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Assessment of Necessary Innovations for Sustainable Use of Conventional and New-Type Geothermal Resources and their Benefits in East Asia

Edited by

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New Zealand is a member country of this project and, as an advanced user of geothermal technology, has been giving important input in working group meetings. However, since New Zealand does not have barriers to geothermal use, at least for power generation, it is not included in the country reports.

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Chapter 1

Introduction and Project Scheme

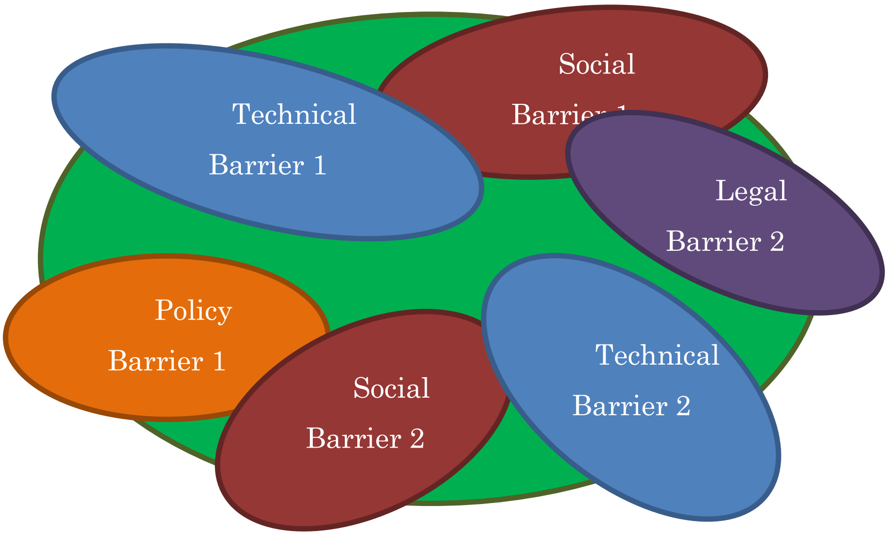
1. Introduction

Many Asian countries have been utilising geothermal resources and attempting to increase their capacity although the types of these resources vary from country to country, from the conventional steam power generation and direct use to the more advanced enhanced/engineered geothermal system (EGS) or ground source heat pump (GSHP).

In our previous research project 'Sustainability Assessment of Utilizing Conventional and New-Type Geothermal Resources in East Asia', several technical aspects, such as reservoir management and base (groundwater) data collection, were found to be extremely important for sustainable use of geothermal resources. Technical and social (including policy, legal, and environmental) barriers that discourage expansion of geothermal utilisation were also studied.

This research aims to extract necessary innovations for sustainable use of geothermal resources in Asian countries. Here, innovation includes both social and technical aspects. The benefits of geothermal utilisation, such as power and heat generation, energy saving, reduction of carbon dioxide (CO_2) emission, and generation of new industries and employment (food, minerals, tourism, healthcare, etc.) will be studied as well to encourage policymakers and business people to invest more in development and utilisation of geothermal energy.

Figure 1.1. Barriers to Geothermal Energy Use



Source: The study team.

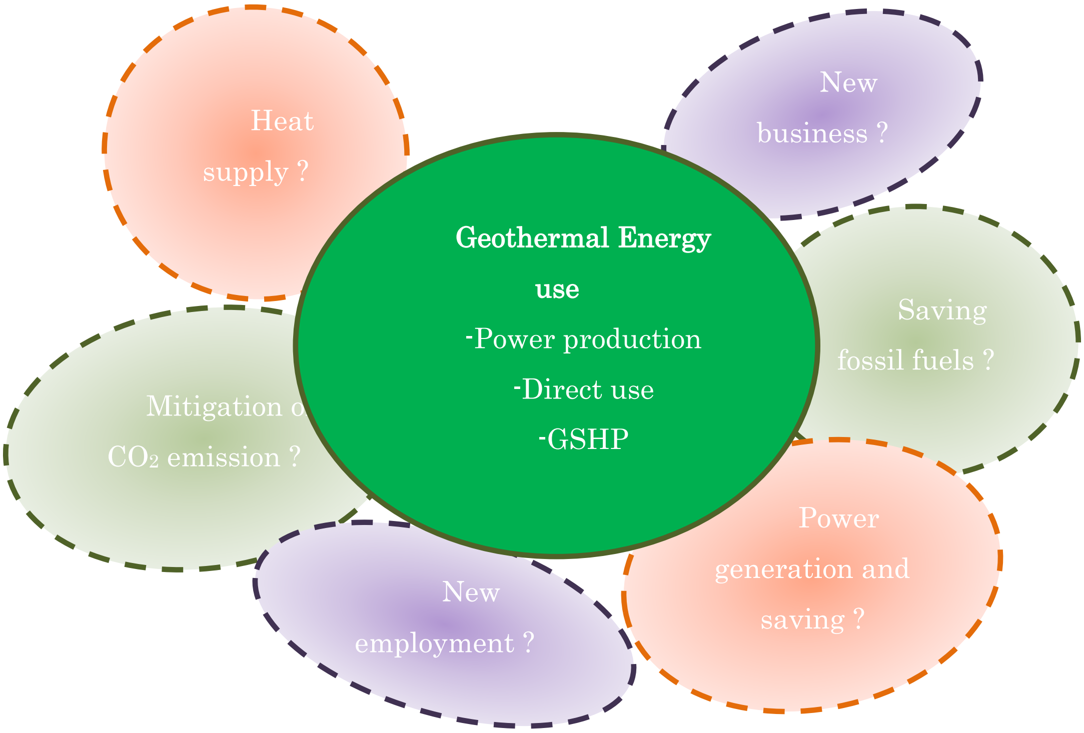
Various barriers are hiding real values of geothermal resources. Removal of these barriers often needs innovations, which can be done only by high-level decisions.

2 Key Objectives of the Research

Barriers against geothermal exploitation should be removed (Figure 1.1), but cost–benefit balance should first be clarified before any effort is done. Benefits derived from geothermal energy use have been commonly advocated (Figure 1.2), but have not been quantified specifically for each country.

The key objectives of this project, therefore, are to clarify the barriers and their contributions in each country and to quantify benefits obtained if each barrier is removed. The essential output of this project will be a table of these estimated numbers, which might be achieved through social and technical innovations in the region (Table 1.1).

Figure 1.2. Benefits of Geothermal Use



CO_2 = carbon dioxide, GSHP = ground source heat pump.

Source: Authors.

Table 1.1. Image of Essential Output of this Project* (Original of this report)

Innovation Benefit	Policy	Legal	Social	Fiscal	Technical	Total
Power generation (kWh/year)						
Heat supply (MJ/year)						
CO_2 mitigation (tonnes/year)						
New employment						
New business						

*Items in the rows to be added in the final result.
CO_2 = carbon dioxide, kWh = kilowatt-hour, MJ = megajoule.
Source: Authors.

3. Study Method and Research Plan

The research plan for this project is shown in Table 1.2.

a) Identification of barriers and additional geothermal potential

- Review current geothermal energy use and its problems in each of the countries covered by this study.
- Identify legal, social, technical, and other barriers that prevent increase and/or sustainable use of geothermal energy.
- Identify amount of additional geothermal energy, which can be utilised if barriers are removed.

b) Identification of contributions of barriers

- Establish a method to evaluate the contributions of each barrier.
- Identify contributions of specific barriers in each country.

c) Identification of necessary innovations

- Identify major common barriers and select barriers to be studied.
- Investigate necessary innovations to overcome these barriers.

d) Estimation of benefits to be derived through the innovation

- Identify possible benefits from additional geothermal energy use, such as additional power/heat supply, CO_2 reduction, new employment, new business, etc.

- ➢ Estimate quantitatively the benefits per additional power/heat capacity.
- ➢ Calculate benefits per innovation (per removal of each barrier).
- ➢ Fill in Table 1.1 with estimated values.

Table 1.2. Research Plan

	2015–2016	**2016–2017**	**2017–2018**
a) Identification of barriers and additional geothermal potential	Review current situation		Review situation
	Identify barriers (fill top line of Table 1.1)		Review barriers and specify country-specific matters
	Identify potential (fill end column 'TOTAL' of Table 1.1)		Review potential
b) Identification of contributions of barriers	Suggest methods	Establish a method	Improve method
		Identify contributions	Review contributions from survey of domestic experts especially for country-specific matters
c) Identification of necessary innovations	Identify major common barriers		
		Select barriers to be studied	
		Investigate necessary innovations	
d) Estimation of benefits by the innovations		Identify possible benefits (Fill the index column of Table 1.1)	
		Suggest methods to estimate benefits	Estimate benefits quantitatively
		Calculate CO_2 mitigation by additional geothermal use	Calculate benefits per each innovation (Fill whole matrix of Table 1.1)
Reporting	Write progress report	Write progress report	Write final report

Source: The study team.

4. Expected Policy Recommendations

Another objective of the project is to provide policymakers with information on social and technical innovations necessary to increase geothermal power and heat supply in the region and on possible outcomes that could be provided by installation of additional geothermal power and heat supply systems.

The expected policy recommendations include the initiation of necessary research, development, and demonstration for technical innovation and social and legal innovative measures, based on the numbers of possible outcomes, such as increase of power and/or heat supply, energy saving (equivalent oil saving), reduction of CO_2 emission, possible new businesses and employment, etc.

The outcome table will help governments make decisions on innovations in laws or regulations and allocate budgets for related research, development, and demonstration.

Chapter 2

Summary of the Research Results

1. The Target Geothermal Energy Use

In this project, target geothermal capacity that may be achieved by removing all barriers was estimated for short and long terms (by 2025 and 2050, respectively) for each country under study. The target value is different from the official vision of each of the governments because effects of removal of barriers are considered. Although the estimation method differs from country to country depending on the domestic conditions, each was obtained as consensus of project members through mutual evaluation. The estimation method by each country is described in each country's report in Chapter 3.

Table 2.1-1 shows the target additional capacities for geothermal power generation. Considering that a start-up geothermal power plant needs 5–10 years from exploration of a prospect to plant construction, target is set as additional capacity that is ready to be developed by 2025 if all barriers are removed (not the capacity which should have been already developed by 2025). The targets for 2050 are based on technical potentials, which are ultimately development targets.

Table 2.1-1. Target Additional Geothermal Power Capacity Ready to be Developed at Target Years

Country	Short-term Target – Ready to be Developed by 2025 (MW_e)	Long-term Target – Ready to be Developed by 2050 (MW_e)
China	500	16,000 (16 GW)*
Indonesia	5,800	29,923
Japan	1,083	100,000 (100 GW)*
Rep. of Korea	200*	800*
Malaysia	250	273.25
New Zealand	150	-
Philippines	1,371	-
Thailand	30	-
Viet Nam	155	680

*Target for China, Japan, and Republic of Korea includes deep EGS.
EGS = enhanced/engineered geothermal systems, GW = gigawatt, MWe = megawatt electric.
Source: The study team.

Table 2.1-2 shows the target additional capacities for direct use. Direct use includes both conventional heat use and ground source heat pump (GSHP). Only China, Japan, the Republic of Korea (henceforth, Korea), and New Zealand, which are interested in direct use, set target values. Amongst these countries, targets of China and New Zealand are mainly for conventional direct heat use while targets of Japan and Korea are for GSHP.

Table 2.1-2. Target Additional Direct-use Capacities Ready to be Used at Target Years

Country	Short-term Target – Ready to be Used by 2025 (MW_t)	Long-term Target – Ready to be Used by 2050 (MW_t)
China	18,000 (conventional) 48,150 (GSHP)	67,500 (conventional) 114,240 (GSHP)
Japan	718 (GSHP)	6,300 (GSHP)
Rep. of Korea	3,425 (GSHP)	-
New Zealand	5 (PJ/year)	-

Note: Direct use in New Zealand is shown as annual energy supply. Others are shown as facility capacity.
GSHP = ground source heat pump, MW_t = megawatt thermal, PJ = petajoule.
Source: Authors.

2. Evaluating Contributions of Each Barrier in the Whole Barriers

2.1 Evaluation method

Barriers to geothermal use were listed and categorised into policy, social, legal, fiscal, and technical barriers (Table 2.2-1).

Geothermal Symposium (AGS11) held in Chiang Mai, Thailand, in November 2016, after project members of the Economic Research Institute on ASEAN and East Asia (ERIA) presented barriers to geothermal energy use in each country. Thirty-three geothermal energy experts at AGS11 evaluated the importance of each barrier by filling up the values (%) in an inquiry form (Appendix-1). However, this evaluation method has the following problems:

1) There might have been barriers not identified by the members of the working group; results might have largely depended on the opinions of presenters; and

Table 2.2-1. Barriers Shown in the Inquiry

Category	Item
Policy	National energy policy
	Lack of economic incentives (subsidies, FiT, tax reduction, etc.)
	Lack of R&D funding
	Domestic business/information protection
	Other policy matters
Social	Lack of experts
	Lack of awareness
	Lack of knowledge, wrong information
	Lack of business models
	Other land uses
	Public acceptance
	Other social matters
Legal	Environmental matters (nature parks and forestry, etc.)
	Legislation or business mechanism
	Lack of incentives (from environmental or energy security aspects)
	Red tape in government (complex and time-consuming bureaucratic processes)
	Other legal matters
Fiscal	High exploration cost
	Low selling price
	No loans from banks nor support from government
	Other fiscal matters
Technical	Lack of information or experience (general)
	Exploration technology
	Data integration or interpretation
	Drilling
	Scaling, erosion, corrosion
	Reservoir engineering and management
	Other technical matters

FiT = feed-in tariff, R&D = research and development.

Source: The study team.

Barrier contributions were evaluated based on results of inquiry to international and domestic experts. Results of inquiry to international experts were obtained at the 11th Asian The

2) The barriers that mutually interact might not have been correctly evaluated.

To solve problems 1) and 2), domestic experts were surveyed in each country, keeping a balance of academia, government and industry. As for problem 3), since analysis of interaction of each barrier was out of the project’s scope, the working group did not investigate the mutual interaction of barriers. Instead, it redefined more precisely each barrier and its solution for each country so that policymakers may be able to make decisions on specific barriers regardless if such barriers are policy barriers or technical ones.

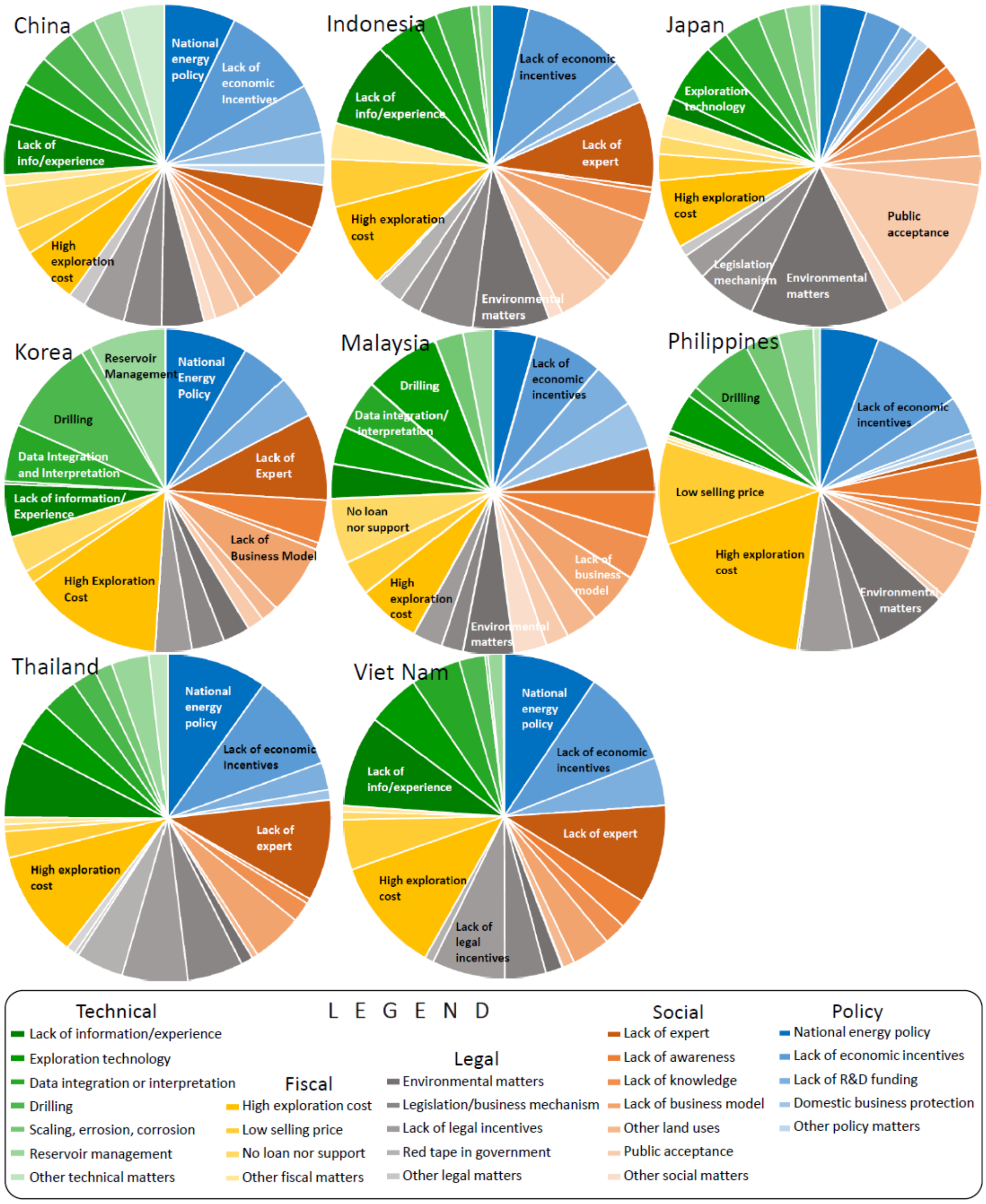
2.2 Barrier evaluation

2.2.1 Results of barrier evaluation

To avoid problems 1) and 2), the results of inquiry to domestic experts were taken as final values for barrier contributions in each country, except those for Indonesia and Thailand where no survey of domestic experts was conducted. The results of inquiry to international experts and domestic experts showed similar tendency for most countries.

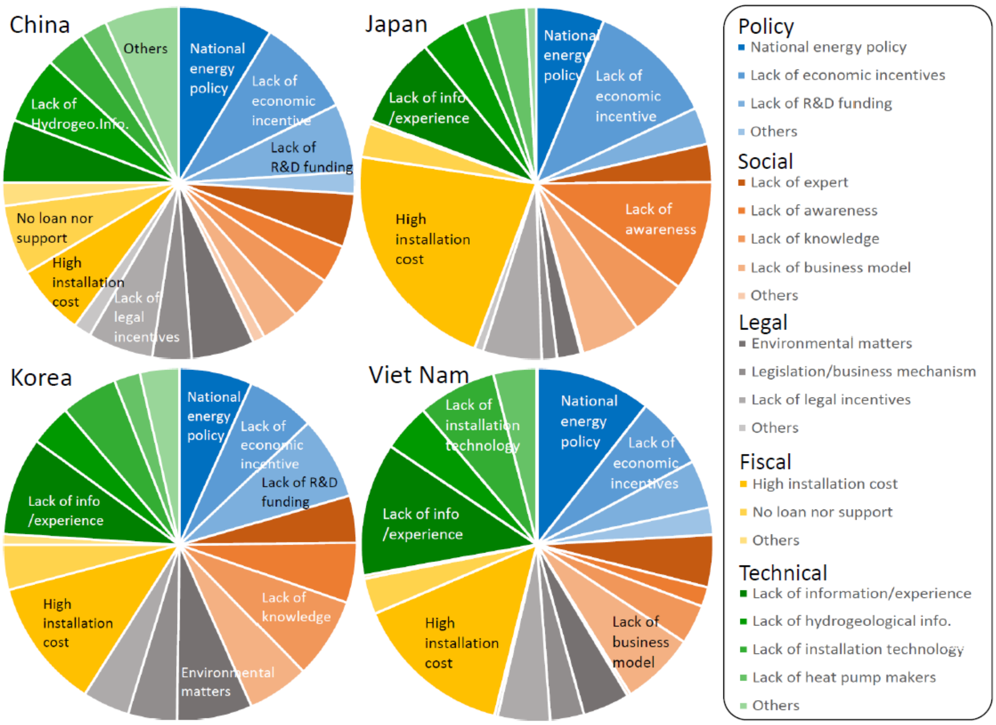
Figure 2.2-1 and Figure 2.2-2 show the evaluation results on barriers to geothermal power generation and direct use, respectively. Surveys on direct use were conducted only in China, Japan, Korea, and Viet Nam, where increase of direct use was expected. For Figure 2.2-2, note that the result of China is for conventional direct use while he results of Japan, Korea, and Viet Nam are for GSHP. For details of these surveys, such as the number of inquiries obtained for each country, see Chapter 3.

Figure 2.2-1. Barriers to Geothermal Power Generation in Each Country as Evaluated by Domestic Experts



R&D = research and development.
Source: Authors.

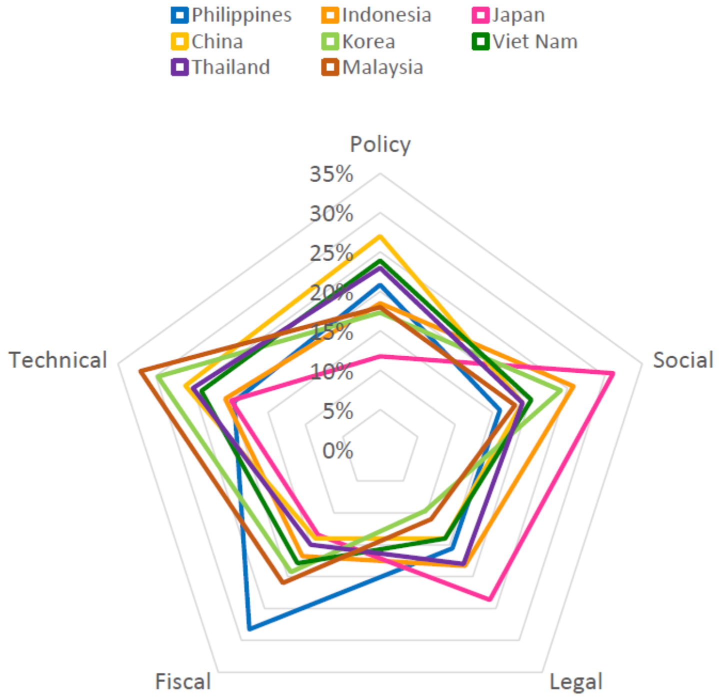
Figure 2.2-2. Barriers to Direct Use and Ground Source Heat Pump in Four Countries as Evaluated by Domestic Experts



Source: Authors.

