
  1. Groundwater and geological survey
  2. Regional groundwater flow simulation
  3. Heat exchange simulation of the site
  4. Making suitability map
     - Weighted overlay method may be used for making suitability map.
     - For closed-loop system, groundwater velocity, sand-gravel ratio and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used.
     - Space heating suitability map needs subsurface temperature data additionally.

South Korea

- For long-term sustainability, monitoring of the system is important. The monitoring is mandated by a law in the case of South Korea but the problem is that the monitoring data has not been properly analysed in many cases.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored.

- Flow rate and temperature of the primary and secondary fluids and electric consumption of the heat pump and circulation pump should be monitored to calculated COP and long-term performance including extracted heat, amongst others.

Thailand

- For GSHP application in tropical regions where only space cooling is needed, the underground temperature should be measured first to ensure the applicability of the GSHP system.
- If the underground is cooler than atmosphere at least in daytime, GSHP may be effective.
- Thus as results of comparison of underground and atmospheric temperatures, applicability of GSHP system is shown for many cities in Thailand.

Viet Nam

- The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated.
- For GSHP application in tropical regions, the ground temperature should be measured first to ensure the applicability of the GSHP system in terms of temperature advantage.
- If the underground temperature is lower than the atmosphere at least in daytime, GSHP may be effective. Thus temperature survey results shows applicability of GSHP system in Ha Noi and many areas in Southern Plain of Viet Nam.

Table 6.2 shows the summary of lessons learned for GSHP in a matrix of problems and solution in each case study.

Table 6.2. Summary of Lessons Learned for Ground Source Heat Pump

China	Cost effective GSHP system design	Mapping shallow geothermal energy conditions, such as water type and soil type
	Monitor thermal recovery of the ground and to assure the balance of heating and cooling	Monitoring of ground temperature
Japan Tsugaru Plain and Yamagata Basin	Heat exchange rate and preferred drilling depth of a GSHP system varies from place to place both for open and closed loop systems.	Geological survey should be done to perform numerical simulation on local heat exchange rate are needed to compile suitability maps of GSHP systems. For sedimentary basins and plains, hydrological surveys should be done as well to conduct groundwater flow simulation to know water level and/or effective heat conductivity of the place.

	Low system performance and high initial and/or running cost because of inappropriate system design.	It may be improved by utilising such suitability maps.
	Procedures for making suitability map	1. Groundwater and geological survey 2. Regional groundwater flow simulation 3. Heat exchange simulation of the site 4. Making suitability map 3 and 4 differ for closed and open loops.
	Other matters learned from the case study	Weighted overlay method may be used for making suitability map. For closed-loop system, groundwater velocity, sand-gravel ratio and water table are used. For open-loop system, horizontal and vertical groundwater flow rate and permeability of geological layers are used. Space heating suitability map needs subsurface temperature data additionally.
South Korea Sejong Metropolitan City	Long-term sustainability	Monitoring of the system is important
	Subsurface temperature monitoring	Idealistically, down to the depth of heat exchange borehole is desired.
	Surface monitoring	Flow rate and temperature of the primary and secondary fluids and electric consumption of the heat pump and circulation pump should be monitored to calculate COP and long them performance including extracted heat.
Thailand Chao Phraya Basin **Viet Nam** Red river plain and Southern Plain	Tropical regions needs only space cooling but subsurface temperature might be high.	Underground temperature should be measured first to ensure the applicability of the GSHP system. If the underground is cooler than the atmosphere at least in daytime, GSHP may be effective.
	Subsurface temperature information	The observation wells can be used to evaluate the subsurface temperatures so that the possibility of GSHP may be evaluated.