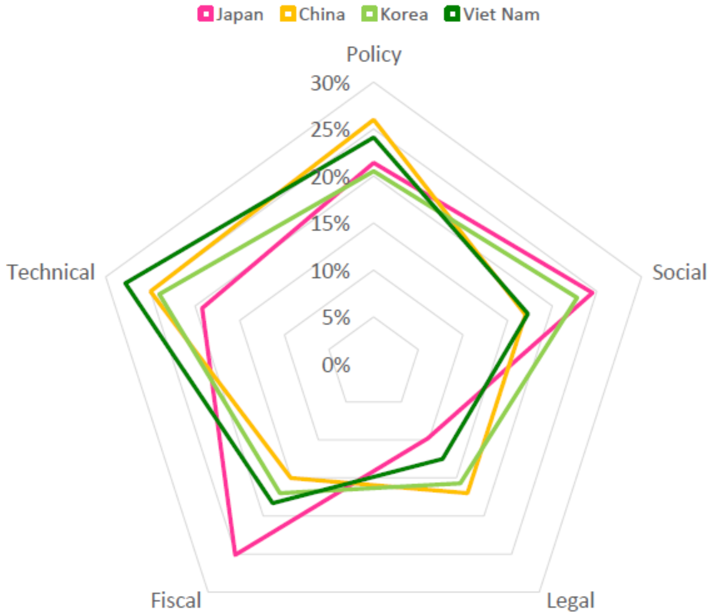
Figure 2.2-3 and Figure 2.2-4 show barriers to geothermal power generation and direct use, including GSHP, respectively. Note that Figure 2.2-4 shows countries that set target for direct use only. In the categories such as policy and legal shown in the figures, the tendency of each county can be identified more clearly. In these figures, fiscal barriers to power generation and GSHP seem rather small for most countries. However, since almost all barriers are seriously linked with fiscal problems, it should not be understood that no fiscal problems exist, since most of these are hidden behind other problems. Policy barriers are also rather small, but again, generally all barriers are related to policy. Thus, in the next stage, barriers in relation to policy should be investigated in more detail.

Figure 2.2-3. Barriers to Geothermal Power Generation in All Countries



Source: Authors.

Figure 2.2-4. Barriers to Direct Use in China, and to GSHP in Japan, Korea, and Viet Nam



Source: Authors.

2.2.2 Discussion on the results of barrier evaluation

Figure 2.2-3 shows that countries with larger social barriers have smaller technical barriers and those with larger technical barriers have smaller social barriers. This may be because countries that already have geothermal power plants are encountering various social barriers while their technical barriers have been somewhat solved. On the other hand, countries without geothermal power plants have not encountered social barriers yet but have been suffering from technical barriers. However, the Philippines, the leading country of geothermal power generation in Asia, has different tendency from the others: its social barriers are quite small while its fiscal barriers are extremely large, followed by policy and technical barriers. Historically, geothermal energy development in the Philippines has been led by the government and its social acceptance has been raised by careful service to the local community, resulting in lower social barriers. However, after the privatisation of power generation, the economic competitiveness of geothermal energy suddenly dropped. On the other hand, its technical barriers are mainly derived from acid fluids, which are raising development costs. Since economic feasibility depends on policy and technology, these three barriers are dominant.

In Figure 2.2-4, social barriers are high in Japan and Korea due to lack of awareness or knowledge. Fiscal barriers in Japan are due to high installation cost. China is a leading country of direct use and GSHP so its fiscal barriers are naturally low. However, its technical barriers are high in relation to reservoir decline due to no-reinjection. In Viet Nam, where GSHP has not been commercially utilised yet, technical barriers are largest. Korea, another leading country of GSHP, also claims technical barriers for further use because GSHP’s effectiveness, such as its coefficient of performance (COP), has not been statistically investigated.

As described in Section 2.2.2.1, many barriers have mutual interactions and a simple inquiry result might not precisely express barrier contributions. Nevertheless, the census results in Figure 2.2-1–Figure 2.2-4 provide a clear insight on what are lacking for more geothermal energy use and what are essential for considering necessary innovations. Therefore, as a first attempt of barrier evaluation, the values (%) shown in these figures will be used in the following analysis.

3. Innovative Ideas on Removal of Barriers

The following are pointed out as innovative ideas on removal of barriers. Innovative ideas primarily mean totally new ideas that may fully change technical or social systems and convert conventional game players into outsiders. However, in this report, innovative ideas include ideas already existing in some countries but new to other countries, which may also change the conventional system.

Policy

- High targets and roadmaps
- New structure of authorities, etc.

Legal

- New permissions by regulations or laws

Economic incentives

- Feed-in tariff (FiT), renewable portfolio standard (RPS), and carbon tax
- Risk control and increasing demand

Social

- Public promotion
- Environmental protection
- Others (government support)

Technical

- Government participation in R&D
- Capacity-building
- Deep resources or low-temperature resources
- Sustainable use

Although these ideas may be applied commonly in all countries and regions, problems in each country should be clarified more precisely so that innovative solutions may be identified more specifically. More specific items for each country are in Chapter 3.

System innovation should be emphasised as well. This is a concept that provides a core contribution to achieve national/international policy goals, including energy security, long-term reduction on carbon emission, and local wealth development. In this context and in a broad sense, it could be understood as covering production, diffusion, and use of new technologies.

At the national level, economic, institutional, and management approaches are needed to support system innovations. These approaches should seek to examine the range of actors involved and their interactions, the role of uncertainty and bounded rationality within decision-making process of learning and expectations, and the role of institutional drivers and barriers.

Since geothermal power generation has resource risks (failure in obtaining sufficient geothermal fluid by each drilling), long lead time, and high initial cost, comprehensive support from the government is needed for each stage of its development. It means FiT or RPS is not sufficient to encourage the private sector to invest in a geothermal resource development project because of significant economic barriers that exist even before the stage of power generation and thus offer no assurance to investors that they would get their money back. From such viewpoint, the effective economic incentives in each stage are compiled in Table 2.3-1.

Table 2.3-1. Applicable Stages of Government Support and Their Significance for Geothermal Business

	Stage / **Type**	**Exploration**	**Development**	**Power Generation**
1	Drilling support	Very important	Important	Still important
2	Low-interest loans	Important	Very important	-
3	FiT, RPS	-	-	Very important
4	Tax reduction	-	-	Important
5	RE certificate		-	Important
6	R&D	Very important	Important	Very important
7	CO_2 tax	Would be an important incentive throughout a project		

CO_2 = carbon dioxide, FiT = feed-in tariff, R&D = research and development, RE = renewable energy, RPS = renewable portfolio standard.

Source: Authors.

4 Possible Benefits of Additional Geothermal Use

4.1 List of possible benefits of geothermal use

Possible direct and indirect benefits of geothermal use were pointed out and categorised by project members (Table 2.4-1 and Table 2.4-2). Direct benefits are automatically obtained by geothermal energy use while indirect benefits are obtained only with additional investments. It should be noted that indirect benefits could be much larger especially in local economic sense.

A survey of literature was then conducted to find base data for quantification of benefits. The benefits to be quantified in the following section are shown in Table 2.4-1.

Table 2.4-1. Benefits of Geothermal Power Generation

	Direct Benefits	Indirect Benefits
Local Economy	➢ Business (accommodation, food, etc.) with development crews ➢ New employment for geothermal facility operations	➢ New businesses using excess heat from geothermal facility
Local Development and Welfare	➢ Infrastructure (roads, bridges, etc.) for construction of geothermal power plants	➢ New welfare facilities using excess heat from geothermal facility ➢ Electrification of the region
Environmental Advantages	➢ Mitigation of CO_2 and other hazardous smokes	
National and Local Energy Security	➢ Continuous power and/or heat supply even in times of energy crises or natural disasters	
National Economy	➢ Saving foreign currency by saving oil and gas ➢ Saving power cost (compared to other renewables)	

CO_2 = carbon dioxide.
Source: The study team.

Table 2.4-2. Benefits of GSHP

	Direct Benefits	Indirect Benefits
Local Economy	➢ New employment for GSHP facility installation ➢ Higher performance of business by saving energy cost	
Local Development and Welfare		➢ Melting of snow on roads and parking lots ➢ New public services and facilities by saving cost for heating and cooling.
Environmental Advantages	➢ CO_2 mitigation by energy saving ➢ Mitigation of urban heat island phenomenon	
National and Local Energy Security	➢ Saving energy (electricity)	
National Economy	➢ Saving foreign currency by saving oil and gas for heating ➢ Saving power cost (compared to other renewables)	

CO_2 = carbon dioxide, GSHP = ground source heat pump.
Source: The study team.

4.2 Quantification of benefits

4.2.1 Direct benefits

a) Power generation and oil savings

Annual power generation *E* (MW-hour/year) by a geothermal power plant with a capacity of *W* (MW) and a capacity factor of *Cf* can be calculated as follows:

$$E = W \times Cf \times 24 \times 365 \qquad (1)$$

Applying a typical capacity factor of 0.7, *E* will be calculated as:

$$E = W \times 0.7 \times 24 \times 365 = 6.132 \times 10^3 W \text{ (MWh/year)} \qquad (1')$$

Although oil thermal plants use various oils such as gasoline, diesel, heavy oil, and crude oil, the variation of heat values is 42 MJ/kg–46 MJ/kg (43.5±0.5 MJ/kg) (http://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx) while the heat value of liquefied natural gas (LNG) is 55 MJ/kg.

The energy efficiency of a conventional thermal power station is typically 33%–48% (40.5±7.5 %) (https://en.wikipedia.org/wiki/Thermal_power_station).

Therefore, using mean values for heat value and efficiency, the electric power generation of an oil thermal plant in watt-hour per kilogramme (Wh/kg) fuel is:

43.5×0.405 (MJ/kg) / 3600 (sec) = 4.89×10^{-3} (MWh/kg) (2a)

That of an LNG plant is:

43.5×0.55 (MJ/kg) / 3600 (sec) = 6.65×10^{-3} (MWh/kg) (2b)

Then the annual oil saving by a W (MW) geothermal power plant would be:

$6.132 \times 10^3 W$ (MWh/year)/ 4.89×10^{-3} (MWh/kg) = 1.235×10^6 W (kg/year) (3a)

= $7.767 \times 10^3 W$ (barrel/year) (3a')

Similarly, the annual LNG saving by a W (MW) geothermal power plant would be:

$6.132 \times 10^3 W$ (MWh/year)/ 6.65×10^{-3} (MWh/kg) = 9.22×10^5 W (kg/year) (3b)

= 4.54×10^4 W (MBtu/year)

(Conversion base: 1 kg LNG = 49,257.899 Btu, MBut: million Btu)

Assuming oil price is US$60/barrel, the foreign currency saving by oil import would be:

$7.767 \times 10^3 W$ (barrel/year) x 60 (US$/barrel) = 4.66×10^5 W (US$/year). (4a)

Assuming gas price is US$5/MBtu, foreign currency saving by gas import would be:

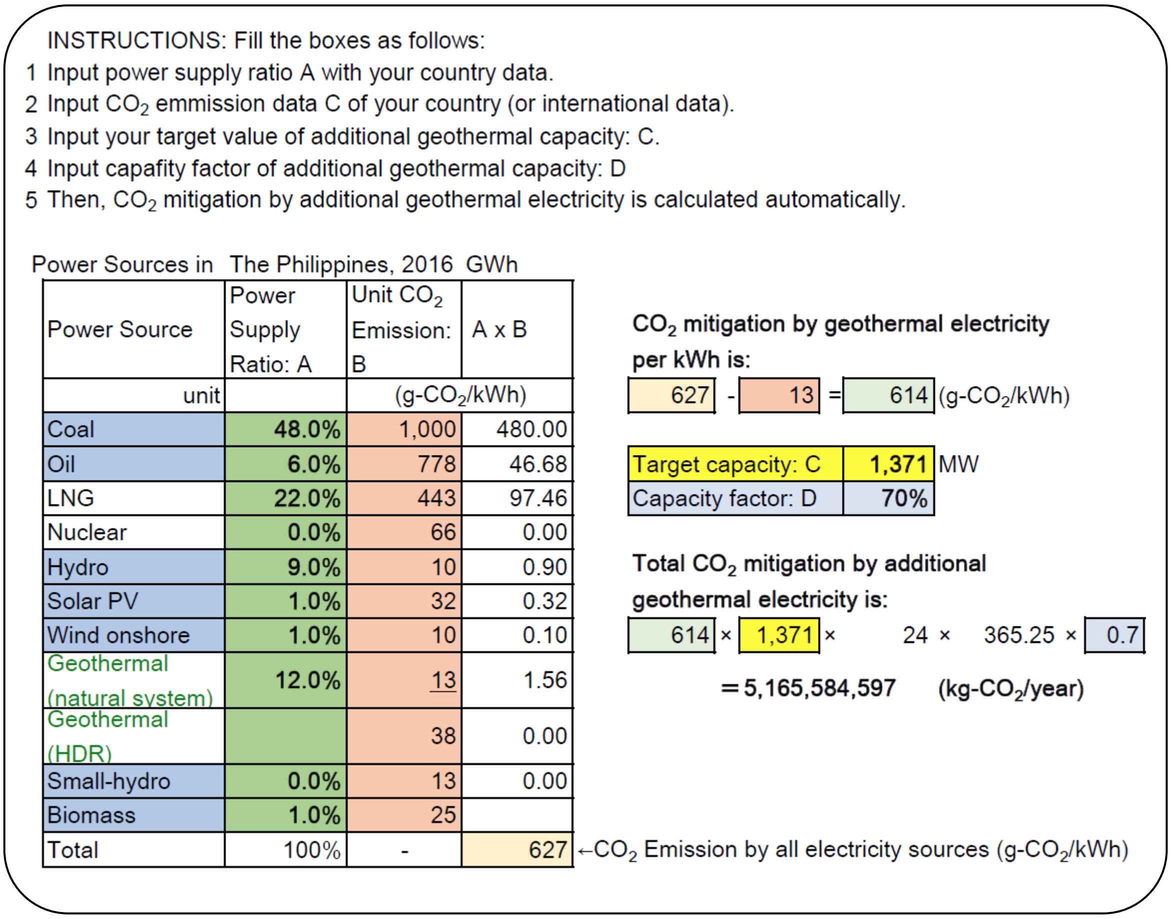
$4.54 \times 10^4 W$ (MBtu/year) x 5 (US$/MBtu) = 2.27×10^5 W (US$/year). (4b)

b) CO_2 mitigation

The possibility of CO_2 mitigation by additional geothermal use is calculated. Assuming that the current electricity or heat source mix in each country is a result of energy policy and that the current mix rate will continue in the near future, CO_2 mitigation by substituting energy source into geothermal is calculated keeping the balance of the rest of energy sources, unless specific condition of the country is described.

Figure 2.4-1 shows the procedure for calculating CO_2 mitigation through additional geothermal power using CO_2 emission data for each electricity source. When such data are not available for a country, best estimation is done by using international reports such as those of the Intergovernmental Panel on Climate Change. Detailed conditions for each country are shown in Chapter 3.

Figure 2.4-1. Procedure for Calculating Net CO_2 Reduction for the Targeted Additional Geothermal Power with an Energy Source Mix – Philippines



INSTRUCTIONS: Fill the boxes as follows:

1 Input power supply ratio A with your country data.
2 Input CO_2 emmission data C of your country (or international data).
3 Input your target value of additional geothermal capacity: C.
4 Input capafity factor of additional geothermal capacity: D
5 Then, CO_2 mitigation by additional geothermal electricity is calculated automatically.

Power Sources in The Philippines, 2016 GWh

Power Source	Power Supply Ratio: A	Unit CO_2 Emission: B	A x B
unit		(g-CO_2/kWh)	
Coal	**48.0%**	1,000	480.00
Oil	**6.0%**	778	46.68
LNG	**22.0%**	443	97.46
Nuclear	**0.0%**	66	0.00
Hydro	**9.0%**	10	0.90
Solar PV	**1.0%**	32	0.32
Wind onshore	**1.0%**	10	0.10
Geothermal (natural system)	12.0%	13	1.56
Geothermal (HDR)		38	0.00
Small-hydro	**0.0%**	13	0.00
Biomass	**1.0%**	25	
Total	100%	-	627

←CO_2 Emission by all electricity sources (g-CO_2/kWh)

CO_2 mitigation by geothermal electricity per kWh is:

627 - 13 = 614 (g-CO_2/kWh)

Target capacity: C	**1,371** MW
Capacity factor: D	**70%**

Total CO_2 mitigation by additional geothermal electricity is:

614 × 1,371 × 24 × 365.25 × 0.7

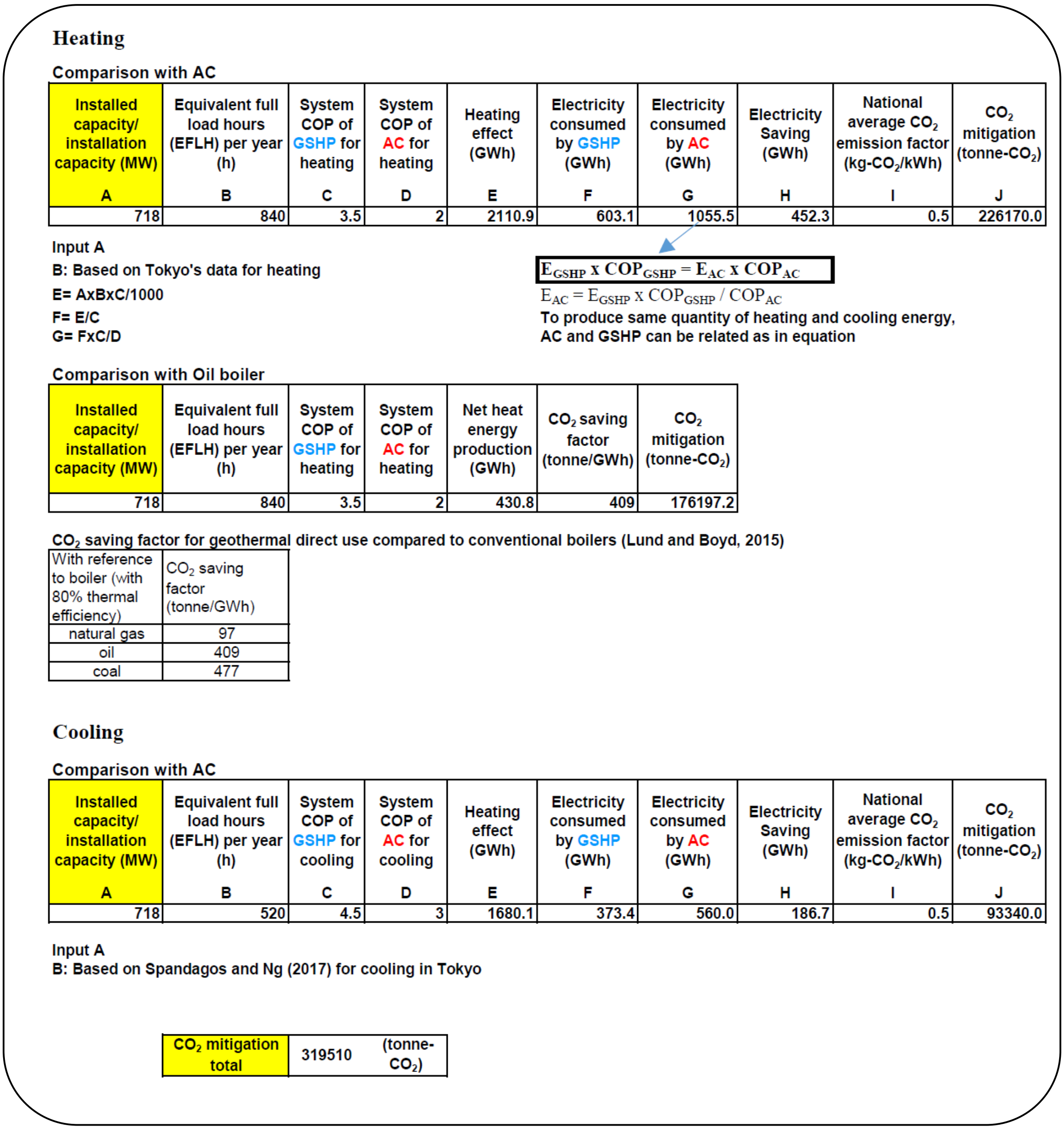
= 5,165,584,597 (kg-CO_2/year)

CO_2 = carbon dioxide, GWh = gigawatt hour, HDR = hot dry rock, kWh = kilowatt-hour, LNG = liquefied natural gas, MW = megawatt, PV = photovoltaics.

Note: For countries where CO_2 emission data for different energy sources are not clear, data from international reports are used.

Source: The study team.

Figure 2.4-2. Procedure for Calculating Net CO_2 Reduction for the Targeted Additional GSHP – Japan



Heating

Comparison with AC

Installed capacity/ installation capacity (MW) A	Equivalent full load hours (EFLH) per year (h) B	System COP of GSHP for heating C	System COP of AC for heating D	Heating effect (GWh) E	Electricity consumed by GSHP (GWh) F	Electricity consumed by AC (GWh) G	Electricity Saving (GWh) H	National average CO_2 emission factor (kg-CO_2/kWh) I	CO_2 mitigation (tonne-CO_2) J
718	840	3.5	2	2110.9	603.1	1055.5	452.3	0.5	226170.0

Input A

B: Based on Tokyo's data for heating

E= AxBxC/1000

F= E/C

G= FxC/D

$$\boxed{E_{GSHP} \times COP_{GSHP} = E_{AC} \times COP_{AC}}$$

$$E_{AC} = E_{GSHP} \times COP_{GSHP} / COP_{AC}$$

To produce same quantity of heating and cooling energy, AC and GSHP can be related as in equation

Comparison with Oil boiler

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Net heat energy production (GWh)	CO_2 saving factor (tonne/GWh)	CO_2 mitigation (tonne-CO_2)
718	840	3.5	2	430.8	409	176197.2

CO_2 saving factor for geothermal direct use compared to conventional boilers (Lund and Boyd, 2015)

With reference to boiler (with 80% thermal efficiency)	CO_2 saving factor (tonne/GWh)
natural gas	97
oil	409
coal	477

Cooling

Comparison with AC

Installed capacity/ installation capacity (MW) A	Equivalent full load hours (EFLH) per year (h) B	System COP of GSHP for cooling C	System COP of AC for cooling D	Heating effect (GWh) E	Electricity consumed by GSHP (GWh) F	Electricity consumed by AC (GWh) G	Electricity Saving (GWh) H	National average CO_2 emission factor (kg-CO_2/kWh) I	CO_2 mitigation (tonne-CO_2) J
718	520	4.5	3	1680.1	373.4	560.0	186.7	0.5	93340.0

Input A

B: Based on Spandagos and Ng (2017) for cooling in Tokyo

CO_2 mitigation total	319510	(tonne-CO_2)

AC = air conditioner, MW = megawatt, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, kWh = kilowatt-hour.

Source: Authors.

c) Local employment

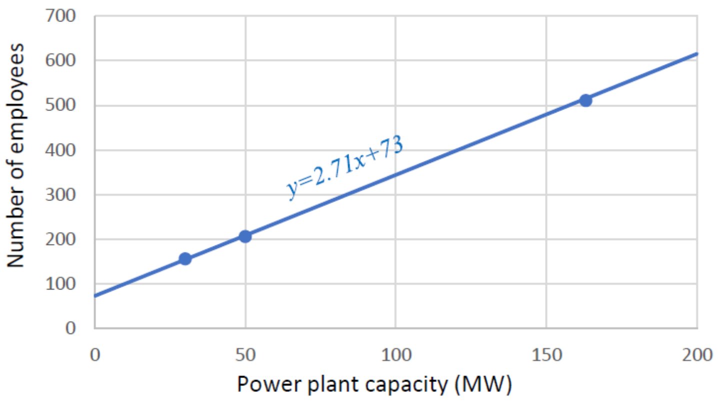
Hienuki et al. (2015) calculated life-cycle employment of geothermal power generation using an extended input–output model. The model shows that the embodied employment of geothermal power generation by life cycle stages is 0.89 [person/GWh] and employment for operation and maintenance is 66% of total employment, assuming plant capacity of 50 MW and capacity factor of 80%. Based on this paper, we calculated the number of local employment as 0.89 x 0.66 = 0.5874 [person/GWh] since operation and maintenance are normally done by local people. For capacity factor of 80%, it can be converted into person per capacity by: 0.5874 [person]/1000 [MWh/yr] x (24[h] x 365[days] x 0.8) = 4.1165 [persons/MW].