Chapter 7

Guidelines for Sustainable Use

7.1. Power Generation and Direct Heat Use

With steam field production, many of the reservoir processes and their attendant problems had developed as the geothermal reservoir responds to field-wide exploitation. Since these problems are derived from physical and chemical processes of the subsurface region, sometimes different solutions are needed for the same and/or similar phenomena occurring at the surface, depending on the field characteristics. For reservoir management, special attention is necessary to the type of the reservoir (single liquid phase, liquid dominated, steam dominated, and super-heated) and fluid chemistry to attain effective reservoir management and therefore sustainability of geothermal energy utilisation. Some of the production-related reservoir processes, their effects and resulting problems as well as the solutions that have been implemented as a direct response to steam and brine withdrawal from the deep reservoir, include:

(1) Reservoir Drawdown

Mass withdrawal from deep and shallow reservoirs leads to pressure and temperature declines and drop in reservoir water level if the steam-water extraction is continuous without pressure and mass support.

➢ Reservoir drawdown and reduction of steam zone pressure (in case of two-phase or steam reservoir) may result in:

- Reduction of the size of steam zone and even damage the steam zone
- Invasion of shallow cooler waters and mixing with production
- Additional drilling needed to maintain steam supply
- Control through optimisation of injection loading and balancing of mass recharge with pressure support
- Control of steam zone through pressure balance of shallow steam zone and deep reservoir is essential

(2) Brine and Condensate Injection

Injection is essential to maintain the reservoir pressure for long-term production. However, several problems may be caused by the injection of cooler fluid. Monitoring injection fluid, including tracer test is essential. Among these injection induced problems, serious ones for reservoir management and their mitigation methods are listed below.

- Injection breakthrough into production zones:
  - May reduce the enthalpy of the produced fluid and steam ratio.
  - Scaling may occur due to cooling of the reservoir by injection fluids and dilution of brine.
  - To prevent injection breakthrough from cooling reservoir, relocation of injection to 'outfield' and/or deeper part may be effective.
  - Production wells 'at risk' should be carefully monitored and allowable injection rates are limited for specific injection wells.
  - Cooler fluid inflow may be avoided by sacrificial peripheral wells continuously being discharged to portable silencers.
  - Use of repeat precision gravity survey is becoming useful to delineate mass changes either through withdrawal or injection.

Injection returns are sometimes beneficial by bringing mass recharge into boiling reservoir, sustaining reservoir pressure, and preventing fine solids discharge from dry-steam to steam-dominated reservoirs. To balance the benefits of mass recharge to the highly two-phase reservoir and the cooling effects of injection breakthrough to the producing wells, the injection wells' load distribution are modified and optimised.

There are also environmental problems induced by injection.

- Subsidence (in case of two phase or steam reservoir)
  - Reduction of shallow steam zone pressure may cause even more serious subsidence than subsidence by fluid production. It may last longer as creep phenomenon even after the cause is removed.
  - It may be avoided to change the injection depth to deeper zones.
  - Shallow geology should be investigated since subsidence occurs at soft near-surface formation.
  - Well locations should be carefully chosen based on shallow geology to avoid subsidence.

(3) Acid Corrosion and Mineral Scaling

Corrosion and scaling are still common problem in many fields, which sometimes prevent us from producing fluid from such zone.

- Acid corrosion
  - Acid brine seriously corrodes wells, pipelines, and power plant components. Dilution of acid fluid may cause calcite scaling.
  - New well design with a cemented blank liner run below acid zones is effective to case off potential acid zones.
  - Effects of acid corrosion in other operating fields are contained through: 1) use of corrosion-resistant alloys for casings and liners, 2) well-head cladding with exotic metals, 3) buffering acidic fluids with caustic soda down hole, and 4) use of corrosion inhibitors.
- Mineral scaling
  - Occurs mostly in production wells with acidic fluid discharge, pipelines, reinjection wells, and turbines.
  - Mechanical cleaning through workovers of wellbores and vertical discharging of wells may be effective at least for a short period.
  - As a more long-term fundamental solution, deeper injection is effective if the injection return accelerates the mineral deposition.
  - Some production fields implement various ways of minimising the risks from mineral scaling, such as: 1) acidizing, 2) scale inhibition, 3) having higher separation pressures (with equivalent high saturation temperatures), and 4) modification of discharge fluid chemistry through acid injection.