Soma et al. (2015) show that the Yanaizu–Nishiyama geothermal power plant and its steam production facility employ 156 local persons. Since the plant's operational capacity is approximately 30 MW (installed capacity: 65 MW), local employment per capacity is 156/30 = 5.2 [persons/MW].

Rodriguez–Alvarez and Vallejos–Ruiz (2010) show development opportunities for the Miravalles area in Costa Rica. According to their paper, the number of workers for 'electricity, gas & water' in the two adjacent villages in 2000 is 511 persons (261+250). Since the paper says that there was no energy supply service before geothermal development, the workers at the Miravalles geothermal power plant are assumed to be local workers. With the plant's 163 MW capacity, local employment per capacity is 3.13 persons/MW (511/163).

Based on these literatures, a clear linear relationship is established between the number of local employment and geothermal power capacity (Figure 2.4-2).

Figure 2.4-2. Relationship Between Geothermal Power Capacity and Local Employment



MW = megawatt.
Source: Authors.

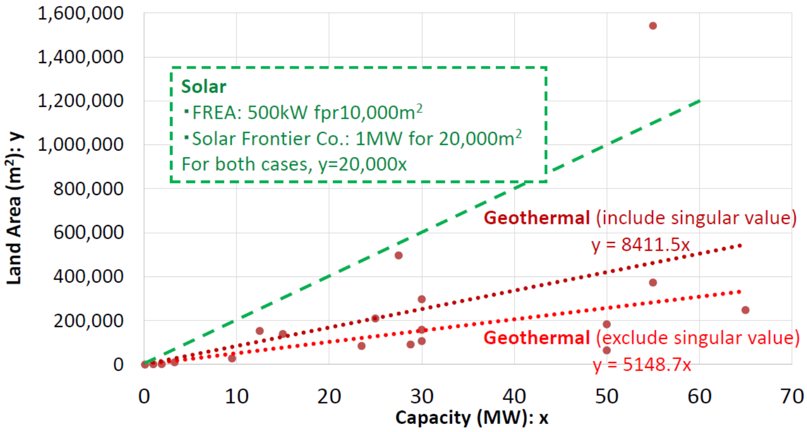
Although three plots are not sufficient to discuss general tendency and smaller power plants may have different curves, we will use in the following sections the linear relationship shown in Figure 2.4-2 ($y = 2.71x + 73$) to roughly estimate the number of possible new local employment generated by geothermal development.

d) Saving land

The exploitation of renewable energy has been encouraged in all nations. Yet, conflicts in land use occur because normally, renewable energy has low energy density and needs large space. On the other hand, geothermal energy has higher energy density than most renewable energy and is able to save land.

Figure 3.3-5 compares solar photovoltaic and geothermal power plant capacities and areas necessary for them. Excluding a singular high value of geothermal power stations, geothermal power plants need only one-fourth of areas compared to that of solar power plants. Since the capacity factor of geothermal power is much bigger than that of solar power, land saving by geothermal power per unit of electricity generated is even higher. Assuming the capacity factor of a geothermal power plant is 70% and that of solar photovoltaics is 12%, the land saving per megawatt of the geothermal power plant for the same electricity generation will be (8411.5 – 5148.7) x 70/12 = 111,518 m^2/MW.

Figure 3.3-5. Solar and Geothermal Power Plant Capacities and Areas



FREA = Fukushima Renewable Energy Institute, kW = kilowatt, m^2 = square metre, MW = megawatt.
Note: Dots show existing geothermal power plants in Japan.
Source: Soma et al., 2015.

4.2.2 Indirect advantages

In many cases, additional business is of much higher significance to local economy than power production or heat use. However, scales of additional projects differ thoroughly depending on business plans of enterprises. Thus, it is difficult to quantify possible business scale based on the capacity of geothermal energy use. Nevertheless, to show the possibility to policymakers, we surveyed literature on successful cases in the world to make a rough estimation of possible additional business.

Table 2.4-4 shows case studies from New Zealand, Thailand, Iceland, Indonesia, and the USA. Amongst them, New Zealand and Iceland cases clearly show annual profits of NZ$400,000 and €15,800,000, respectively, with their related geothermal power plant capacities at 161 MW_e and 75 MW_e (+ 150MW_t), respectively. Since Iceland's case is a highly successful one with highly diversified management, expecting a similar scale of profit would lead us to an overestimation. We therefore selected the case of New Zealand to study and interviewed a prawn farm owner in November 2017.

According to the owner, prawn farming itself is not profitable because electricity for the circulation pump of ponds costs much although heat supply is provided in quite low price by the Taupo geothermal power plant. Nevertheless, a decent annual profit of NZ$500,000 is constantly obtained from the tourism business that includes a prawn restaurant, prawn fishing, and other outdoor attractions. Similarly, its tourism-related business has 75 employees while prawn farming itself employs five.

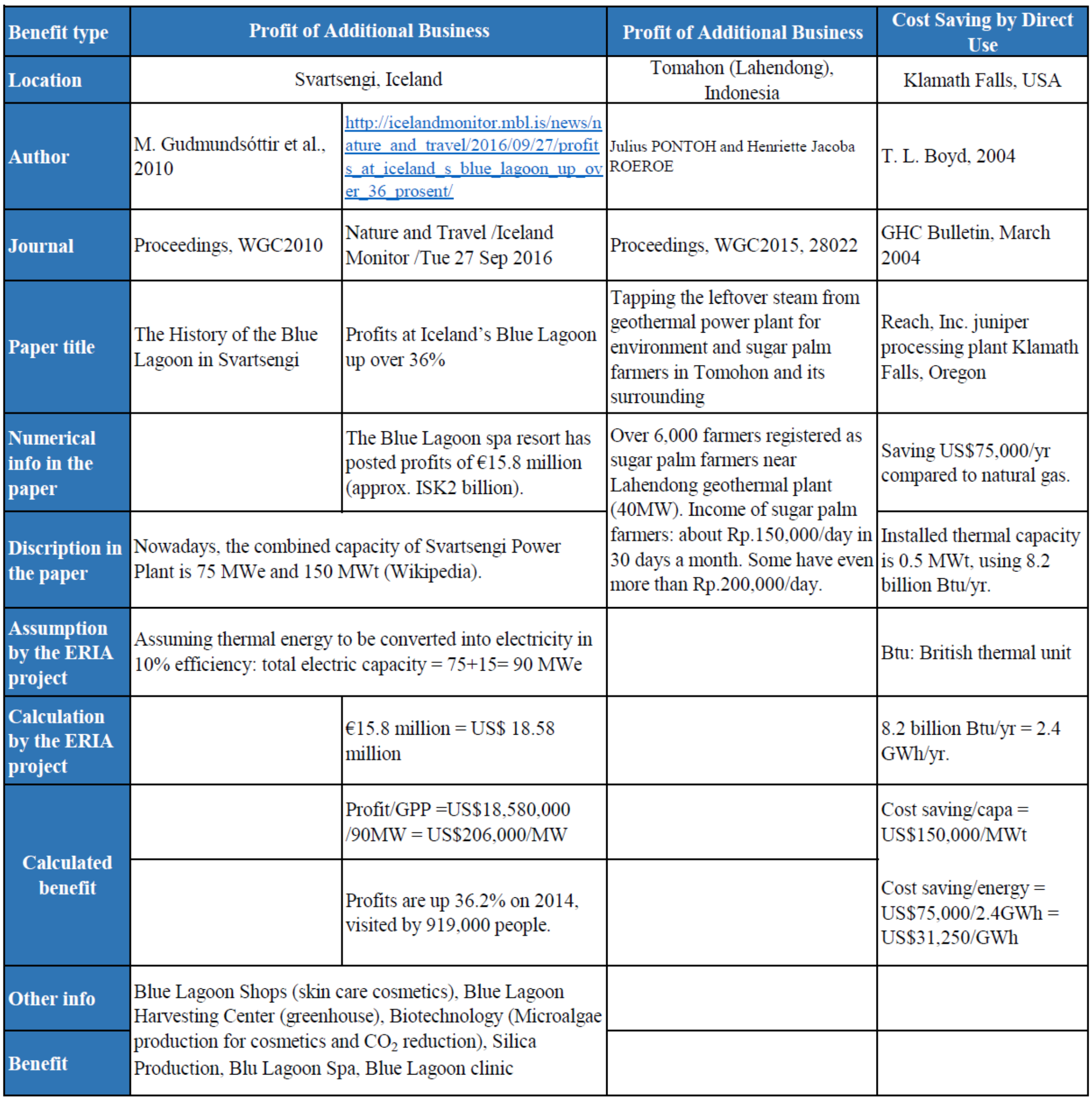
Thus, profit from additional business is largely dependent on the business model that only if the business model is adequate will one may expect decent business using extra heat from geothermal power plant even in regions where space heating is not necessary. Thus, to estimate profit from additional business in our region, we applied the profit per capacity of geothermal power plant as shown in Table 2.4-4(1), that is NZ$ 2,484/MW = US$1,788.48/MW (NZ$1 = US$0.72). With the number of local employees at 80, that would be 0.5 person/MW.

Beside new businesses, additional economic effects are expected because new businesses invest in personnel hiring and material purchase. In the case of the prawn park in New Zealand, the local economic effects are valued at NZ$500,000 as shown in Table 2.4-4(1). Converting them into benefits per original power plant's capacity, the economic effects of new business is NZ$3105.59/MW (= US$2236.0/MW). These figures will be used in calculating indirect benefits.

Table 2.4-4. Quantitative Information on the Benefits of Geothermal Use (1)

Benefit type	**Profit of Additional Business**		**Profit of Additional Business**
Location	**Toupo, New Zealand**		**Fang, Thailand**
Author	**J. W. Lund, 1995**	November 2017 Interview to the owner by ERIA project member	**J. Hirunlabh et al., 2004**
Journal	GHC Bulletin, October 1995	Acquired in 1991 from the former owner	GHC Bulletin, September 2005
Paper title	**Prawn park - Taupo, New Zealand**	(Interview to the owner of the Prawn Park)	**Chili and garlic drying by using waster heat recovery from a geothermal power plant**
Numerical info in the paper	(P29) Total area 6ha costs NZ$500,000. Return is NZ$150,000/ha (=NZ$900,000/6ha)	Tourism profit: NZ$500,000/yr +α. Visitors: 60,000 people/yr.	Cost of drying chili: 53.32Baht (US$1.44)/kg, garlic: 35.07Baht (US$0.95)/kg
Discription in the paper	Taupo total capacity in 1995 is 161MW.	Total labor: 80 people (prawn firming 5, tourism 75) Running cost for prawn firming: NZ$350,000/yr -> NZ$200,000/yr (by purchasing low price heat from Contact Energy Co. and do cascade use.) Profit is NZ$500,000/yr. (Profit is mainly from tourism, almost no profit by prawn farming itself.)	Considering Fang geothermal system (300 kW binary)
Assumption by the ERIA project			
Calculation by the ERIA project	Profit is NZ$400,000/yr		
Calculated benefit	**Profit/GPP** = NZ$2484/MW=US$1788.48		
	Economic effect/GPP (empoyment, material purchase) is NZ$500,000 -> NZ$3105.59/MW -> *.72 =US$2236.0/MW	Cost saving is $150,000/yr. Employment: 80 people.	
Other info	Profit in farming dairy cattle is merely NZ$2,500/ha	Major cost: electricity (30kW water pump: $10,000/month), feeds, labor.	
Benefit		New business: selling intellectual property (know-how of fish firming)	

Table 2.4-4. Quantitative Information on the Benefits of Geothermal Use (2)



Benefit type	Profit of Additional Business		Profit of Additional Business	Cost Saving by Direct Use
Location	Svartsengi, Iceland		Tomahon (Lahendong), Indonesia	Klamath Falls, USA
Author	M. Gudmundsóttir et al., 2010	http://icelandmonitor.mbl.is/news/nature_and_travel/2016/09/27/profits_at_iceland_s_blue_lagoon_up_over_36_prosent/	Julius PONTOH and Henriette Jacoba ROEROE	T. L. Boyd, 2004
Journal	Proceedings, WGC2010	Nature and Travel /Iceland Monitor /Tue 27 Sep 2016	Proceedings, WGC2015, 28022	GHC Bulletin, March 2004
Paper title	The History of the Blue Lagoon in Svartsengi	Profits at Iceland's Blue Lagoon up over 36%	Tapping the leftover steam from geothermal power plant for environment and sugar palm farmers in Tomohon and its surrounding	Reach, Inc. juniper processing plant Klamath Falls, Oregon
Numerical info in the paper		The Blue Lagoon spa resort has posted profits of €15.8 million (approx. ISK2 billion).	Over 6,000 farmers registered as sugar palm farmers near Lahendong geothermal plant (40MW). Income of sugar palm farmers: about Rp.150,000/day in 30 days a month. Some have even more than Rp.200,000/day.	Saving US$75,000/yr compared to natural gas.
Discription in the paper	Nowadays, the combined capacity of Svartsengi Power Plant is 75 MWe and 150 MWt (Wikipedia).			Installed thermal capacity is 0.5 MWt, using 8.2 billion Btu/yr.
Assumption by the ERIA project	Assuming thermal energy to be converted into electricity in 10% efficiency: total electric capacity = 75+15= 90 MWe			Btu: British thermal unit
Calculation by the ERIA project		€15.8 million = US$ 18.58 million		8.2 billion Btu/yr = 2.4 GWh/yr.
Calculated benefit		Profit/GPP =US$18,580,000 /90MW = US$206,000/MW		Cost saving/capa = US$150,000/MWt
		Profits are up 36.2% on 2014, visited by 919,000 people.		Cost saving/energy = US$75,000/2.4GWh = US$31,250/GWh
Other info	Blue Lagoon Shops (skin care cosmetics), Blue Lagoon Harvesting Center (greenhouse), Biotechnology (Microalgae production for cosmetics and CO_2 reduction), Silica Production, Blu Lagoon Spa, Blue Lagoon clinic			
Benefit				

GHC = Geo-Heat Center, GWh = gigawatt hour, MW = megawatt, MWe = megawatt electric, MWt = megawatt thermal, USA = United States of America, WGC = World Geothermal Congress.

Source: The study team.

4.3 Summary of benefits in member countries

The summary of benefits in China, Indonesia, Japan, Korea, Malaysia, the Philippines, Thailand, and Viet Nam), calculated by equations in the previous sections, are summarised in Table 2.4-5. Note that the same equation was applied for benefits of all countries based on the target capacity and target capacity factor of each country. For more country-specific benefits, please read Chapter 3.

Table 2.2-5. Possible Benefits of Removal of All Barriers to Geothermal Power Generation (1) 2025

Item		Unit	China	Indonesia	Japan	Korea	Malaysia	Philippines	Thailand	Viet Nam	TOTAL
Target capacity		MW	500	5,800	1,083	20	250	1,371	30	155	9,989
Target capacity factor		%	70%	70%	70%	85%	70	70%	70%	70%	
a) Power generation		MWh/year	3,068,100	35,589,960	6,645,505	149,022	1,534,050	8,412,730	184,086	951,111	62,346,422
b) Annual fuel saving	**by oil**	barrel/year	3,883,495	45,048,542	8,411,650	219,150	1,941,748	10,648,543	233,010	1,203,883	80,136,671
	by LNG	kg/year	461,000,050	5,347,600,580	998,526,108	22,391,431	230,500,025	1,264,062,137	27,660,003	142,910,016	9,367,916,159
		Million Btu/year	22,707,894	263,411,569	49,185,298	1,102,955	11,353,947	62,265,045	1,362,474	7,039,447	461,443,868
c) Saving in foreign currency	**by oil**	US$/year	233,009,700	2,702,912,520	504,699,010	13,149,000	116,504,850	638,912,597	13,980,582	72,233,007	4,808,212,267
	by LNG	US$/year	113,539,470	1,317,057,846	245,926,491	5,514,774	56,769,735	311,325,225	6,812,368	35,197,236	2,307,219,340
d) CO_2 mitigation		(tonnes-CO_2/year)	2,439,140	25,064,123	3,907,617	60,354	1,081,479	5,165,585	92,054	1,030,053	41,194,207
e) Local employment		persons	1,428	15,791	3,008	127	751	3,788	154	493	27,654
f) Saving land compared to PV		m^2	55,759,000	646,804,400	120,773,994	2,230,360	27,879,500	152,891,178	3,345,540	17,285,290	1,113,953,302
(g) Profit from additional business		US$	894,240	10,373,184	1,936,924	35,770	447,120	2,452,006	53,654	277,214	17,865,127
(h) Local employees by additional business		persons	250	2,900	542	10	125	686	15	78	4,995
(i) Local economic effects of additional business		US$	1,118,000	12,968,800	2,421,588	44,720	559,000	3,065,556	67,080	346,580	22,335,404

Btu = British thermal unit, CO_2 = carbon dioxide, kg = kilogramme, LNG = liquefied natural gas, m^2 = square metre, MW = megawatt, MWh = megawatt hour, PV = photovoltaics.

Note: CO_2 mitigation ratio to target capacity differs for each country and region because current emission factor and assumed capacity factor differ.

Source: The study team.

Table 2.2-5. Possible Benefits of Removal of All Barriers to Geothermal Power Generation (2) 2050

Item		Unit	China	Indonesia	Japan	Korea	Malaysia	Philippines	Thailand	Viet Nam	TOTAL
Target capacity		MW	16,000	29,923	1,000,000	800	273.25	1,371	30	680	1,049,077
Target capacity factor		%	70%	70%	70%	85%	70	70%	70%	70%	
a) Power generation		MWh/year	98,179,200	183,613,513	6,136,200,000	5,960,880	1,676,717	8,412,730	184,086	4,172,616	6,340,220,541
b) Annual fuel saving	**by oil**	barrel/year	124,271,840	232,411,642	7,766,990,000	8,766,000	2,122,330	10,648,543	233,010	5,281,553	8,150,724,918
	by LNG	kg/year	14,752,001,600	27,589,008,992	922,000,100,000	895,657,240	251,936,527	1,264,062,137	27,660,003	626,960,068	967,407,386,568
		Million Btu/year	726,652,605	1,358,976,618	45,415,787,804	44,118,194	12,409,864	62,265,045	1,362,474	30,882,736	47,652,455,339
c) Saving in foreign currency	**by oil**	US$/year	7,456,310,400	13,944,698,506	466,019,400,000	525,960,000	127,339,801	638,912,597	13,980,582	316,893,192	489,043,495,079
	by LNG	US$/year	3,633,263,024	6,794,883,092	227,078,939,019	220,590,969	62,049,320	311,325,225	6,812,368	154,413,679	238,262,276,697
d) CO_2 mitigation		(tonnes-CO_2/year)	78,052,480	129,309,268	3,608,141,274	2,414,160	1,182,057	5,165,585	92,054	4,518,942	3,828,875,816
e) Local employment		persons	43,433	81,164	2,710,073	2,241	814	3,788	154	1,916	2,843,583
f) Saving land compared to PV		m^2	1,784,288,000	3,336,953,114	111,518,000,000	89,214,400	30,472,294	152,891,178	3,345,540	75,832,240	116,990,996,766
(g) Profit from additional business		US$	28,615,680	53,516,687	1,788,480,000	1,430,784	488,702	2,452,006	53,654	1,216,166	1,876,253,680
(h) Local employees by additional business		Persons	8,000	14,962	500,000	400	137	686	15	340	524,539
(i) Local economic effects of additional business		US$	35,776,000	66,907,828	2,236,000,000	1,788,800	610,987	3,065,556	67,080	1,520,480	2,345,736,731

Btu = British thermal unit, CO_2 = carbon dioxide, kg = kilogramme, LNG = liquefied natural gas, m^2 = square metre, MW = megawatt, MWh = megawatt hour, PV = photovoltaics.

Note: CO_2 mitigation ratio to target capacity differs for each country and region because current emission factor and assumed capacity factor differ.

Source: The study team.

Table 2.2-3. Possible Benefits of Removal of All Barriers to GSHP

	Unit	China	Japan	Rep. of Korea
Target Capacity	MW_t	66,150	5,582	3,425
Annual Heating	GWh /year	221,380,000	2,110.9	2,305.8
Annual Cooling	GWh /year	-	1,680.1	745.6
Annual CO_2 Mitigation	(tonnes-CO^2/year)	51,420,000.0	319,510.0	1,451,266

CO_2 = carbon dioxide, GWh = gigawatt hour, MW_t = megawatt thermal.
Source: The study team.

Reference

Imamura, Eiichi and Koji Nagano 2010), 'Evaluation of Life Cycle CO_2 Emissions of Power Generation Technologies: Update for State-of-the-art Plants', *CRIEPI Research Report,* Report Number Y09027.

Chapter 3

Country Reports

1. China

1.1 Current situation of geothermal energy use and national policy

1.1.1 Current energy policy and energy mix

Current energy policy

With the rapid growth of China's economy in recent decades, its energy consumption has also increased significantly. The dominance of coal in China's energy structure has aggravated the country's air pollution situation, prompting an energy revolution in production and consumption that started in 2012. The aim was to control energy consumption, enhance energy saving and cost reduction, and support low-carbon industry and new and renewable energy to protect the national energy security (Hu, 2012).

Promoting clean space heating in winter in China's northern region was emphasised in 2016. The purpose was to reduce haze, change rural lifestyle, and realise energy revolution in production and consumption (Xi, 2016).

Plans for energy and renewable energy had been done before, but the 13th Five-year Plan of Geothermal Energy Development and Utilization in 2017 was the first time that geothermal energy was listed among its specialised plans. Although China's Law of Renewable Energy in 2006 stipulated wind, solar, biomass, geothermal, and ocean energies as renewable energy, the government has only given economic incentives to wind, solar, and biomass energy.

In 2017, a resolute battle was waged for blue sky and a quick resolve made for coal-fired pollution mitigation (Li, 2017). At the same time, the National Development and Reform Committee issued the Development Planning of Strategic Emerging Industries, deploying new energy as strategic emerging industries, including geothermal power generation, geothermal district heating, GSHP, etc. (NDRC, 2017)

Energy mix in China

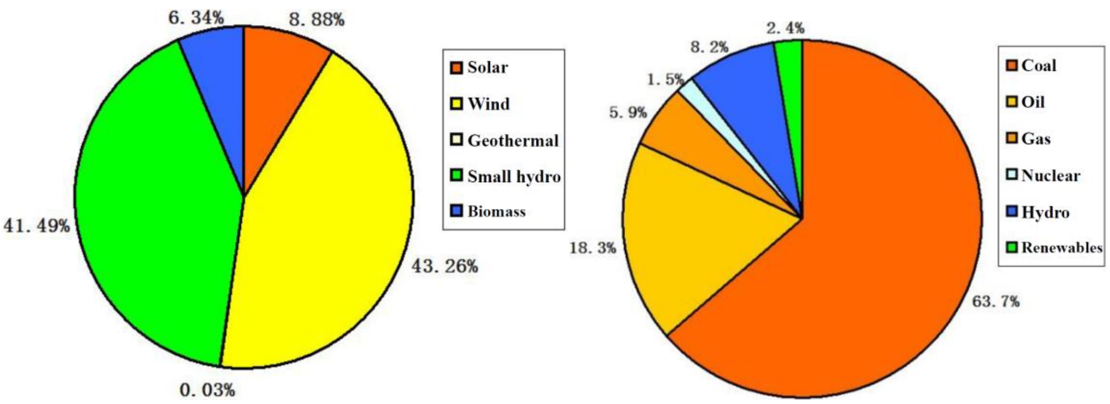
The *China Statistics Yearbook 2016* shows that China's energy mix in 2015 was still dominated by coal (63.7%), although reduced a little from the previous year's 64.0%. During the same year, non-fossil energies increased a bit (12.1%) from previous year's 12.0%, while non-hydro renewable electricity increased from 1.9% to 2.4% (NBSC, 2016 and 2017). However, amongst renewable electricity, wind power and small hydropower remained dominant with a rate of more than 40%. Geothermal electricity was just 0.03%.

Table 3.1.1-1. China’s Energy Structure and Renewable Electricity Mix, 2015

Energy Structure		Renewable Electricity	
Type	**Proportion**	**Type**	**Proportion**
Coal	63.70%	**Solar**	8.88%
Oil	18.30%	**Wind**	43.26%
Gas	5.90%	**Geothermal**	0.03%
Nuclear	1.47%	**Small hydro**	41.49%
Hydro	8.24%	**Biomass**	6.34%
Renewables	2.39%		

Source: National Bureau of Statistics of China, 2016, 2017.

Figure 3.1.1-1. China’s Energy Structure (left) and Renewable Electricity Mix (right), 2015



Source: National Bureau of Statistics of China, 2016, 2017.

1.1.2 Geothermal energy use in China

Geothermal resources

The geothermal resource survey and estimation project in China, funded by China Geological Survey under arrangement with the Ministry of Land and Resources, was completed in 2015. It shows potential for shallow geothermal energy, hydrothermal, geothermal, and enhanced/engineered geothermal (EGS) systems.

Table 3.1.1-2. Geothermal Resource Potential in China

	Type	Temperature	Depth	Potential	Reference
Power Generation	Hydrothermal	>150°C	200~3000 m	8466 MW$_e$	Huang, 2014
	EGS	>150°C	3000~10000 m	25.2×10^6EJ	Wang, 2015
Direct Use	Hydrothermal	25~150°C	200~3000 m	3.66×10^4EJ	Wang, 2015

EGS = enhanced/engineered geothermal systems, EJ = exajoule, m =metre, MW$_e$ = megawatt electric.
Source: Huang, 2014; Wang, 2015.

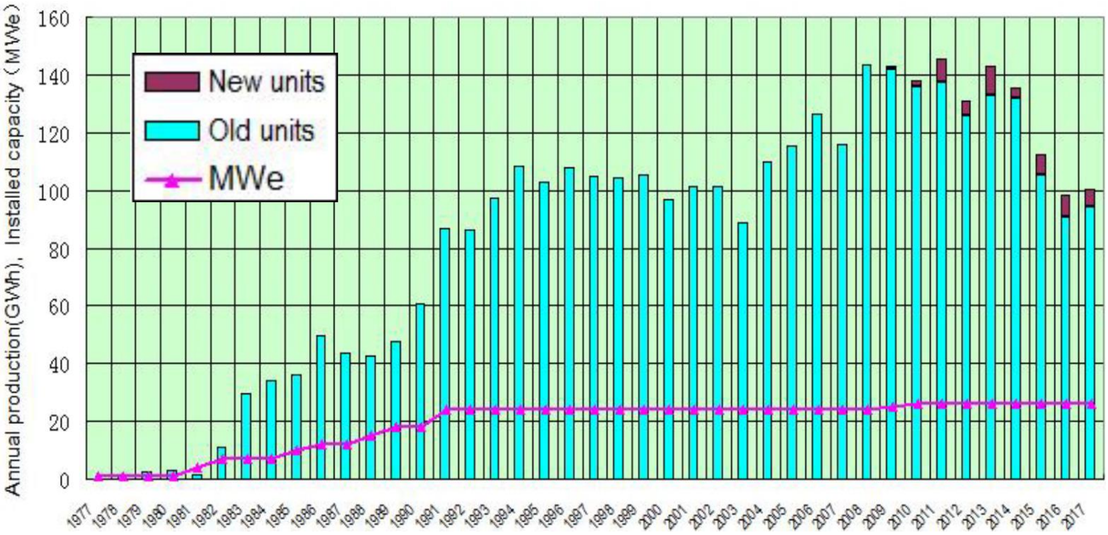
<u>Current geothermal use</u>

(1) Geothermal power generation

During the 12th five-year planning in 2011–2015, a private enterprise started to build the Yangyi geothermal power plant in Tibet. Designed for 32-MW$_e$ installed capacity, the project was not completed due to national preferential policy (economic incentives), impracticability, lack of technology on high-temperature geothermal exploration, lack of experts, lack of loan support, etc.

China's main force of geothermal power generation is still the Yangbajain geothermal power plant in Tibet. It started operation in 1977 and completed its total installed capacity of 25.18 MW$_e$ in 1991 with double flash units. A 1-MW$_e$ test unit was retired in 2009 and two 1-MW$_e$ total flow units were started in 2010. The power plant now has a total 26.18 MW$_e$ capacity. Its high peak of over 140 GWh was reached in 2009–2014. Since three years ago, however, the power plant has started to show its age, with its annual production now reduced to about 100 GWh.

Figure 3.1.1-2. Timeline of the Yangbajain Geothermal Power Plant



GWh = gigawatt hour, MW$_e$ = megawatt electric.
Source: Authors.

Still in operation is a 300-kW_e power plant in Fengshun, Guangdong province. The first geothermal power generation plant in China, it started operation in 1970 and is still operational through the technical support of the Guangzhou Institute of Energy Conservation.

Intermittently operating are some small units such as the Yangyi (400 kW_e + 500 kW_e) and the North China oil field (400 kW_e).

Since 2017, a private enterprise in Henan has been operating a 1.2-MW_e geothermal power unit in Ruili, Yunnan province, and a private enterprise has been operating a 200-kW_e geothermal power unit in Kangding, Sichuan province.

(2) Geothermal space heating

Geothermal space heating allows full play for medium-low-temperature geothermal resources. Geothermal district heating has made more progress after the government started promoting clean space heating and controlling haze problems. In 2014, geothermal district heating expanded to 60.32 million m^2 with installed capacity of 2,946 MW_t and annual energy use of 33,710 TJ (WGC2015, 2014). It reached 90 million m^2 with installed capacity of 4,400 MW_t and annual energy use of 50,300 TJ in 2016.

(3) Baths and swims

Since ancient time, hot spring has traditionally been used for bathing and medical treatment. From the 1990s, China's market economy developers have elevated hot spring baths into hot spring resorts that favour tourism. With the promotion of health and raising culture as its theme, the scheme received favourable response from consumers and increased value and profit for geothermal use. In 2014, geothermal baths and swims had installed capacity of 2,508 MW_t and used energy of 31,637 TJ. They have since increased by about 10% annually.

(4) Geothermal greenhouse and aquaculture breeding

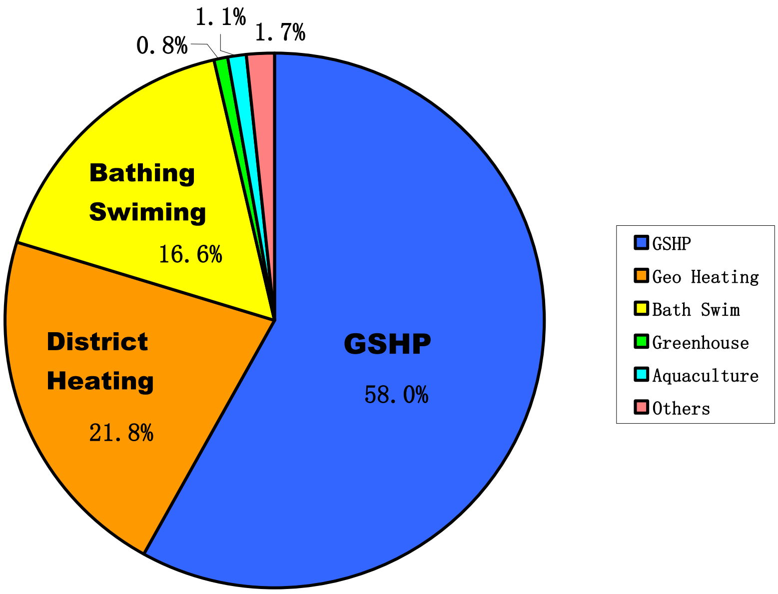
Along with the growth in economy and improvement in people's living standard came high market demand for seasonal fresh vegetables, high-range flowers, and live aquatic products. Geothermal greenhouse planting and aquaculture breeding have taken full advantage of the potential value of low-temperature geothermal power in a bid to satisfy market requirement and, in the process, achieve high economic benefits. By 2014, geothermal greenhouses and aquaculture had installed capacity of 154 MW_t and 217 MW_t, respectively, and used energy of 1,797 TJ and 2,395 TJ, respectively. In 2016, their used energy was about 1,900 TJ and 2,500 TJ, respectively. It has since increased annually by 3% and 2%, respectively.

(5) Ground source heat pump

China's current geothermal direct use is mostly ground source heat pump (GSHP). In the past, the regions located south of latitude 33° had no space heating during winter, where the average January air temperature is 0~1°C. At present, the middle and lower reaches of the Yangtze River have popularly implemented winter space heating, making a vast market for GSHP application. The Wuhan municipal government, for instance, has promoted a 'warm winter and cool summer' project where all new buildings will use GSHP system. China Geological Survey has completed surveys and estimations for shallow geothermal energy in 336 main cities nationwide. The results show suitable, basically suitable, and unsuitable areas for GSHP application. Many local governments have given preferential policy support and subsidies to it. In 2015, GSHP application reached 400 million m^2 using shallow geothermal energy of 109,000 TJ. In 2016, this application reached 490 million m^2 and used energy of 134,000 TJ. The annual progressive increase rate is 22%.

Figure 3.1.1-3 shows the annual energy used for geothermal direct use structure in China in 2016. GSHP's share was 58.0%, while the proportions of conventional geothermal use for district heating and bathing/swimming were 21.8% and 16.6%, respectively.

Figure 3.1.1-3. China's Geothermal Direct Use (Annual Energy Used), 2016



GSHP = ground source heat pump.
Source: Authors.

1.2 Target of geothermal power generation

1.2.1 Target for 2025

China's geothermal use target in 2025 is presented in the 2016 annual report of the geothermal energy project of the Economic Research Institute for ASEAN and East Asia (ERIA). We summarise it here using data from three channels:

(1) China Academy of Engineering's research report on China's geothermal development roadmap (Huang, 2014).

(2) China Geological Survey's modified data on geothermal project hosted by the Institute of Hydrogeology and Environment Geology (Wang, 2015).

(3) National Development and Reform Committee's 13th five-year planning on geothermal energy development and utilisation (NDRC, 2017).

The data from the above sources are listed in Table 3.1.2-1. We then made an integrated analysis based on the past process of China's geothermal development and considered removing existing best factor to reach most possible target. The ERIA report target is also listed in the table. Further research after the ERIA report is needed to answer the query on how to rely on possible innovation to improve and reach the target and benefits.

Table 3.1.2-1. Target Comparison of Three Groups and Selected Numbers in this Report

Item	(1) in 2025	(2) in 2025	(3) in 2020	ERIA report in 2025
Power Generation	200 MW_e	700 MW_e	500 MW_e	400 MW_e
EGS	100 MW_e	100MW_e	-	100 MW_e
Direct Use Except GSHP	14,330 MW_t	18,000MW_t (in 2020)	18,000MW_t (in 2020)	18,000 MW_t
Ground Source Heat Pump	25,680 MW_t	19,260MW_t (in 2020)	22,470MW_t (in 2020)	48,150 MW_t

EGS = enhanced/engineered geothermal systems, ERIA = Economic Research Institute for ASEAN and East Asia, GSHP = ground source heat pump, MW_e = megawatt electric, MW_t = megawatt thermal.
Source: Modified from Huang, 2014; Wang, 2015; and NDRC, 2017.

Based on Table 3.1.2-1, we made Table 3.1.2-2 to show details of the target value, especially for direct use, in the ERIA report.

Table 3.1.2-2. Target Number of Installed Capacity and Energy Utilisation for 2025

Installed Capacity of Power Generation	**Conventional Geothermal System**	**Enhanced Geothermal System**
	400 MW$_e$	100 MW$_e$
	500 MW$_e$	
	Eighteen times bigger than the 2015 capacity (28 MW$_e$)	
Energy Utilisation of Direct Use (conventional and GSHP, respectively)	Direct use except GSHP	GSHP
	18,000 MW$_t$	48,150 MW$_t$
	221,380 TJ/year	409,980 TJ/year
	400 million m^2 of heating area	1,500 million m^2 of heating area
	66,150 MW$_t$ (631,360 TJ/year)	
	It is 3.7 times bigger than in 2015 (17,870 MW$_t$)	

GSHP = ground source heat pump, m^2 = square metre, MW$_e$ = megawatt electric, MW$_t$ = megawatt thermal, TJ = terajoule.
Source: Original table of this project.

1.2.2 Target for 2050

1. Geothermal power generation

According to China Academy of Engineering's research report on China's geothermal energy development roadmap, the long-term target up to 2050 is 1,000 MW$_e$ for conventional geothermal power generation and 15 GW$_e$ for EGS (Huang, 2014).

2. Geothermal direct heat use and GSHP

According to the same China Academy of Engineering's research report, the long-term target in 2050 for direct heat use is 67,500 MW$_t$ with capacity factor of 0.36, so annual energy used will be 766,650 TJ; while it is 114,240 MW$_t$ with capacity factor of 0.20 for GSHP, so annual energy used will be 720,530 TJ.

1.3 Barriers to geothermal power generation and necessary innovations

1.3.1 Inquiry and results

1. Results of inquiry from AGS11

Results from AGS11 inquiry were discussed during the ERIA geothermal energy project working group meeting in November 2016, and included in the 2016 ERIA report.

2. Inquiry from the China geothermal symposium

(1) Inquiry from the China geothermal symposium

In August 2017, the Geothermal Council of China Energy Society hosted a geothermal symposium in Dongying, Shandong province, where voluntary inquiries were solicited from the more than 100 participants from universities, research institutes, enterprises, and governments. A total of 37 valid inquiries were taken into statistics. A few of international results from AGS11 were considered but were given up during the ERIA project meeting in Malaysia. Instead, results of inquiry to domestic experts were used in this report.

The statistics and final results for geothermal power generation listed in Table 3.1.5 are shown in Figure 3.1.4.

1.3.2 Analysis of major barriers

(1) Uppermost of barriers are policy barriers. Especially, the lack of economic incentives (9.6%) and national energy policy (7.2%) are listed as first and second amongst 27 detailed policy barriers.

(2) The second main barriers are technical barriers, especially the lack of information and experience (5.1%).

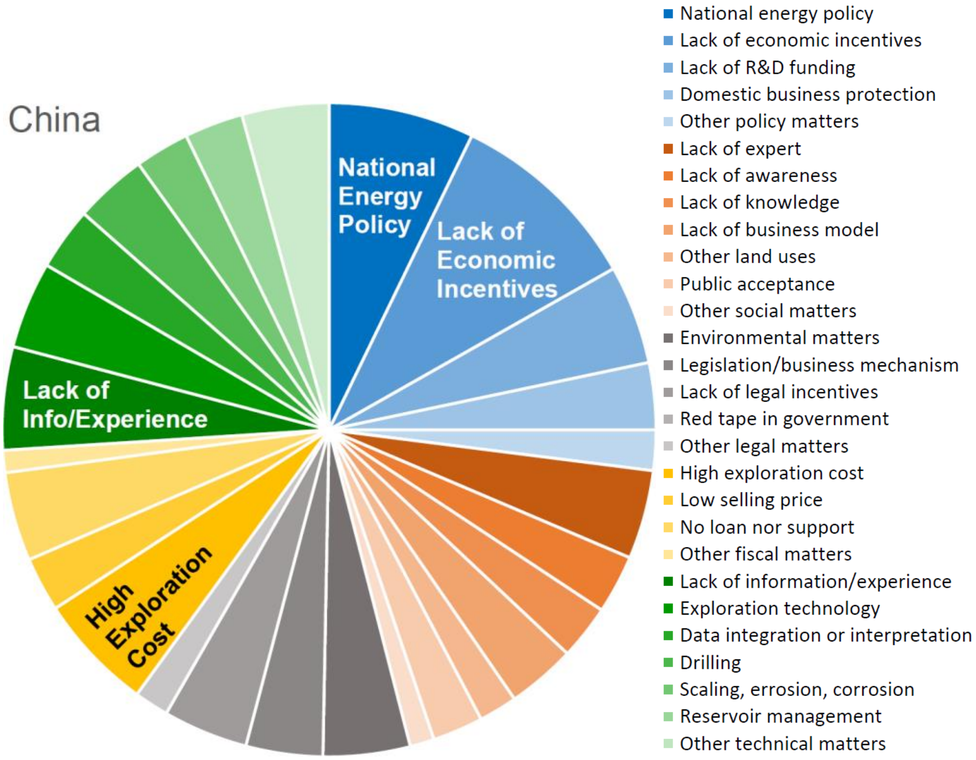
(3) High exploration cost, a fiscal barrier, is also of high proportion (5.8%).

Table 3.1.3-1. Statistics of Barriers to Geothermal Power Generation in China

Barrier	Items of Barriers	Final Results from Domestic Inquiry (%)	
Policy	National energy policies	27	7.2
	Lack of economic incentives (subsidies, FiT, tax reduction, etc.)		9.6
	Lack of R&D funding		4.9
	Domestic business/information protection		3.3
	Others		2.0
Social	Lack of experts, lack of geothermal specialisations in universities	19	4.4
	Lack of awareness		2.9
	Lack of knowledge, wrong information		2.7
	Lack of business models		3.4
	Other land uses		1.9
	Public acceptance		2.5
	Others		1.2
Legal	Environmental matters (nature parks and forestry, etc.)	14	4.3
	Legislation or business mechanism		3.8
	Lack of incentives (on environmental or energy security aspects)		4.2
	Others		1.7
Fiscal	High exploration cost	14	5.8
	Low selling price		2.7
	No loans from banks or support from government		4.4
	Others		1.1
Technical	Lack of information or experience (general)	26	5.1
	Exploration technology		4.3
	Data integration or interpretation		3.1
	Drilling		3.6
	Scaling, erosion		2.7
	Reservoir engineering and management		2.9
	Others		4.3
Total		100	100

FiT = feed-in tariff, R&D = research and development.
Source: Authors.

Figure 3.1.3-1. Final Results of Inquiry on Barriers to Geothermal Power Generation in China



R&D = research and development.
Note: Major barriers are labelled.
Source: Authors.

1.3.3 Peculiar barriers hidden behind other superficial barriers

Power generation is the weak spot in China’s geothermal energy use. Chinese geothermal energy workers are fervently hoping to change such situation. Other than the lack of economic incentives and national energy policies – which make developers shrink back at the first sight of such barriers – another big barrier is lack of experience and expertise, a peculiarly hidden barrier which, in essence, means the lack of geothermal specialisation in Chinese universities. When it comes to high-temperature geothermal power generation, it is obvious that China has no sufficiently and properly trained engineers.

The Tibetan geothermal geological team that built the Yangbajain geothermal power plant was unique because of its expertise on high-temperature geothermal exploration. However, those experienced engineers and technicians have either retired or transferred to explore other works as there have been no geothermal exploration projects in China in the last 20 years or so. Some provinces have newly established geothermal exploration teams and geothermal research institutes but unfortunately have no experience in high-temperature exploration. Certainly, more than 24 geological and geophysical engineers and researchers built the 24-MW_e Yangbajain geothermal power plant. Now that China is planning to build a 500-MW_e geothermal power plant, how many geothermal engineers would we need? Unfortunately, China has no sufficient geothermal engineers yet and no geothermal specialisation in Chinese universities as well (CERS, 2016). Ageing geothermal energy experts are crying out in alarm that China needs foreign experts to advice its high-temperature exploration and power plant building. But even that is not permitted.

1.3.4 Necessary innovations

Policy Aspect

(1) Issue necessary economic incentives

It is necessary that China issue national policy for economic incentives. At present, solar power, wind power, and biomass power get fixed subsidies for grid purchase price. But there is no formal governmental document for similar subsidy for geothermal electricity. There is no FiT mechanism for geothermal power generation. The renewable portfolio standard mainly serves wind power and solar power projects.

(2) Establish demonstration projects

China should establish national or departmental demonstration projects to show advance template suitable for popularisation. During China's 12th five-year plan, a private company invested in the construction of the 32-MW Yangyi geothermal power plant in Tibet. This project is great progress in China's geothermal power generation after 20 years of stagnation. Although we had suggested the need for national support through the creation of a demonstration project that could ensure successful power generation and establish confidence among investors, the proposal failed to get support and died prematurely due to financial problems.

(3) Open Chinese–foreign cooperation

Opening Chinese–foreign cooperation for national or departmental research projects will gain Chinese experts more experience in technology and management and avoid detours.

Social Aspect

(1) Set up geothermal energy specialisations in universities

Training geothermal energy professionals should fit the demand of geothermal power development. The few graduate students on geothermal technology are insufficient to meet the growth demand. Some experts with doctoral degrees do not even dare venture into geothermal energy front lines and satisfy themselves instead in laboratory and office research.

(2) Enhance publicity on geothermal energy

Various media (internet, TV, cinema, arts, etc.) should be utilised to promote geothermal energy.

Legal Aspect

(1) Issue laws on geothermal resources

The country should issue laws on geothermal resources and their methods of management. At present, geothermal resources are being managed as water resources in many cities where licence for geothermal exploitation is obtained from their water bureaus. Water bureaus do not understand geothermal energy, with most of them erroneously thinking it would drop groundwater level. If ever they approved, they require that geothermal wells be drilled in dense areas. Laws on geothermal resources and their management should clarify that the Ministry of Land and Resources is the authorised department for geothermal resources.

(2) Enhance management for geothermal reinjection

Enhancing management for reinjection of geothermal tail water in a legal framework is a good measure for sustainable use.

Fiscal Aspect

(1) Establish geothermal risk fund

Many developers worry about the risks involved in geothermal drilling. China should encourage investors in geothermal technology by establishing risk fund for geothermal resource exploration.

(2) Provide low-interest loans

Low-interest loans are welcome for small and medium-scaled enterprises involved in geothermal energy projects.

Technical Aspect

(1) Geothermal reserves preparation

Exploration and assessments should be done prior to geothermal resource development projects. Proper geothermal resource exploration should be funded by the national government. Investment by private developers should not start from resource exploration because it involves high risk and needs long period.

(2) Public geothermal database

Previous achievements in geological exploration are important reference for geothermal resource exploration and well drilling. However, open data are usually not available because these are kept by private companies. Thus, the country’s public data management system should be improved.