(4) Superheated zones

Fluid production may turn steam zones into super-heated zones. Although some dry-steam production fields show increased production with water injection, special attention is needed for such zones to sustain steam supply. Solids discharge may occur in superheated steam zones.

- Controlling superheated steam zone
  - Pressure balance of shallow steam zone and deep reservoir is essential.
  - Well balanced injection may be useful.
  - Pressure monitoring in these zones is important.
  - Other operating fields' methods to address effects of super-heated steam and erosion include: 1) use of wellhead washing either with river water, brine, or condensates, and 2) drilling of deeper replacement wells into the liquid reservoir of existing production horizons.

(5) Meteoric Recharge

Since it is a natural phenomenon, it is difficult to control and difficult to trace. Its flow pattern is controlled by natural barriers such as impermeable fault.

- Cooling by meteoric recharge
  - It necessitated the relocation of the entire production system in a part of Tiwi (Philippines).
  - For its monitoring, repeat precision gravity survey is useful for long term and tritium tracer was useful for shorter term.
  - Cooler fluid inflow may be avoided by sacrificial peripheral wells continuously being discharged to portable silencers.

Beside these specific technical issues, several important matters should be pointed out.

- Low permeability wells are enhanced by: 1) stimulation using massive water injection, 2) thermal cracking, or 3) with acid injection.
- Careful exploration and monitoring
  - For better understanding of the reservoir, continuous observation, analysis, and interpretation of the reservoir data are essential.

- Major surveillance activities include: 1) monitoring of quantity of steam produced, 2) geochemistry and reservoir engineering data of wells, production reservoirs, and reinjection sinks, and 3) microgravity and induced seismicity from mass withdrawal and injection.
- Integration of monitoring data leads to improved reservoir management strategies and sound resource management can sustain production over time.

➢ Disciplined human resources

- The key to overcoming operational problems is having a strong multi-disciplinary resource team in place that can understand and react to the issues and provide workable solutions.

7.2. Ground Source Heat Pump Systems

(1) Making suitability map

➢ For sustainable use of GSHP systems, a system design suitable for the hydrogeological settings of the location and GSHP application purpose is needed.

➢ Heat exchange rate and preferred drilling depth of a GSHP system varies with local hydrogeological settings.

➢ For sedimentary regions, groundwater and geological surveys to perform numerical simulation on groundwater flow and local heat exchange are needed to compile suitability maps of GSHP systems. For hard rock regions, mapping of heat conductivity of rock is recommended to make suitability map.

➢ Design of GSHP systems can be improved by utilising the suitability map, such that high system performance and cost reduction may be achieved.

➢ Suitability maps for sedimentary regions can be made in the following order of procedures:

1. Groundwater and geological survey
    - Groundwater survey should be widely conducted in a basin or plain, by collecting data from existing wells.
    - Water table, chemical component (electric conductivity) of groundwater, and temperature profile of the well should be measured.
    - Temperature profile should be measured in observation wells or unused wells where the temperature reached the equilibrium to the ground temperature.

- On the other hand, water chemistry should be measured at regularly used wells with fresh groundwater.
- Geological surveys should be conducted to understand the basic structure of the region. Sand-gravel ratio of shallow layers needs special attention to estimate hydraulic conductivity of the layer.

2. Atmospheric temperature survey (for tropical climate only)

- For tropical areas where only space cooling is needed but subsurface temperature is high, a comparison of atmospheric temperature and subsurface temperature at the target place should be done first (after temperature survey of the wells) to see the applicability of GSHP systems.
- Monthly mean maximum and minimum air temperatures may be used in the comparison.
- Similar methods can be applied for moderate climate areas to estimate cost performance of GSHP for space heating.