(3) Reinjection technology

Research for reinjection technology for geothermal tail water especially in sandstone reservoirs should be enhanced and suitable techniques be popularised to help developers and users solve difficulties.

1.4 Benefits of geothermal power generation in China

1.4.1 Mitigation of CO_2 emission (kg-CO_2/kW)

We recalculated Table 3.1.4-1 for power source and Table 3.1.4-2 for renewable electricity based on the newest data on energy mix.

The conventional power costs (grid purchase prices) for coal and hydropower in Table 3.1.4-1 and for solar PV and wind power onshore in Table 3.1.4-2 were adopted from data from China Energy Research Society (CERS, 2016) while others were based on international data.

Table 3.1.4-1. CO_2 Emission from Power Sources in China, 2015

Power Source	Power Supply: A	Power Supply Ratio: B		Unit CO_2 Emission: C	Conventional Power Cost: D	B x D	B×C
Unit	PJ			(g-CO_2/kWh)	USc/kWh		
Coal	**80,238**	64%		1,000	**6.6**	4.21	637.32
Oil	**23,051**	18%		778	**5.0**	0.92	142.44
LNG	**7,432**	6%		443	**5.0**	0.30	26.151
Nuclear	**1,852**	1%		66	**5.0**	0.07	0.9709
Hydro	**10,379**	8%		10	**4.7**	0.39	0.8244
Renew-ables	**2,948**	2%		**14.2**	**7.2**	0.17	0.3313
TOTAL/ Average	125,900	100%		808	5.9	6	**808**

CO_2 = carbon dioxide, g-CO_2 = gramme of carbon dioxide, kWh = kilowatt-hour, LNG = liquefied natural gas, PJ = petajoule, USc = United States cent.
Sources: A: National Bureau of Statistics of China, 2017; C: Benjamin K. Savacool, 2008; D: China Energy Research Society, 2016.

Table 3.1.4-2. CO_2 Emission from Renewable Power Sources in China, 2015

Power Source	Power Supply: ^{A}	Ratio in renewables: ^{B}	CO_2 Emission: ^{C}	Power Cost: ^{E}	CO_2 reduction cost	B×C	CO_2 reduction
Unit	GWh		(g-CO2/ kWh)	USc/ kWh	USc/ (g-CO2)		g-CO2/ kWh
Solar PV	**51,713**	**9%**	32	**14**	0.010466	2.8412	776.04
Wind onshore	**251,955**	**43%**	10	**8**	0.002659	4.3258	798.04
Geothermal (natural system)	**155**	**0%**	**13**	**7**	0.001411	0.0035	795.04
Geothermal (HDR)	**0**		**38**	**7**	0.001457	0	770.04
Small hydro	**241,659**	**41%**	13	**5**	- 0.001104	5.3938	795.04
Biomass	**36,960**	**6%**	25	**7**	0.001433	1.5864	783.04
Biogas			11	**7**	0.001408	0	797.04
TOTAL	582,442	100%				**14.15**	

CO_2 = carbon dioxide, g-CO_2 = gramme of carbon dioxide, GWh = gigawatt hour, HDR = hot dry rock, kWh = kilowatt-hour, PV = photovoltaics, USc = United States cent.
Sources: A: National Bureau of Statistics of China, 2017;
C: http://www.japanfs.org/ja/news/archives/news_id035082.html; E: China Energy Research Society, 2016.

The target geothermal power generation, which includes conventional geothermal and enhanced/engineered geothermal system, will have new installed capacity of 500 MW_e if the barriers are removed by innovations in 2025. It would be 17 times bigger than the current generation status (as of 2017).

Calculation of CO_2 mitigation by geothermal electricity:

808 – 13 = 795 (g/CO_2/kWh).

If with additional capacity of 500 MW (total increased target from 2015) with a capacity factor of 70%:

795 × 500 × 24 × 365.25 × 70% = 2,439,139,500 kg-CO_2/year = 2.44 million tonnes of CO_2/year.

If with additional capacity of 300 MW (partial increase by removal of barriers) with a capacity factor of 70%:

795 × 300 × 24 × 365.25 × 70% = 1,463,483,700 kg-CO_2/year = 1.46 million tonnes of CO_2/year.

1.4.2 New employment

We follow the calculation method of the working meeting in this research project using Excel template.

Tibetan region

The main geothermal power generation plant in China is the Yangbajain geothermal power plant, with 200 personnel. It produces 100 GWh annually during the last three years.

Because 100 GWh/year = 200 persons.

It means that 2.00 persons-year/GWh.

The target for 2025 is 3,066 GWh, half (1,533 GWh) in Tibet and another half in other regions.

Therefore 1,533 GWh × 2.00 persons-year/GWh = 3,066 persons for Tibet region.

Other regions

Other regions have higher effect, say 100 GWh/year = 85 persons

or 0.85 person-year/GWh.

Therefore 1,533 GWh × 0.85 person-year/GWh = 1,303 persons for other regions.

Total new employment

For new employment, it will be 3,066 + 1,303 = 4,369 persons or an average of 8.7 persons/MW.

1.4.3 Direct economic benefits

The use of geothermal energy will increase direct economic benefits, which we estimate as follows.

Increased sale of geothermal electricity.

Increased geothermal power of 500 MW_e in 2025.

For capacity factor of 0.70, the operation hours would be 8,760 × 0.7 = 6,132 hours per year.

Thus, 500 MW_e × 6,132 h = 3,066 GWh.

The average electricity price in China is CNY0.80 per kWh.

Annual sale of 3,066 GWh × 0.80CNY/kWh = CNY2,452.8 million = US$368.8 million.

1.4.4 Indirect economic benefits

Indirect economic benefits will come from restaurants, shops, supermarkets, assorted businesses, and services. The indirect economic benefits are about 1.5–3 times more than that of direct economic benefits.

3.1.4.5 Regional development

Geothermal power development can drive regional development. Yangbajain was a small village before the power station was constructed there. Yangbajain's infrastructure has now changed rapidly with the extended road system, water and electricity supplies, telecom and postal services, banks, shops, restaurants, etc. The local population has increased more than 10 times.

1.5 Summary of barriers to and benefits of geothermal power generation

- The first barriers to geothermal power generation in China are the policy barriers and the second are the technical barriers. A peculiar barrier hidden behind other barriers is the lack of specialisation on geothermal technology in Chinese universities, resulting in critical shortage of technicians especially for high-temperature geothermal resource exploration and power generation (Zheng, 2017).
- Economic incentives are the main suggested necessary innovation for removing barriers. The national subsidies to wind power and solar PV promoted the great growth of both. Geothermal power generation has never had such subsidy policy
- It is necessary to establish national demonstration projects for geothermal power generation and hot dry rock EGS development. A few years ago, a private enterprise invested in the development of the Tibet Yangyi geothermal power plant. Unfortunately, it did not get support as a national demonstration project and subsequently failed when the developer's fund dwindled. This led to developers losing confidence in pursuing similar projects.
- Geothermal power generation could reduce CO_2 emission. An additional 500 MW generation could contribute to CO_2 mitigation by 2.44 million tonnes annually. It will also lead to about 4,300 additional employment. It will also save fossil fuels and reduce energy costs. Indirect economic benefits include saving costs for CO_2 mitigation and new businesses such as greenhouse agriculture, fish farming, tourism, etc. It will lead to regional development and prosperous local economy.

As quantified, the benefits of removing barriers are summarised in Table 3.1.5-1.

Table 3.1.5-1. Quantification of Barriers to and Benefits of Geothermal Power Generation in China

Item		Unit	Policy	Social	Legal	Fiscal	Technical	Total	Remark	
Barrier contribution in category		%	**27**	**19**	**14**	**14**	**26**	100		
Target capacity		MW	135	95	70	70	130	**500**		
Target power generation		MWh/year	828,387	582,939	429,534	429,534	797,706	3,068,100	**70%**	capacity factor
	Electricity	J(elect)/year	2.98E+15	2.10E+15	1.55E+15	1.55E+15	2.87E+15	1.10E+16	kWh= 3.6×10^6J	
	Equivalent heat	J(heat)/year	7.46E+15	5.25E+15	3.87E+15	3.87E+15	7.18E+15	2.76E+16	assuming 40% efficiency	
Saving land (compared to same power by PV)		m^2	1.46E+07	1.03E+07	7.58E+06	7.58E+06	1.41E+07	5.41E+07		
Electricity sales	Developer's benefit	US$/year	115,974,180	81,611,460	60,134,760	60,134,760	111,678,840	429,534,000	**0.14**	US$/kWh
Electricity sales tax	Government's benefit	US$/year	9,277,934	6,528,917	4,810,781	4,810,781	8,934,307	34,362,720	**8%**	
Saving oil (barrel of oil equivalent)		boe/year	1,218,216	857,263	631,668	631,668	1,173,097	4,511,912	1 boe≈ 6.12×10^9J(heat)	
CO_2 mitigation		(t-CO_2/yr)	658,568	463,437	341,480	341,480	634,176	**2,439,140**		
Saving energy cost compared to PV	Factor	US$/MWh	18.900	13.300	9.800	9.800	18.200	70		
	Total saving	US$	57,987,090	40,805,730	30,067,380	30,067,380	55,839,420	214,767,000		
Saving CO_2 reduction cost compared to PV	Factor	US$/kg-$CO_2$	0.024	0.017	0.013	0.013	0.024	0.09		
	Total cost	US$	59,632	41,963	30,920	30,920	57,423	220,858		
Land Saving for CO_2 reduction compared to PV	Factor	m^2/kg-CO_2		-	-	-	-	22.72	from 'Land' Table	
	Total saving	m^2	14,962,577	10,529,221	7,758,373	7,758,373	14,408,408	55,416,953	for mitigation of 19I	
Direct: New employment for GPP			386	271	200	200	371	1,428		2.71x+73
Indirect: New business profit		US$	241,443	169,905	125,193	125,193	232,501	894,235	1,778	1788.47x NZ example
Indirect: New business economic effect		US$	301,860	212,420	156,520	156,520	290,680	1,118,000	2,236	2236x NZ example

boe = barrel of oil equivalent, CO_2 = carbon dioxide, GPP = geothermal power plant, J= joule, kg = kilogramme, kWh = kilowatt-hour, m^2 = square metre, MW = megawatt, MWh = megawatt hour, NZ = New Zealand, PV = photovoltaics, t-CO_2 = total carbon dioxide.

Source: Authors.

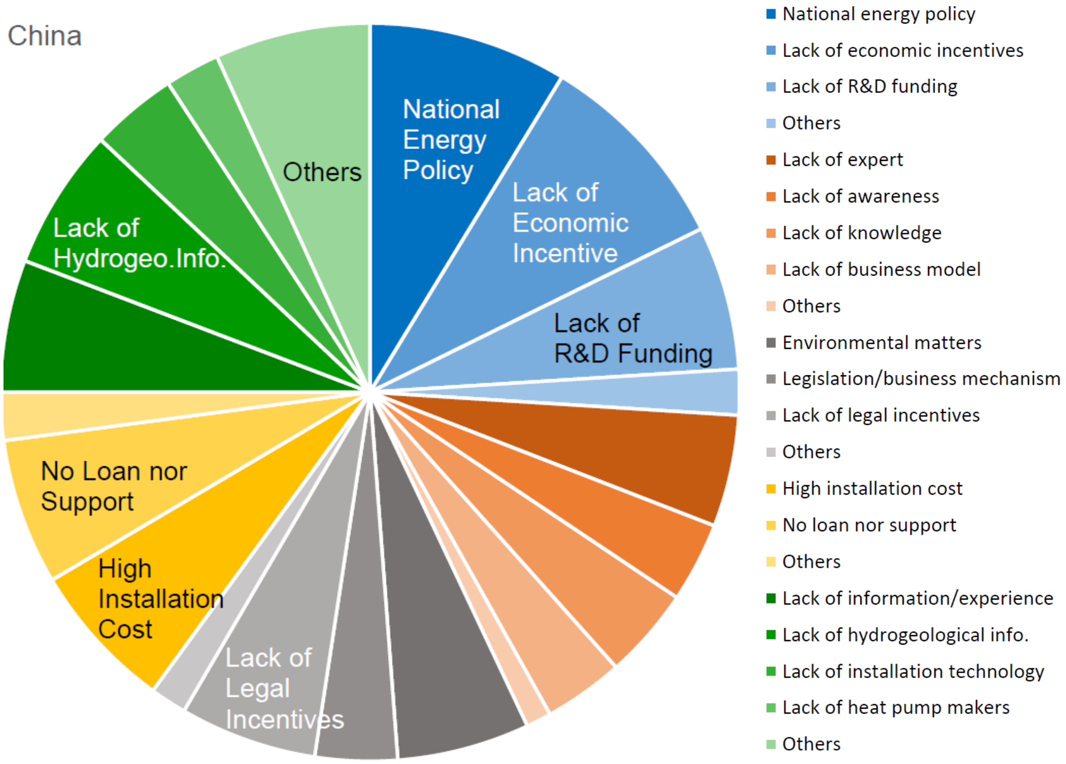
1.6 Barriers to direct use/GSHP and necessary innovations

1.6.1 Inquiry and results

We used the domestic inquiry from the geothermal symposium and adopted the results.

The corresponding statistical results and final used results for direct heat use/GSHP are shown in Table 3.1.6-1 while the final results are shown in Figure 3.1.6-1.

Fig. 3.1.6-1. Barriers to Geothermal Direct Heat Use/GSHP as Final Results in China



Note: Major barriers are labelled.
Source: Authors.

1.6.2 Analysis of major barriers

(1) The uppermost barriers are policy barriers, especially the lack of economic incentives (9.0%) and national energy policy (8.7%), which are listed as first and second amongst 27 detailed items.

(2) The second main barriers are technical barriers, especially the reinjection technique (6.8%), which is listed third amongst 27 detailed items.

(3) Also of high proportion (6.5%) is exploration cost. It belongs to the fiscal barriers and is listed fourth amongst 27 detailed items.

Table 3.1.6-1. Statistics of Barriers to Geothermal Direct Heat Use with Main Portion of GSHP in China

Barrier	Items of Barriers	Final Results of Domestic Inquiry (%)	
Policy	National energy policy	26	8.7
	Lack of economic incentives		9.0
	Lack of R&D funding		6.3
	Others		2.0
Social	Lack of experts, lack of geothermal specialisation in universities	17	4.9
	Lack of awareness		3.5
	Lack of knowledge, wrong information		4.0
	Lack of business models		3.5
	Others		1.1
Legal	Environmental matters (nature parks and forestry, etc.)	17	5.8
	Legislation or business mechanism		3.6
	Lack of incentives (from environmental or energy security aspects)		6.0
	Others		1.6
Fiscal	High installation cost	15	6.5
	No loans from banks nor support from government		6.4
	Others		2.1
Technical	Lack of information or experience (general)	25	5.8
	Hydrogeology information		6.2
	Lack of installation technology		3.8
	Lack of heat pump makers		2.4
	Others		6.8
Total		100	100

GSHP = ground source heat pump, R&D = research and development.
Source: Authors.

1.6.3 Peculiar barriers hidden behind superficial barriers

As with geothermal power generation, there is no direct heat use and GSHP specialisation in Chinese universities.

1.6.4 Necessary innovations

Policy Aspect

There are aspects in policy that serve as major barriers to direct heat use/GSHP since there is no uniform national policy on economic incentives for them. Unbalanced local policies exist in different provinces or cities that make unbalanced growth for direct heat use and GSHP. There has been rapid growth in places with preferential policy. The Beijing government, for instance, promotes using clean energy for winter heating, with the government-subsidised geothermal power or GSHP replacing coal. Although the Hebei provincial government is learning from Beijing, it gives lesser subsidy.

<u>Social Aspect</u>

As with geothermal power generation, Chinese universities should set up geothermal specialisation to develop geothermal professionals.

<u>Legal Aspect</u>

Present environmental administrations usually rely on penalty but despise reward. Geothermal power utilisation should be encouraged and given economic or legal incentives. To promote winter clean heating in the northern China region, some local governments have planned to subsidise geothermal heating or ground source heat pump instead of coal heating. For rural areas planning to shift from coal use to geothermal power use, some GSHP companies are willing to undertake projects even if these would yield lesser benefits for them. Thus, the suggestion for local governments is to award economic or honorary incentives to the best projects.

<u>Fiscal Aspect</u>

Establishing geothermal risk fund is necessary, especially for hydrothermal-type geothermal well drilling due to certain risks involved in such undertaking. Providing loans of low interest, for example, is necessary for GSHP projects.

<u>Technical Aspect</u>

Reinjection for direct heat use and GSHP of groundwater circle has yet to fit the demand of fast growth. Mid-small installation companies have yet to possess the ability for operating reinjection. Proper training on reinjection technique should be popularised as it is necessary for sound development of geothermal energy development.

1.7 Benefits of direct use/GSHP in China

1.7.1 Mitigation of CO_2 emission (kg-CO_2/kW)

If the barriers are removed by innovations in 2025, the target geothermal direct use will have new installed heat capacity of 66,150 MW_t, which includes conventional heat use and GSHP. We can calculate the CO_2-emission reduction.

With installed heat capacity of 66,150 MWt,

The annual energy use (TJ) = MWt × Capacity Factor ÷ 0.03171,

For direct heat use: 18,000 MWt × 0.39 ÷ 0.03171 = 221,380 TJ,

For GSHP: 48,150 MWt × 0.27 ÷ 0.03171 = 409,980 TJ,

Total direct use equals the above put together: 221,380 + 409,980 = 631,360 TJ/year thermal energy used.

Then, 1 tonne of standard coal = 1,000 kg × 7,000 kcal/kg × 4186.8 J/kcal = 29.3×10^9 J,

It is, therefore, the equivalent 1 million tonnes of standard coal = 29,300 TJ,

Thus, we can calculate the annual energy saving in terms of coal equivalent:

631,360 TJ/year ÷ 29,300 TJ/(tonne_{ce}) = 21.55 million tonnes of standard coal.

In China, we use 1 tonne of standard coal = 2.386 tonnes of CO_2,

Thus, 21.55 million tonnes of standard coal × 2.386 = 51.42 million tonnes of CO_2,

Therefore, an additional 51.42 million tonnes of CO_2/year of emission reduction from geothermal direct heat use/GSHP.

1.7.2 New employment

Here, we analyse as an example the Nangong village of Fengtai district in Beijing. A total of 3,000 peasants living in the village were formerly engaged in field husbandry. Since drilling three geothermal wells in 2000–2006, the village has been hailed as 'the first geothermal village in China'. The agricultural economy has changed into geothermal economy. Except for the aged, children, and students, Nangong's young adult labour force are now employed at the geothermal site, working at various levels of geothermal integrated utilisation such as hot spring hotels, hot spring water world, hot spring fishing halls, etc. Agricultural technicians work in geothermal greenhouses and aquaculture halls. Maintenance workers serve in geothermal district heating and thermal water supply facilities. More people work in restaurants, shops, and supermarkets, etc. (Pan, 2003).

We now calculate benefits using results of the above case study. Two geothermal wells are used for production and one for reinjection. The production wells yield 72°C geothermal water with a total flow rate of 170 m^3/h. Because the production wells are not utilised round the clock for the whole year, their annual production is 120 million m^3.

The temperature of the geothermal water used ranges between 72°C and 15°C.

The annual energy used: 120 million m^3/year × 1,000 L/m^3 × (72–25)°C × 4,186.8 J/L.°C = 286.37 TJ.

With an estimated 40% of young adults forming the labour force in the village, the geothermal business has 1,200 employees.

Consequently, the annual energy used is 286.37 TJ equals 1,200 employees.

286.37 TJ ÷ 1,200 employees = 0.239 TJ/employee.

Thus, 0.239 TJ/year of geothermal energy used equals one employee.

The Nangong village, however, is implementing rural-level employment, which means 'low salary, high employment'. Compared with other hot spring business examples, the Nangong index is rather low. Therefore, we correct nationwide geothermal employment level. The corrected index is 0.5 TJ/employee.

For direct heat use of 221,380 TJ (see Table 3.1.2-2) in 2025: 221,380 TJ ÷ 0.5 TJ/employee = 443,000 employees.

For GSHP of 409,980 TJ (see Table 3.1.2-2) in 2025: 409,980 TJ ÷ 0.5 TJ/employee = 820,000 employees.

Thus, with direct heat use and GSHP: 443,000 + 820,000 = 1,263,000 new employees.

1.7.3 Direct economic benefits

Taking Beijing as model, each 1 m^3 of geothermal water could create: district heating – CNY10; domestic hot water supply – CNY8–12; greenhouse – CNY15; hotel with bath – CNY53, hot spring resort – CNY293 (BBLR, 2006). Beijing gets direct economic benefits of CNY1.1 billion based on the above values and corresponding proportions used.

Meanwhile, Beijing exploits geothermal water at 7.72 million m^3 per year with temperature range of 37–89°C.

The total used geothermal energy can be calculated: 720 million m^3/year $\times$ 1,000 L/m^3 $\times$ (37+89)/2 °C $\times$ 4,186.8 J/L.°C = 2,036 TJ TJ.

We use the relationship for 2,036 TJ as equivalent to CNY1.1 billion of benefits.

CNY1.1 billion ÷ 2,036 TJ = CNY0.54 million/TJ.

We use this index to calculate direct economic benefits in 2025.

The 2025 target of direct use will be 221,381 TJ (see Table 3.1.2-2).

So, 221,381 TJ ÷ CNY0.54 million/TJ = CNY410.0 billion = US$64.0 billion.

(3) Benefits from GSHP

Space heating can collect heating fee from users.

In North China, the heating fee is CNY25/m^2. This can be used as the average rate.

The 2025 target for GSHP will reach 1,500 million m^2.

So, 1,500 million m^2 $\times$ CNY25/m^2 = CNY37.5 billion = US$5.8 billion.

1.7.4 Indirect economic benefits

We use the same case study of the Nangong village in Fengtai district, Beijing. Indirect economic benefits come from restaurants, shops, supermarkets, and assorted businesses and services. There are more employees in such businesses than those in direct use business. Indirect economic benefits are about 1.5–3 times more than direct economic benefits.

1.7.5 Regional development

Nangong was a typical rural village before. After implementing geothermal power economy, the village has thoroughly changed its old features with 200,000 m^2 of commercial and residential buildings forming a block of streets, featuring assorted restaurants, shops, supermarkets, schools, banks, telecom companies, etc. Indeed, geothermal development can drive regional development.

1.8 Summary of barriers to and benefits of direct use/GSHP

- For geothermal direct heat use/GSHP in China, the first barriers are policy barriers and the second are technical barriers. Peculiar barriers hidden behind superficial barriers include the lack of geothermal specialisation in universities.

- A necessary innovation suggested for removing barriers is to have a uniform national policy on economic incentives for direct heat use and GSHP. It affects developer's positivity and reduces speed of growth.

- A benefit for geothermal direct heat use/GSHP is the reduction of CO_2 emission. New direct heat use/GSHP of 66,150 MW_t would contribute 51.42 million tonnes of CO_2 reduction annually. Also, it will increase employment to about 1,263,000 persons. The direct economic benefit would be US$5.8 billion annually. Indirect benefits would be about 1.5–3 times more than that of direct economic benefits. They will push regional development and create prosperous local economy.

The quantified barriers to and benefits of direct heat use/GSHP are in Table 3.1.8-1.

Table 3.1.8-1. Quantified Barriers to and Benefits of Direct Heat Use/GSHP

	Policy	**Social**	**Legal**	**Fiscal**	**Technical**	**Total**
Barrier Contributions as Results of Census (%)	26%	17%	17%	15%	25%	100%
Expected Additional Geothermal Capacity if Barriers are Removed (MW_t)	17,199.0	11,245.5	11,245.5	9,922.5	16,537.5	66,150
Expected Additional Annual Energy Used (TJ)	164,154	107,331	107,331	94,704	157,840	631,360
Expected Annual CO_2 Mitigation (k tonne-CO_2)	13,377.0	8,746.5	8,746.5	7,717.5	12,862.5	51,450
Expected Annual Toxic Gas (NO_x and CO_x) Mitigation (tonne)	128,960	84,320	84,320	74,400	124,000	496,000
Expected Annual New Employment for the Plant	328,380	214,710	214,710	189,450	315,750	1,263 k
Expected Direct Effects to l Local Economy (million US$)	1,508	986	986	870	1,450	5,800
Expected Indirect Effects to Local Economy (million US$)	3,393	2,218	2,218	1,958	3,263	13,050

CO_2 = carbon dioxide, CO_x = carbon oxides, GHSP = ground source heat pump, MW_t = megawatt thermal, NO_x = nitrogen oxides, TJ = terajoule.

Source: Authors.

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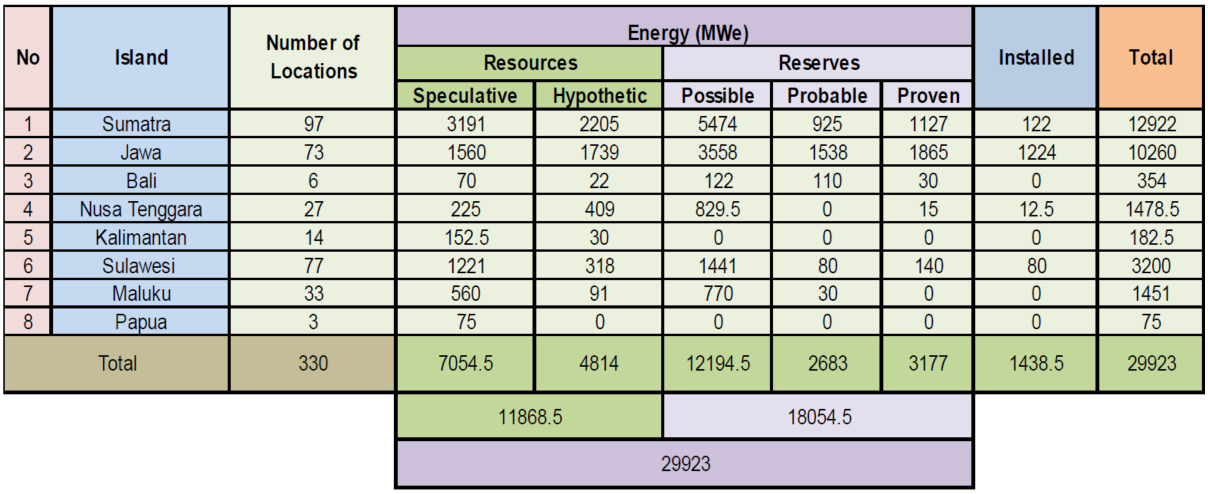
2. Indonesia

2.1 Current situation of geothermal energy use and national policy

By 2015, Indonesia had an installed capacity of 1,438.5 MW from 11 geothermal fields: Kamojang, Darajat, Wayang Windu, Patuha, Gunung Salak, Dieng, Ulubelu, Sibayak, Lahendong, Ulumbu, and Mataloko. These fields may still be able to generate additional power since they have bigger reserves ready for development. Moreover, additional power may be produced by private developers from geothermal fields that are at development stage or exploration stage, possibly generating about 5,800 MW_e from both probable and proven reserves by 2025 (Table 3.2.1-1).

Table 3.2.1-1. Geothermal Potential in Indonesia, as of April 2016



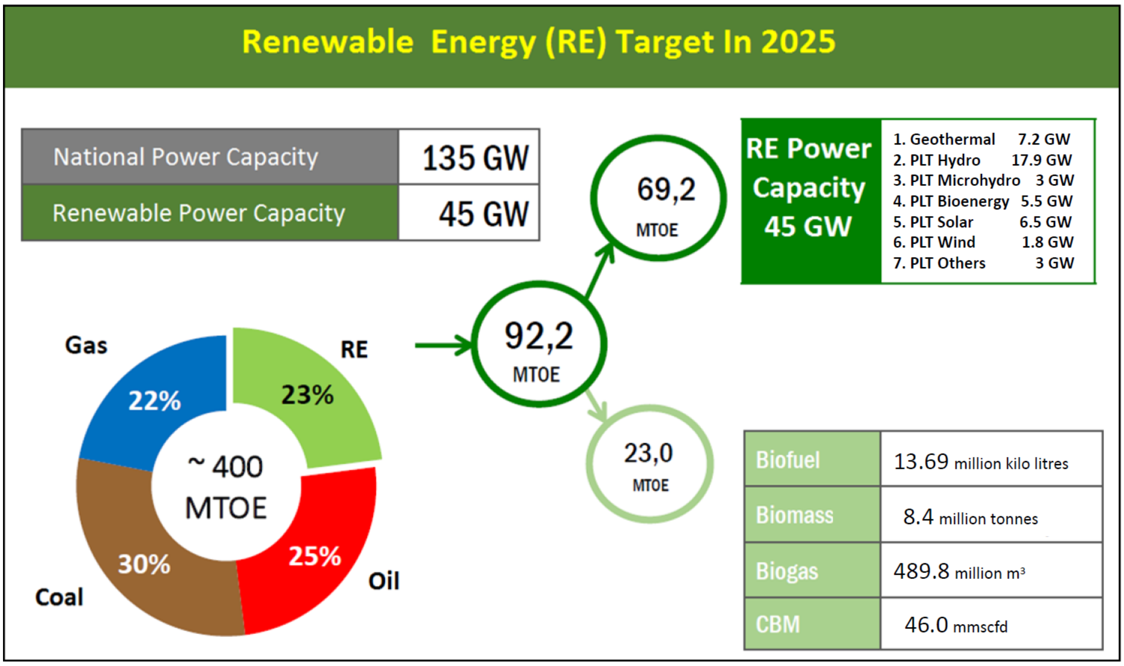
No	Island	Number of Locations	Energy (MWe)					Installed	Total
			Resources		Reserves				
			Speculative	Hypothetic	Possible	Probable	Proven		
1	Sumatra	97	3191	2205	5474	925	1127	122	12922
2	Jawa	73	1560	1739	3558	1538	1865	1224	10260
3	Bali	6	70	22	122	110	30	0	354
4	Nusa Tenggara	27	225	409	829.5	0	15	12.5	1478.5
5	Kalimantan	14	152.5	30	0	0	0	0	182.5
6	Sulawesi	77	1221	318	1441	80	140	80	3200
7	Maluku	33	560	91	770	30	0	0	1451
8	Papua	3	75	0	0	0	0	0	75
Total		330	7054.5	4814	12194.5	2683	3177	1438.5	29923
			11868.5		18054.5				
			29923						

MWe = megawatt electricity.

Source: Geothermal Department of Indonesia, 2016.

Taking into account all national potentials to fulfill energy needs and considering the barriers and the alternative solutions for them, the Indonesian government issued in 2014 a national energy plan for 2015–2050 aimed at providing a detailed programme of implementing a national energy policy. In the policy, renewable energy should contribute 23% to the energy mix in 2025 from the current 7%. For the electricity sector, the power capacity that should be achieved by utilising renewable sources is about 45 GW by 2025.

Figure 3.2.1-1. Renewable Energy Development Plan of Indonesia Until 2025



National Power Capacity	135 GW
Renewable Power Capacity	45 GW

1. Geothermal 7.2 GW
2. PLT Hydro 17.9 GW
3. PLT Microhydro 3 GW
4. PLT Bioenergy 5.5 GW
5. PLT Solar 6.5 GW
6. PLT Wind 1.8 GW
7. PLT Others 3 GW

Biofuel	13.69 million kilo litres
Biomass	8.4 million tonnes
Biogas	489.8 million m^3
CBM	46.0 mmscfd

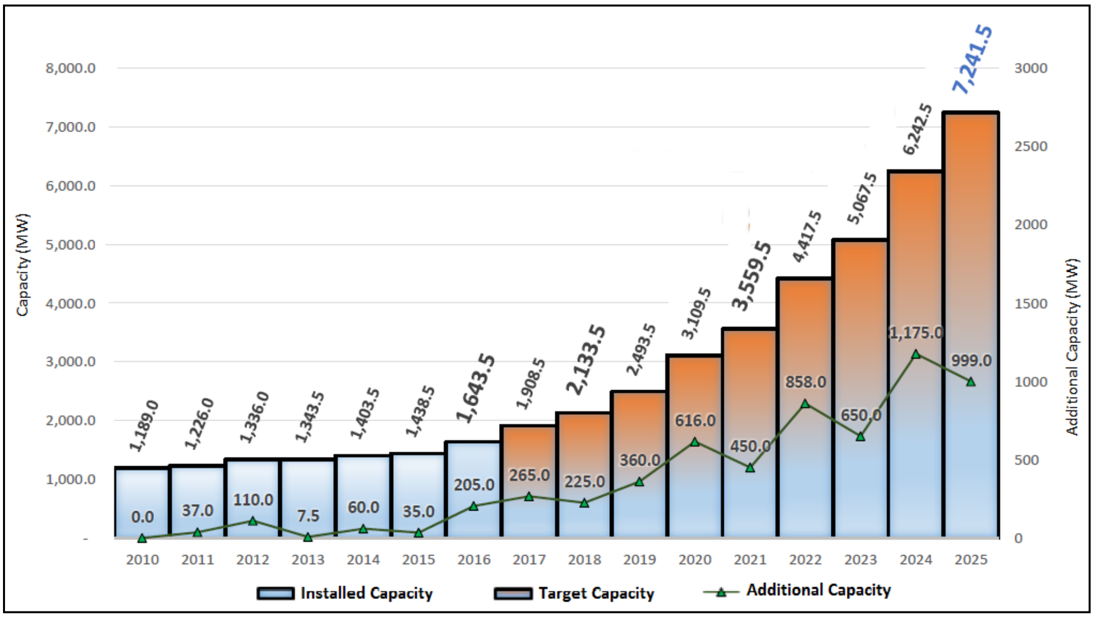
CBM = coal bed methane, GW =gigawatt, m^3 = cubic metre, mmscfd = million standard cubic feet per day, MTOE = million tonnes of oil equivalent, RE = renewable energy.

Source: Ministry of Energy and Mineral Resources, 2016.

For the geothermal energy sector, a stepwise plan has been drawn up to achieve a total installed capacity of 7,200 MW in 2025 where additional power and total power capacity for each year is indicated (Figure 3.2.1-2).

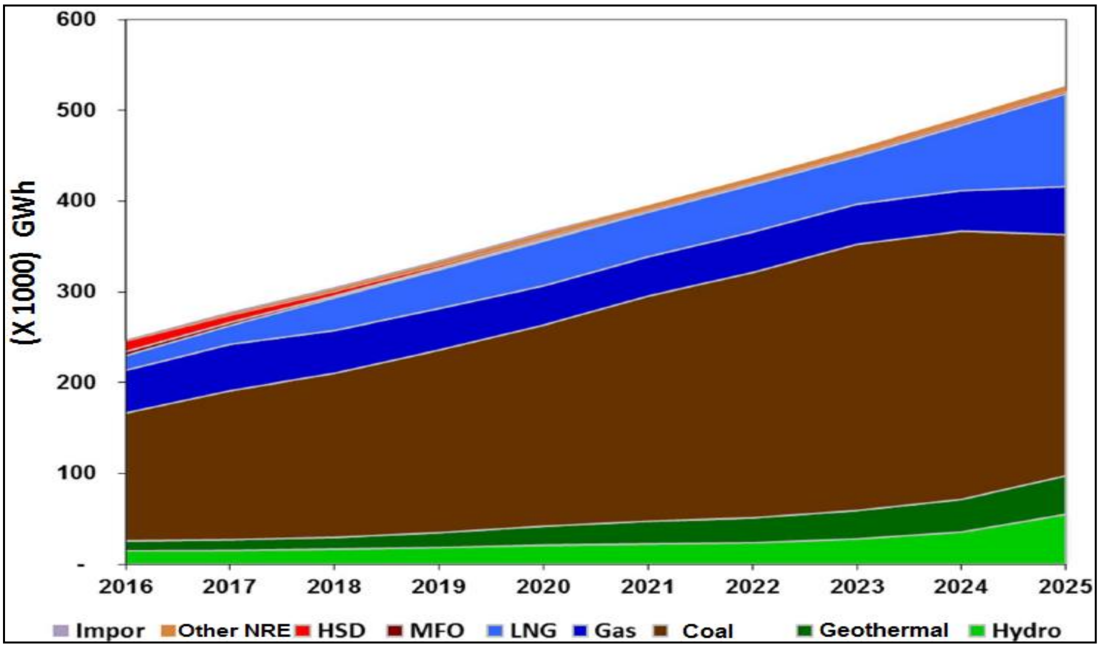
Figure 3.2.1-3 shows the contribution of geothermal power to the national electricity mix. Although coal is still a dominant source in 2025, geothermal power and hydropower will be the most significant renewable energy sources in the national electricity mix.

Figure 3.2.1-2. Geothermal Power Development Plan in Indonesia Until 2025



MW = megawatt.
Source: Ministry of Energy and Mineral Resources, 2016.

Figure 3.2.1-3. Electricity Power Development Plan Until 2025



GWh = gigawatt hour, HSD = high speed diesel, LNG = liquefied natural gas, MFO = medium fuel oil, NRE = non-renewable energy, Impor = Imported fuels.

▲: Additional power for each year, ■: Total capacity.

Source: Department of Renewable Energy and Saving Energy, Indonesia, 2016.

To speed up geothermal energy development, the Indonesian government is conducting the following.

1) Government drilling (risk sharing by the government)

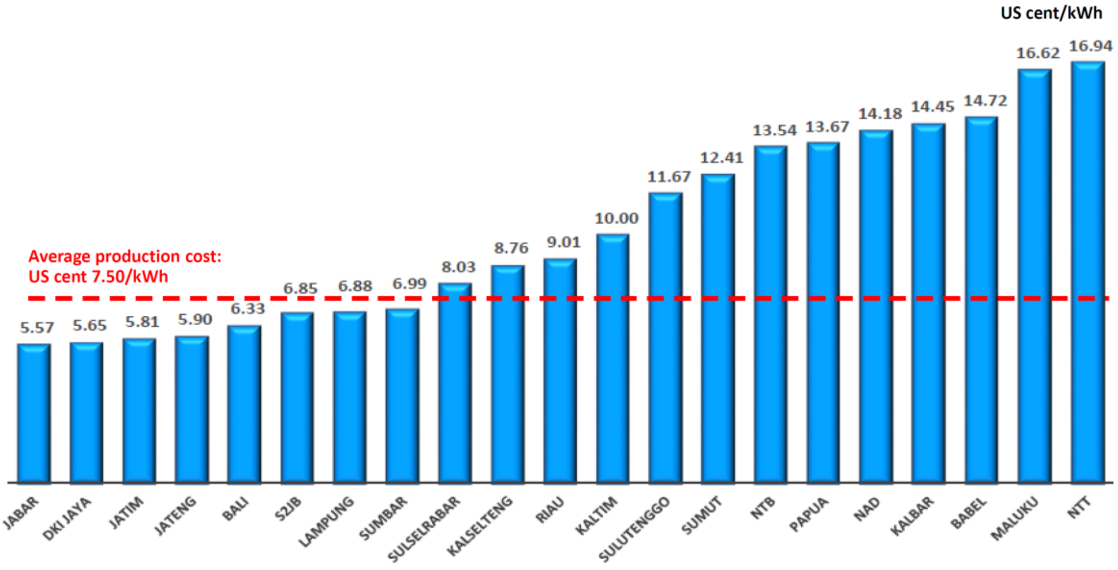
The Indonesian government has started to minimise production costs to lower electricity price. As geothermal exploration is a high-cost and risky phase, the government should take efforts to get involved in more advanced explorations. The government, however, tends to avoid use of the national budget for explorations. Thus, the government's geothermal exploration can be implemented by utilising contingent grants from international donors such as the World Bank and the Asian Development Bank. The government can also utilise the geothermal fund facility set up by the Ministry of Finance as a revolving fund for exploration. This fund, reserved in Multi Sarana Infrastruktur, a state investment company, is jointly managed by the Ministry of Energy and Mineral Resources and the Ministry of Finance. Should exploratory drilling be successful, the working area could be tendered and the winning bidder would refund the exploration cost and give a certain margin to Multi Sarana Infrastruktur. This revolving fund could be sourced from the national budget for use by government exploration institutions such as Geological Agency in conducting slimhole exploration drillings, which are much cheaper but effective tools for resource confirmation. Similar to the above fund mechanism, the tender winner should refund the government.

2) Feed-in tariff

Many developers in Indonesia are willing to spend for exploration cost for geothermal power if the return on their investment is attractive. The government has formulated a new partial feed-in tariff (FiT) for geothermal energy based on several determinants such as power capacity, regional zoning, accessibility, and power generation technology. The government, however, issued Minister of Energy and Mineral Resources Regulation No 12/2017 which states that by January 2017, geothermal price is a FiT based on *biaya pokok produksi* (regional production cost) of Perusahaan Listrik Negara (PLN) or State Electrical Power Company. Based on this regulation, price of geothermal power is a maximum 100% of *biaya pokok produksi* above the national average and the rest will be negotiated between developers and PLN.

Until now, production cost is based on the PLN production cost in 2015 (Figure 3.2.1-4). With reference to this figure, the average cost is US$7.50/kWh. The higher costs are in the eastern parts of Indonesia. Therefore, in terms of *biaya pokok produksi*, the eastern parts should be more attractive for geothermal energy investment than the western parts.

Figure 3.2.1-4. Production Cost of Perusahaan Listrik Negara in 2015

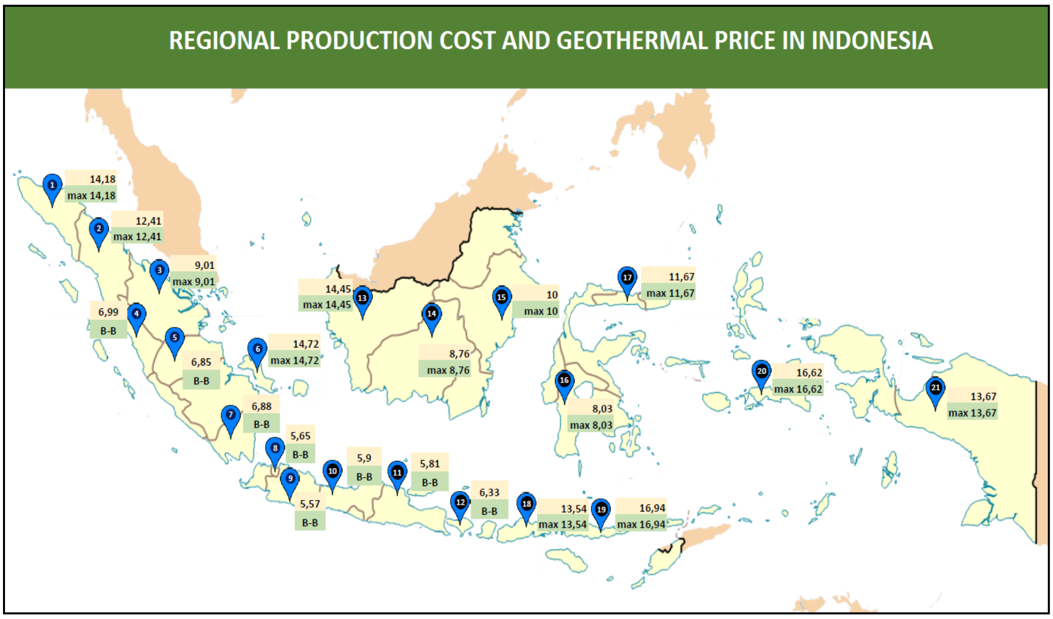


kWh = kilowatt-hour.

Note: The production cost of PLN varies based on regional zoning. The average cost is US$0.75/kWh.

Source: Ministry of Energy and Mineral Resources, 2016.

Figure 3.2.1-5. Regional Geothermal Power Price Based on Production Cost of Perusahaan Listrik Negara, 2015



max = maximum.

Source: Ministry of Energy and Mineral Resources, 2016.

2.2 Target capacity estimation for geothermal power

Indonesia is an archipelago where the population of each island is not homogenous and where economic growth rates vary, causing variations in electricity demands. The growth of electricity demand in Indonesia from 2015 to 2024 is shown in Table 3.2.2-1.

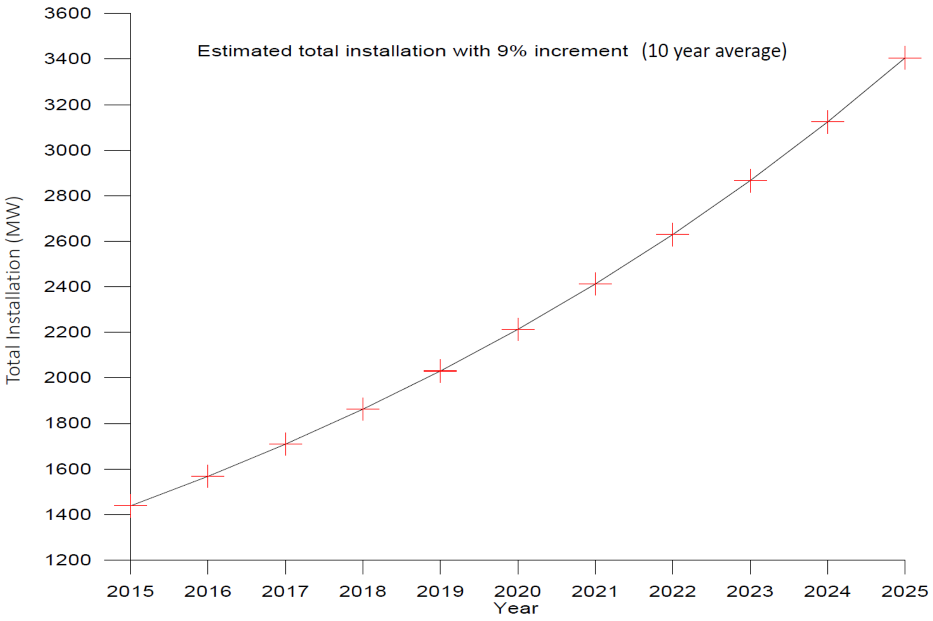
Table 3.2.2-1. Estimated Increase in Rate of Electricity Consumption in Indonesia

Area	Increase in Rate of Electricity Consumption (in %)					
	2015	2016	2018	2020	2022	2024
Indonesia	8.7	9.0	8.9	8.4	8.7	8.8
Java–Bali	7.6	7.8	7.6	7.5	7.9	7.8
Eastern Part	12.9	14.5	14.2	9.9	9.2	9.2
Sumatra	11.7	11.1	11.1	11.2	11.8	11.2

Source: PT PLN (national electric power company of Indonesia), 2014.