3. Regional groundwater flow simulation

- Regional groundwater flow simulation in a scale of whole plain or basin should be conducted to get input data for local heat exchange simulation for the places without well data.
- Water table, chemical component (electric conductivity) of groundwater, and temperature profile of the well may be used as a constraint for regional groundwater flow simulation.

4. Heat exchange simulation of the site

- Using results of groundwater flow simulation as boundary conditions, a local heat exchange simulation will be conducted. Its result will be used for making a suitability map.
- For a closed-loop GSHP system, the thermal response test result is an important input data for heat exchange simulation, as well as groundwater flow rate (or effective heat conductivity), and hydraulic head of the place.
- For an open-loop GSHP system, hydraulic conductivity, porosity, heat capacity, and heat conductivity are needed.

5. Making suitability map

- Weighted overlay method may be used for making a suitability map.

- For a closed-loop system, overlaid parameters are groundwater velocity, sand-gravel ratio, and water table.
- For an open-loop system, overlaid parameters are horizontal and vertical groundwater flow rate and permeability of geological layers.
- Making a suitability map for both space heating and cooling in moderate climate areas needs only parameters listed above, while that for space heating needs subsurface temperature data additionally.

(2) Thermal response test (TRT)

A thermal response test on site is recommended especially for large facilities to confirm the system design is appropriate.

(3) Monitoring the installed GSHP system

- For long-term sustainability, monitoring of the system is important.
- Ideally, the subsurface temperature down to the depth of subsurface heat exchanger will be monitored to measure the real effective thermal conductivity and to monitor the subsurface thermal influence.
- Also, ideally the air temperature of the air-conditioned room will be monitored to assure that the system is working effectively.
- The flow rate and temperature of the primary and secondary fluid and electric consumption of the heat pump and circulation pump should be monitored to calculate actual COP and long-term performance including extracted heat from underground, saving energy and running cost.

For GSHP systems, simulation on the system performance using subsurface characteristics data may be done for system design. Unlike geothermal power plants, system performance is mainly controlled by system design suitable for the subsurface characteristics of the site, not by the nature of the resource. Monitoring is conducted to check the real system performance.

Chapter 8

Conclusions and Recommendations

The ERIA research project 'Sustainability Assessment of Utilising Conventional and New Type Geothermal Resources in East Asia' has started to develop guidelines for sustainable use of geothermal energy. The guidelines should be referred to by engineers and managers who newly begin a geothermal business, or by related researchers.

To make these guidelines, as the first step, a census and its analysis had been done on the current status of geothermal use, technology, and management, and barriers and opportunities in each member country.

According to the results of the census, the highest technological interest related to sustainability of geothermal power generation and direct heat use are, in order of priority:

- monitoring and reservoir engineering
- reinjection
- anti-scaling
- anti-corrosion and anti-erosion

For GSHP systems, the following are pointed out to be important:

- basic hydrogeological data collection
- system monitoring

Note that 'sustainability' in this case is resource sustainability and not environmental or social sustainability.

Therefore as the second step, collection of case studies on these topics was conducted. Finally a guideline for sustainable use of geothermal energy were made based on the compilation of these case studies. Case studies and the guidelines were achieved separately for power generation and direct heat use systems and GSHP systems since the necessary technologies are different for these two categories.

Although the solutions shown in the guidelines may contribute to sustainable use of geothermal energy for the current state, continuous studies are needed for the future. Therefore recommendations to policymakers for more sustainable utilisation of geothermal energy are:

- For the present, the guidelines in this report should be distributed and used as a result of a review on the current best practices in the Asian region.
- Continuous study should be done for the sustainable use of geothermal energy in the future, especially for the topics listed above. Government support for such study is desired.

Besides the guidelines, based on the results of the census on the current status, Chapters 2 to 4 provide recommendations to policymakers for more intensive utilisation of geothermal energy. These recommendations are also summarised in the Executive Summary. It is strongly recommended for policymakers and high-level government officials to refer to these recommendations for rapid and sound increase of geothermal energy use.