Realistic development of geothermal electricity until 2025 should start from fields with reserves confirmed by exploration drilling, as indicated by probable reserves of about 2,600 MW_e and proven reserves of about 3,100 MW_e (Table 3.2.1). The reserves, mostly located in Java and Sumatra, are now being utilised up to 1438.5 MW_e of their capacity, with about 4,200 MW_e more for utilisation. If the reserves are developed with an assumed annual increase rate of 9%, a capacity of 3,400 MW_e can be utilised by 2025 (Figure 3.2.2-1).

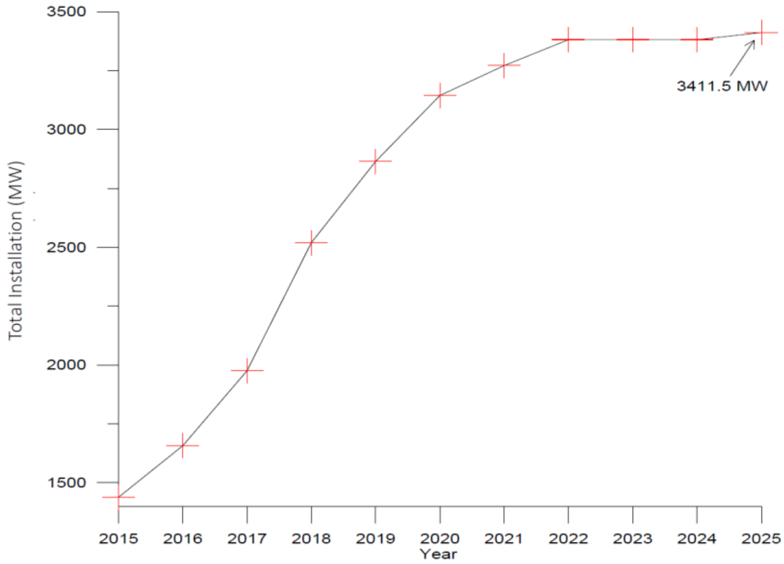
Figure 3.2.2-1. Prediction of Geothermal Electricity Development in Indonesia



Note: Prediction uses available probable and proven reserves with increase rate of 9%.
Source: Government Regulation No. 79/2014, Indonesia, 2014.

The government, however, has a policy, through Government Regulation No. 79/2014, of maximising the use of renewable energy sources, where new and renewable energy is projected to contribute 23% of the national demands (Figure 3.2.2-2).

Figure 3.2.2-2. Government's Plan on Geothermal Electricity Development in Indonesia Using Available Probable and Proven Reserves



MW = megawatt.
Source: Government Regulation No. 79/2014, Indonesia, 2014.

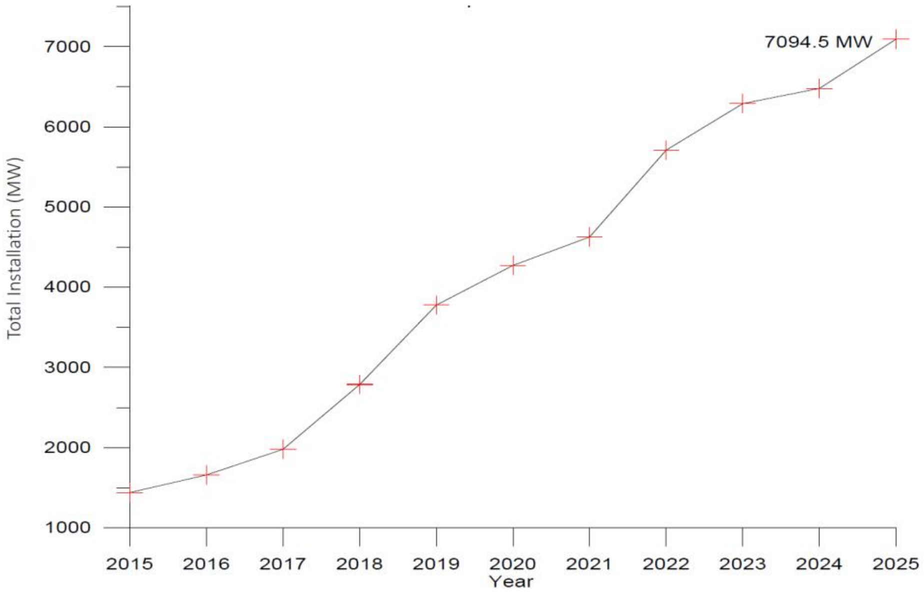
To maximally take advantage of the available probable and proven geothermal reserves, it is necessary to increase their rate of development. With 15% increase rate, a 5,800-MW_e capacity will be available by 2025 (Figure 3.2.3).

Figure 3.2.2-3. Prediction of Geothermal Electricity Development in Indonesia Using Available Probable and Proven Reserves with Increase Rate of 15%

MW = megawatt.
Source: Government Regulation No. 79/2014, Indonesia, 2014.

To increase the share of geothermal energy in the national energy mix, the government plans to build a geothermal power plant using not only probable and proven reserves but also prospective possible reserves, the lowest level of reserves which can be confirmed by surface exploration without drilling. By utilising some prospective possible reserves as well, the government is projecting to develop 7,000 MW of geothermal power for electricity by 2025 (Figure 3.2.4).

Figure 3.2.2-4. Government Plan on Geothermal Electricity Development in Indonesia Using Available Probable and Proven Reserves and Some Prospective Possible Reserves



MW = megawatt.

Source: Republic of Indonesia, 2014.

2.3 Barriers to geothermal power generation, and necessary innovations

2.3.1 Barriers to geothermal power generation

Inquiry on barriers to geothermal power generation in Indonesia was made during the 11th Asian Geothermal Symposium in Chiang Mai, Thailand, in November 2016. International experts verified barriers based on a presentation by an Indonesian member of this project.

According to the results of inquiry, lack of economic incentives, high exploration cost, lack of experience in geothermal power development, lack of experts among new developers, and environmental problems are the five highest barriers to geothermal power development in Indonesia (Figure 3.2-1). Also considered as high barriers are lack of business models, lukewarm public acceptance, and existing legislation/business mechanism.

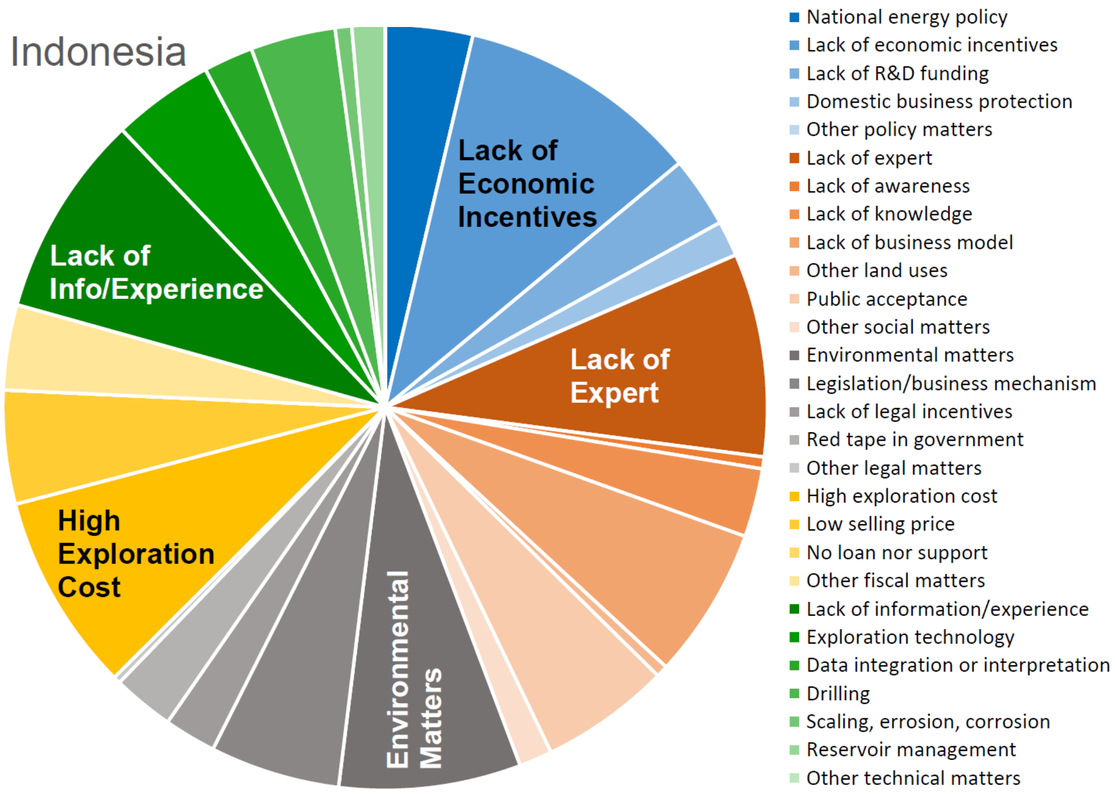
Electricity in Indonesia is mostly subsidised in all regions regardless of its source. However, even as a clean and renewable source of energy, geothermal power has no economic value. Thus, in most cases, geothermal power has to compete with cheaper fossil energy sources such as coal and natural gas, especially in major islands such as Java and Sumatra. Faced with hard competitions from cheaper sources, geothermal power needs fiscal and/or non-fiscal instruments as economic incentives.

The high risk and cost of geothermal exploration stage is also a problem in Indonesia since the government still puts the risk on developers alone, except for preliminary surveys. Some domestic experts expect the government to take more risks by conducting deep exploration drillings. Others are of the opinion that developers may take the risk but should have better price of geothermal power in return.

Among domestic developers, especially newcomers, many have inadequate experience in geothermal power development. Most of those licenced for development of new geothermal areas have often failed to execute the exploration phase within the allocated period as they lack capacity or expertise to carry out the task. This is also caused by inadequate criteria set by the government in qualifying bidders for projects.

Since many prospective geothermal resource sites are located in forest areas, geothermal power projects tend to occupy protected and/or conservation areas. This is a complicated problem and may take a long way of being solved. Another major environment-related problem is public acceptance. Most communities around geothermal project areas do not understand what geothermal energy is. Any incident occurring in an oil and gas exploration area is enough to frighten people and arouse antipathy towards exploration activities.

Figure 3.2-1. Results of Inquiry to Outside Experts on Barriers to Geothermal Power Generation in Indonesia



Note: Major barriers are labelled.
Source: The study team.

2.3.2 Innovative ideas to remove barriers

The Indonesian government has already been conducting risk-sharing drillings and FiT as innovatice ideas to remove barriers (see Section 3.2.1). Results of these policies may be obtained in a few years. Additionally, the following are considered in this project as innovative ideas to remove barriers.

1) Business mechanism

In the last 10–15 years, our experience in geothermal power development tells us that a good business mechanism is very important. The lack of it produces none of best-practice developers and induces lack of expertise. The mechanism problem is now minimised by the issuance of stronger geothermal energy laws and better government regulations to assure that there would be more qualified developers with necessary expertise.

2) Education programmes to strengthen expertise

To strengthen expertise, geothermal energy educational programmes have been established in major domestic universities. Vocational training on geothermal energy development is also being advocated at a government institution under the Ministry of Energy and Mineral Resources.

3) Environmental matters

Overlapping problems between forestry areas and geothermal energy development areas have been solved by the issuance in June 2016 of environmental service regulations for geothermal projects in forestry areas. However, technical mechanisms and coordination between the Ministry of Forestry and MEMR on implementing the regulations are crucial to smoothly solve problems.

4) Public acceptance

Problems of public acceptance should be minimised by disseminating information on the benefits of geothermal energy development in communities around areas of development. Since the issuance of the Geothermal Law 21/2014, the development of geothermal power under the authority of the central government has continued. However, involving local governments in information dissemination is very important since they have wider access to communities.

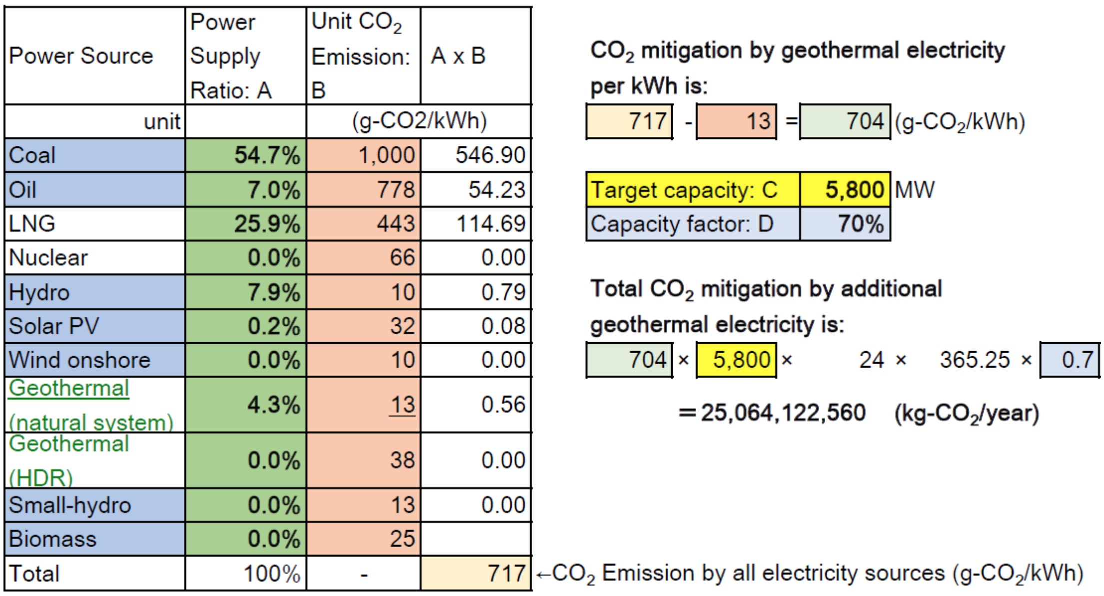
2.4 Benefits of geothermal power generation in Indonesia

The benefits of geothermal power generation in Indonesia were quantitatively analysed following the procedure in Section 2.4.2.1 b).

1) CO_2 mitigation

CO_2 mitigation by an additional geothermal capacity of 5,800MW is calculated as 25,064,122,560 kg-CO_2/year (Figure 3.2.4-1).

Figure 3.2.4-1. CO_2 Mitigation by Additional Geothermal Power



Power Source	Power Supply Ratio: A	Unit CO_2 Emission: B	A x B
unit		(g-CO2/kWh)	
Coal	**54.7%**	1,000	546.90
Oil	**7.0%**	778	54.23
LNG	**25.9%**	443	114.69
Nuclear	**0.0%**	66	0.00
Hydro	**7.9%**	10	0.79
Solar PV	**0.2%**	32	0.08
Wind onshore	**0.0%**	10	0.00
Geothermal (natural system)	**4.3%**	13	0.56
Geothermal (HDR)	**0.0%**	38	0.00
Small-hydro	**0.0%**	13	0.00
Biomass	**0.0%**	25	
Total	100%	-	717

←CO_2 Emission by all electricity sources (g-CO_2/kWh)

CO_2 mitigation by geothermal electricity per kWh is:

717 - 13 = 704 (g-CO_2/kWh)

Target capacity: C	**5,800**	MW
Capacity factor: D	**70%**	

Total CO_2 mitigation by additional geothermal electricity is:

704 × 5,800 × 24 × 365.25 × 0.7

= 25,064,122,560 (kg-CO_2/year)

CO_2 = carbon dioxide, g-CO_2 = gramme of carbon dioxide, HDR = hot dry rock, kWh = kilowatt-hour, LNG = liquefied natural gas, MW = megawatt, PV = photovoltaics.
Source: Authors. Data source for column A: PwC Indonesia, 2017; B: Benjamin K. Savacool, 2008.

2) Other benefits

Other benefits are calculated following the procedure for target capacity in Section 2.4.2.1. Expected benefits by removal of each category of barriers are calculated based on barrier contributions (Table 3.6.3-1). Note that these barriers are interrelated and removal of one barrier may stop further geothermal power development. Nevertheless, this estimation may give policymakers insights on the benefits to be gained by barrier removal. Table 3.2.4-1 summarises the calculated benefits.

Table 3.2.4-1. Direct Benefits and (Expected) Indirect Benefits from Geothermal Power Generation by Removal of Barriers

Item		Unit	Barriers significance and benefits by removal of each barrier					Total benefit	Remarks
			Policy	Social	Legal	Fiscal	Technical		
Barrier significance		%	18	26	18	17	21	100	
Target capacity		MW	1044	1508	1044	986	1218	5,800	W
Target capacity factor		%						70%	Cf
a) Power generation		MWh/year	6,406,193	9,253,390	6,406,193	6,050,293	7,473,892	35,589,960	W x 24 x 365.25 x Cf
b) Annual fuel saving	by oil	barrel/year	8,108,738	11,712,621	8,108,738	7,658,252	9,460,194	45,048,542	11,096 W x Cf
	by LNG	kg/year	962,568,104	1,390,376,151	962,568,104	909,092,099	1,122,996,122	5,347,600,580	1,317,143 W x Cf
		Million Btu/year	47,414,082	68,487,008	47,414,082	44,779,967	55,316,430	263,411,569	0.04926 W
c) Saving foreign currency	by oil	US$/year	486,524,254	702,757,255	486,524,254	459,495,128	567,611,629	2,702,912,520	60.0 US$/Barrel
	by LNG	US$/year	237,070,412	342,435,040	237,070,412	223,899,834	276,582,148	1,317,057,846	5.0 US$/Btu
Electricity sales	developer's	US$/year							
d) CO_2 mitigation		(tonne-CO_2/year)	4,511,542	6,516,672	4,511,542	4,260,901	5,263,466	25,064,123	from "CO_2" Table
e) Local employment		persons	2,842	4,106	2,842	2,684	3,316	15,791	2.71W+73
f) Saving lands compared to solar PV		m^2	116,424,792	168,169,144	116,424,792	109,956,748	135,828,924	646,804,400	111,518 W
(g) Expected profit of additional businesses		US$/year	1,867,173	2,697,028	1,867,173	1,763,441	2,178,369	10,373,184	1,788 W
(h) Expected local employee by additional businesses		persons	522	754	522	493	609	2,900	0.5 W
(i) Expected local economic effect of the additional		US$/year	2,334,384	3,371,888	2,334,384	2,204,696	2,723,448	12,968,800	2,236 W

Btu = British thermal unit, CO_2 = carbon dioxide, LNG = liquefied natural gas, m^2 = square metre, MW = megawatt, MWh = megawatt hour, PV = photovoltaics.
For symbols *Cf* and *W*, please refer to equation (1) in section 2.4.2.1.
Source: Authors.

3) Promotion of the development of eastern Indonesia

Here is another benefit that is not quantified but should be described.

Indonesia’s eastern part has many volcanic islands with good quality of geothermal resources. About 1,600 MW of geothermal power is generated in Java, Sumatra, and North Sulawesi. A small portion is generated in Flores Island, one of the small volcanic islands in the eastern part.

However, despite the potential in the eastern part of Indonesia, geothermal power development is not attractive due to high tariff, small market, and inadequate infrastructure. Therefore, promoting geothermal power development in the eastern region should mean lower tariff, particularly for Flores Island and its neighbouring islands in East Nusa Tenggara, which have the highest tariff (US$16.94/kWh) in the region.

2.5 Summary of barriers to and benefits of geothermal power generation

The highest barriers to geothermal power generation in Indonesia are lack of economic incentives, high exploration cost, lack of experience and expertise of new developers, and environmental problems.

The suggested innovative ideas to remove barriers to geothermal energy use in Indonesia, including the existing ones, are as follows:

- Risk sharing by government in explorations
- Feed-in tariff
- Good business mechanism
- Education programmes to strengthen expertise
- Environmental incentives
- Public acceptance
- Future targets

Note that the benefits of geothermal energy use in Indonesia include promotion of the development of eastern Indonesia, CO_2 emission mitigation, and creation of local employment and new businesses.

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3. Japan

3.1 Current situation of geothermal energy use and national policy

3.1.1 Brief history of geothermal power generation

The Matsukawa power plant, the first geothermal power plant in Japan, began operation in 1967 with a capacity of 9.5 MW for the use of Japan Metals & Chemicals Co. Ltd. Triggered by the oil crises in the 1970s, the Agency of Natural Resources and Energy, under the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry or METI) established the New Energy Development Organization (at present, the New Energy and Industrial Technology Development Organization) in 1980. This organisation then conducted nationwide resource assessments and geothermal technology development and subsidised geothermal drillings through the private sector. By 1999, 17 geothermal power plants were already developed with a total capacity of 530 MW.

After 1999, no new geothermal power plants opened for more than a decade mainly because of legal and socio-economic barriers. With the federal policy pushing for nuclear power at that time, no improvement was made on the laws and regulations that limit cost competitiveness of geothermal power. Only certified electric companies could generate and sell electricity so that the business model for geothermal power developers was merely to sell modestly priced geothermal steam to electric companies. Other barriers to geothermal development at the time were the restrictions on natural parks, where 80% of geothermal resources are found, and negative campaigns by hot spring owners. Many property owners running *onsen* or hot spring bathing facilities and traditional inns were concerned about eventual degradation of their springs due to geothermal energy development. Their campaigns against geothermal energy development resulted in delays or discontinuation in the issuance of geothermal drilling permission by the local government. Thus, the private sector found uneconomical the geothermal energy business even with government subsidies for drilling.

In summary, the three major barriers to geothermal energy development were 1) regulations on natural parks, 2) high development risk and cost, and 3) negative campaigns by hot spring owners.

However, after the nuclear accident caused by the great east Japan earthquake in 2011, the first two barriers have been somewhat removed. The federal government has changed several regulations on natural parks (Nature Conservation Bureau, 2015) and has given new economic incentives – through Japan Oil, Gas and Metals National Corporation, a funding agency of METI – to geothermal power development such as subsidies for exploration or drilling and debt guarantee for construction (JOGMEC, 2016). The liberalisation of the electricity market, which was accelerated after the nuclear accident, has also encouraged geothermal developers. Since April 2016, the Cabinet Office has decided to fully liberalise rights for generation and sales of electricity so that any geothermal power developer can generate and sell electric power.

Although resistance of hot spring owners may not be easily mitigated by government regulations, the Ministry of Environment (MOE), in 2014, made a new guideline for geothermal drilling. It indicates standard procedure of discussion amongst stakeholders and a time limit for issuing drilling permission (Nature Conservation Bureau, 2014) to help private developers. Given such support from the government, the private sector has started moving towards geothermal power development. Since 2011, dozens of small geothermal power plants have been installed with total capacity of approximately 10MW. Two bigger power plants (>10MW each) will begin operation in 2019.

3.1.2 Current energy policy and energy mix

In July 2015, METI released the Long-Term Energy Supply–Demand Outlook (METI, 2015; ANRE, 2016), based on the 4th Strategic Energy Plan of Japan, which emphasises growth of renewable energy use. According to this report, electricity demand in 2014 was 966.6 TWh and is expected to be 980.8 TWh in 2030 with comprehensive energy saving. Geothermal power is expected to share approximately 1.0% (10.65 TWh) of total power supply by 2030. It is a rather modest target compared to other renewables, mainly because of its long lead time and other social issues. Still, this modest target is a challenge to geothermal power developers to triple their capacity from the current one.

Geothermal power currently contributes 0.2% to the national power supply in Japan with a total installed capacity of 520 MW_e as of July 2016 (Japan Geothermal Association, 2016).

Table 3.3.1-1. Electric Power Source Mix in Japan: Before and After the Nuclear Accident in 2011, and Target in 2030

	2010 (Just Before Nuclear Accident)	2014 (For Total, 2013)	2030 (Target)
Total power demand		966.6 TWh	980.8 TWh
Coal	25.0 %	31.0 %	~26 %
Oil	6.6 %	10.6 %	~3 %
LNG	29.3 %	46.2 %	~27 %
Other Gases	0.9 %	0 %	0 %
Nuclear	28.6 %	0 %	~20–22 %
Hydro	8.5 %	9.0 %	~9 %
Other Renewables **(Geothermal)**	1.1 % (0.25 %)	3.2 % (0.2 %)	~13–15 % (1 %)

LNG = liquefied natural gas, TWh = terawatt hour.
Source: Ministry of Economy, Trade and Industry, Japan, 2015.

3.2 Target capacity estimation for geothermal power and direct use

3.2.1 Estimation of target potential in 2025

The potential geothermal power supply was estimated by MOE (2010) based on the survey conducted by National Institute of Advanced Industrial Science and Technology (2009). The MOE report in 2010 shows the total potential for flash power plant systems (over 150°C) of 23,570 MW_e including national park areas. The practical potential of the region outside national parks that has economic feasibility of less than ¥20/kWh is 2,200 MW_e. It also shows the total potential for binary systems (120°C–150°C) of 1,080 MW_e (including national park areas) with their practical potential of 200 MW_e.

MOE's estimated geothermal potential for economic exploitation includes regions inside national parks within 1.5 km from the boundary. The potential of resources over 150°C and 120°C–150°C are 6,360 MW_e and 330 MW_e, respectively. Our estimation is based on these figures.

Table 3.3.2-1. Total Geothermal Potential and Economically Feasible Geothermal Potential

	Total Potential (Including All National Parks)	Economically Feasible Potential Outside National Parks	Economically Feasible Potential Including National Parks Within 1.5 km from the Boundary
150 °C<	23,570 MW_e	2,200 MW_e	6,360 MW_e
120–150 °C	1,080 MW_e	200 MW_e	330 MW_e

MOE = Ministry of Environment, MW_e = megawatt electric.
Source: Ministry of Environment, 2011.

In July 2015, METI released the Long-Term Energy Supply–Demand Outlook (METI, 2015) based on the 4th Strategic Energy Plan of Japan. In this report, geothermal power generation is estimated to supply 1.0% of total power generation in Japan (1,065 TWh) in 2030. This geothermal power generation (approximately 10.6 TWh) is approximately equivalent to power capacity of 1,550 MW_e. Since the current capacity in Japan is 520 MW_e, the additional capacity would be 1,030 MW, which would be our target value.

However, in this estimation, METI mainly considers flash systems with resources of 150°C or higher but does not consider the resources whose temperature is lower than 150°C. In order to consider all possibilities for our target, we should add resources whose temperature is lower than 150°C. We assume that resources in temperature range of 120°C–150°C would be economically feasible for binary systems. Based on MOE (2011), the potential, including inside national parks within 1.5 km from the boundary, in this temperature range is 330 MW_e.

Thinking that 1,030 MW_e, the target value for 150°C or higher, is approximately 16% of the economically feasible potential, including a part of national parks, we define the target value for resources of 120°C–150°C as 53 MW_e, which is 16% of the potential in that temperature zone.

In summary, we propose the additional geothermal power plant target of 1,083 MW_e (1,030 + 53 MW_e).

3.2.2 Estimation of target potential in 2050

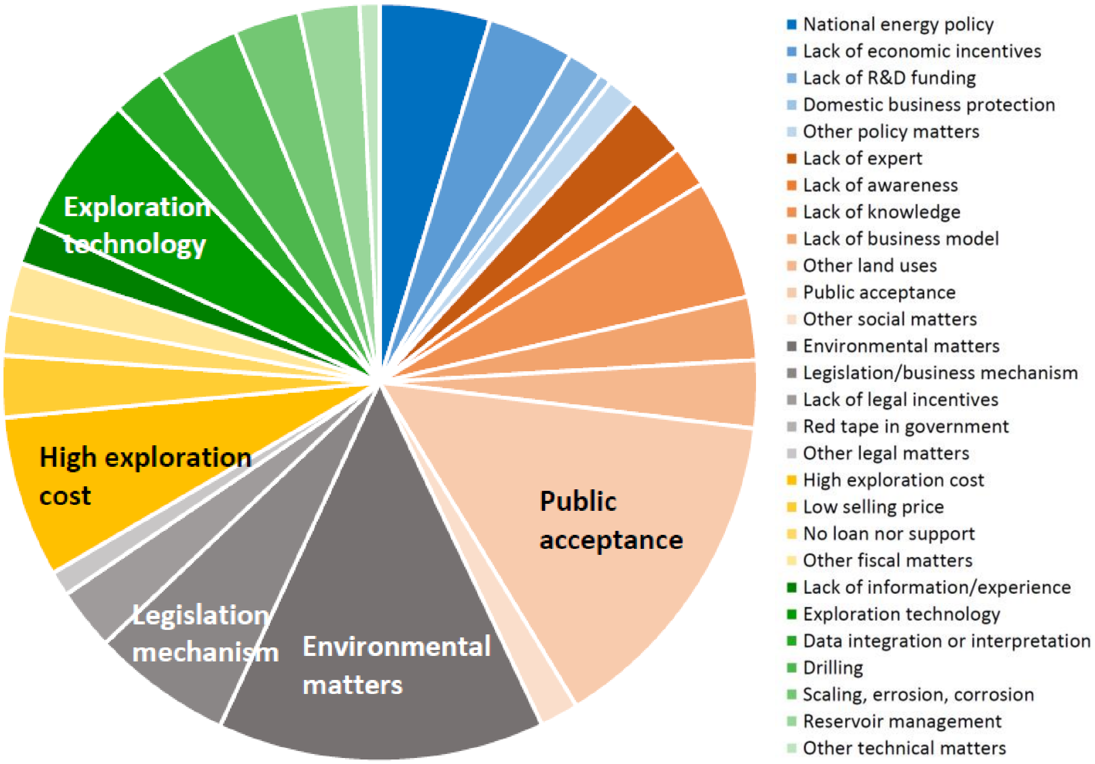
In addition, there is a long-term target towards 2050 by implementing 'supercritical geothermal power generation'. The Cabinet Office of the government of Japan, in the National Energy and Environment Strategy for Technological Innovation Towards 2050, places supercritical geothermal power generation as one of the eight most prioritised technologies to drastically reduce CO_2 emission (Council for Science, Technology and Innovation, 2016). It has a potential to increase Japan's geothermal power generation volume by an order of 10 or even greater, although there exist diverse scientific unknowns and necessary technological breakthroughs. It is expected that more commercial power plants fed by supercritical geothermal resources will be in operation in 2050 with a total capacity of 50 GW–100 GW. Since various technical challenges are needed for its realisation, we assume 100 GW_e as our target value for 2050 if technical barriers are removed.

3.3 Barriers to geothermal power generation, and necessary innovations

3.3.1 Barriers

Figure 3.3.3-1 was obtained from domestic experts based on 77 answers from the business sector (developers, consultants, manufacturers), research institutes, universities, and funding agencies) in a survey on 15 February 2017. Since these domestic experts cover all aspects and know the current situation well, the authors take this result (not the one from foreign experts in AGS11) for barrier contribution analysis.

Figure 3.3.3-1. Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in Japan



Source: Authors.

According to Figure 3.3.3-1, highest barriers are environmental matters and public acceptance, followed by high exploration cost.

Public acceptance barrier is mainly due to negative campaigns by hot spring business people who are concerned about potential effects to hot spring of geothermal energy development. Since hot spring bathing is a serious business in Japan, it is a big barrier to geothermal energy development.

Environmental barriers in Japan have two major aspects: one is development limitation in nature parks, which has been largely reduced after the nuclear power plant accident in 2011. The other one is the three-year-long environmental assessment, which is requested before concession is given to a geothermal power plant. High exploration cost is still a problem, although it is largely reduced recently by government support such as subsidies for exploration drilling and preliminary exploration by the government.

3.3.2 Barriers peculiar in Japan

Many domestic experts pointed out the problem of grid connection. Since major electric power companies that own grids set limit to power line capacity, an additional power supplier needs to pay considerable cost for construction of new power line should major electric power companies refuse conventional grid connection. The government has decided not to support new suppliers on this matter because geothermal power developers have already been given FiT and other economic incentives. Therefore, new ideas for local grid system or regional power use are needed.

3.3.3 Necessary innovations

Limitation in parks: New zoning for resource use may be applied. To do so, detailed resource assessment in natural parks should be done to find out effective ways of zoning.

Problem of public acceptance: Continuous effort for mutual understanding and long-term monitoring of hot spring resources are necessary. Hot spring monitoring data for FiT application, which are collected by private developers and shared with local stakeholders only in the current situation, should be shared with the academe or national institutions.

Exploration risk: Data on wells, especially temperature logging data on geothermal wells and other deep wells, should be shared with other developers and researchers. The government should collect and open access to these data.

Limitations in grid connection: New ideas for local grid system or regional power use (off-grid system) are needed.

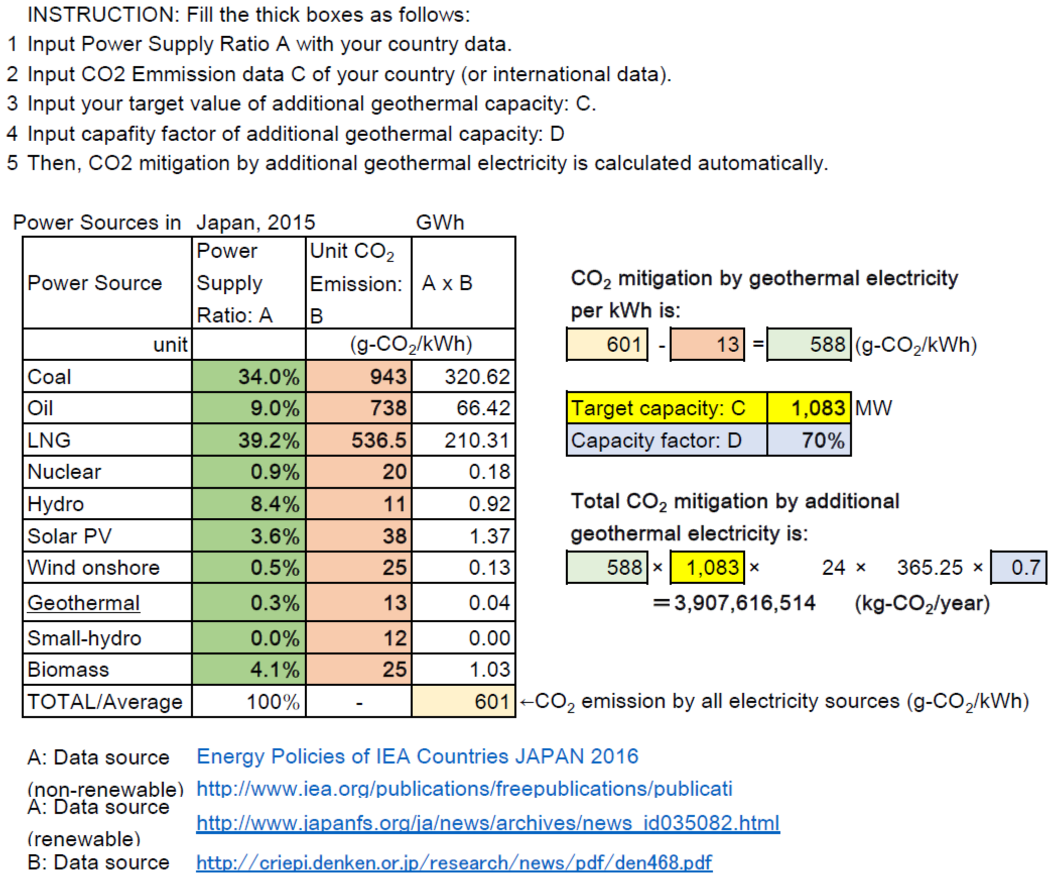
3.4 Benefits of geothermal power generation use in Japan

3.4.1 CO_2 emission reduction (kg-CO_2/kW)

CO_2 emission reduction by geothermal power use is calculated based on CO_2 emission data by Imamura and Nagano (2010) and current energy mix by METI (2016), which is 601-13 = 588 g-CO_2/kWh (Figure 3.3.4-1). Applying our target additional capacity of 1,075 MW and capacity factor of 70%, annual CO_2 reduction is:

588 x 1,083 x 24 x 365.25 x 0.7 = 3,907,616,514 kg-CO_2/year

Figure 3.3.4-1. CO_2 Mitigation by Additional Geothermal Power



INSTRUCTION: Fill the thick boxes as follows:

1 Input Power Supply Ratio A with your country data.
2 Input CO2 Emmission data C of your country (or international data).
3 Input your target value of additional geothermal capacity: C.
4 Input capafity factor of additional geothermal capacity: D
5 Then, CO2 mitigation by additional geothermal electricity is calculated automatically.

Power Sources in Japan, 2015 GWh

Power Source	Power Supply Ratio: A	Unit CO_2 Emission: B	A x B
unit		(g-CO_2/kWh)	
Coal	34.0%	943	320.62
Oil	9.0%	738	66.42
LNG	39.2%	536.5	210.31
Nuclear	0.9%	20	0.18
Hydro	8.4%	11	0.92
Solar PV	3.6%	38	1.37
Wind onshore	0.5%	25	0.13
Geothermal	0.3%	13	0.04
Small-hydro	0.0%	12	0.00
Biomass	4.1%	25	1.03
TOTAL/Average	100%	-	601

←CO_2 emission by all electricity sources (g-CO_2/kWh)

CO_2 mitigation by geothermal electricity per kWh is:

601 - 13 = 588 (g-CO_2/kWh)

Target capacity: C	1,083 MW
Capacity factor: D	70%

Total CO_2 mitigation by additional geothermal electricity is:

588 × 1,083 × 24 × 365.25 × 0.7

=3,907,616,514 (kg-CO_2/year)

A: Data source (non-renewable) Energy Policies of IEA Countries JAPAN 2016
http://www.iea.org/publications/freepublications/publicati
A: Data source (renewable) http://www.japanfs.org/ja/news/archives/news_id035082.html
B: Data source http://criepi.denken.or.jp/research/news/pdf/den468.pdf

CO_2 = carbon dioxide, g-CO_2 = gramme of carbon dioxide, kWh = kilowatt-hour, LNG = liquefied natural gas, PJ = petajoule.
Sources: for column A (non-renewables): IEA, 2017; for column A (renewables): Japan For Sustainability, 2014; for column B: Imamura and Nagano, 2010.

3.4.2 New employment for geothermal power plant (persons/kW)

Hienuki et al. (2015) analysed life cycle employment of solar, wind, and geothermal power generation in Japan using an extended input–output model. The calculated employment intensity of a 50-MW geothermal power plant is 0.89 person-year/GWh. Since operation and maintenance, which is 66% of the total employment, is normally done by local labour, the local labour intensity for geothermal power is 0.59 person-year/GWh. It is easily converted into 4.12 persons/MW because the capacity factor of 80% is used in this analysis. Labour intensity for solar and wind power are 2.8 and 0.69 person-year/GWh, respectively, but they are not local labour. It means that energy cost of geothermal power is lower but better for local economy than solar or wind power.

This number matches well with an actual geothermal power plant. Soma et al. (2015) show that there are 156 local employees in the Yanaizu–Nishiyama geothermal power plant. Since its running capacity is approximately 30 MW, its labour density is 5.2 persons/MW. A larger plant capacity used in the model calculation might result in slightly lower local labour intensity. Assuming that the average capacity of additional geothermal power plants by 2030 is 30 MW, expected new employment is 5.2 persons-year/MW x 1,076 MW = 5,595 persons-year.

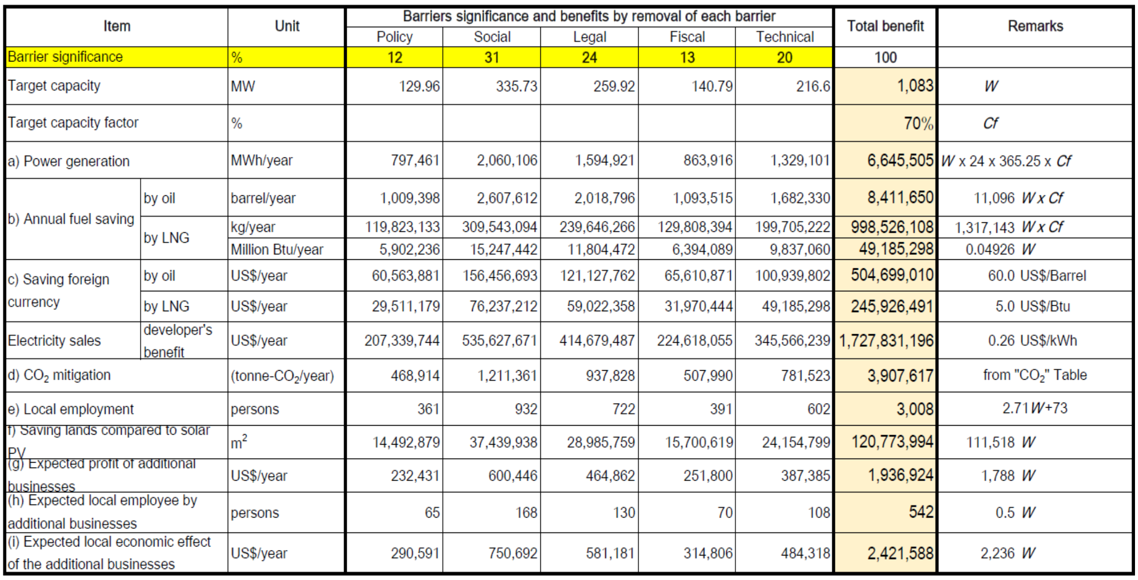
3.4.3 Other direct and indirect effects on local economy

Food and accommodation for people in geothermal power exploration and construction, income tax from geothermal power plant, etc. would be direct effects to local economy. There are many indirect effects to local economy observed in many geothermal sites. Most common business is hot water supply to local community using extra heat from the power plant. Other small businesses include steam supply for dying factory or seawater drying (salt production), hot water supply to agricultural use, etc.

3.5 Summary of barriers to and benefits of geothermal power generation

Table 3.3.5-1 shows barriers to geothermal energy use in Japan and expected benefits if barriers are removed.

Table 3.3.5-1. Expected Benefits if Barriers are Removed in Japan



Item		Unit	Barriers significance and benefits by removal of each barrier					Total benefit	Remarks
			Policy	Social	Legal	Fiscal	Technical		
Barrier significance		%	12	31	24	13	20	100	
Target capacity		MW	129.96	335.73	259.92	140.79	216.6	1,083	*W*
Target capacity factor		%						70%	*Cf*
a) Power generation		MWh/year	797,461	2,060,106	1,594,921	863,916	1,329,101	6,645,505	*W* x 24 x 365.25 x *Cf*
b) Annual fuel saving	by oil	barrel/year	1,009,398	2,607,612	2,018,796	1,093,515	1,682,330	8,411,650	11,096 *W x Cf*
	by LNG	kg/year	119,823,133	309,543,094	239,646,266	129,808,394	199,705,222	998,526,108	1,317,143 *W x Cf*
		Million Btu/year	5,902,236	15,247,442	11,804,472	6,394,089	9,837,060	49,185,298	0.04926 *W*
c) Saving foreign currency	by oil	US$/year	60,563,881	156,456,693	121,127,762	65,610,871	100,939,802	504,699,010	60.0 US$/Barrel
	by LNG	US$/year	29,511,179	76,237,212	59,022,358	31,970,444	49,185,298	245,926,491	5.0 US$/Btu
Electricity sales	developer's benefit	US$/year	207,339,744	535,627,671	414,679,487	224,618,055	345,566,239	1,727,831,196	0.26 US$/kWh
d) CO_2 mitigation		(tonne-CO_2/year)	468,914	1,211,361	937,828	507,990	781,523	3,907,617	from "CO_2" Table
e) Local employment		persons	361	932	722	391	602	3,008	2.71*W*+73
f) Saving lands compared to solar PV		m^2	14,492,879	37,439,938	28,985,759	15,700,619	24,154,799	120,773,994	111,518 *W*
(g) Expected profit of additional businesses		US$/year	232,431	600,446	464,862	251,800	387,385	1,936,924	1,788 *W*
(h) Expected local employee by additional businesses		persons	65	168	130	70	108	542	0.5 *W*
(i) Expected local economic effect of the additional businesses		US$/year	290,591	750,692	581,181	314,806	484,318	2,421,588	2,236 *W*

Btu = British thermal unit, CO_2 = carbon dioxide, LNG = liquefied natural gas, m^2 = square metre, MW = megawatt, MWh = megawatt hour, PV = photovoltaics. For symbols *Cf* and *W*, please refer to equation (1) in section 2.4.2.1.

Note: Since feed-in tarif price is currently quite high in Japan, annual electricity sales is very high.

Source: The study team.

3.6 Barriers to GSHP use, and necessary innovations

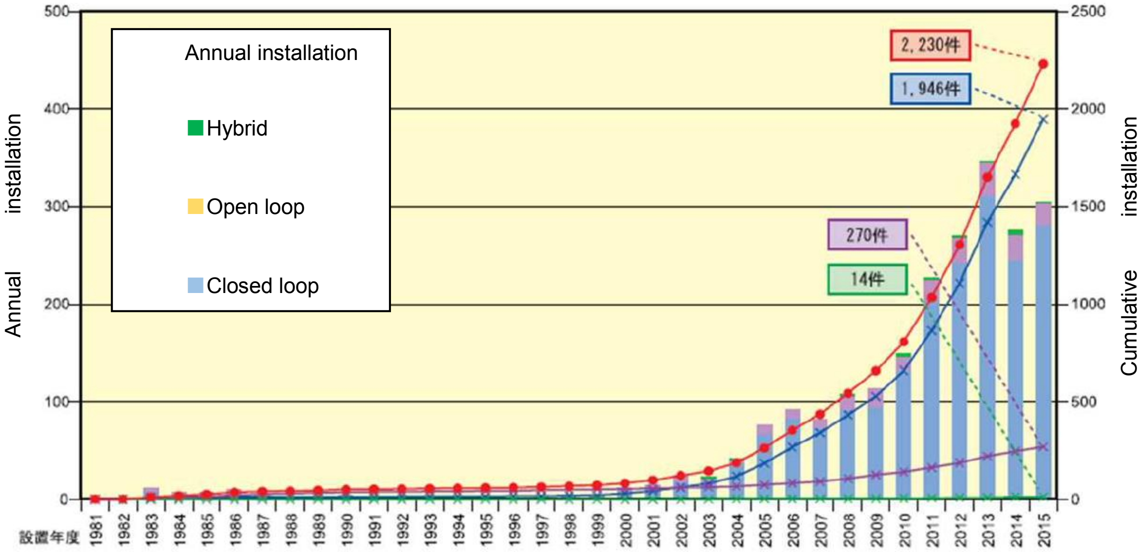
3.6.1 Brief history of GSHP use, target installation, and barriers in Japan

1) Brief history

Several open-loop GSHP systems were installed in Japan's urban areas in the 1960s and 1970s. However, new installations of open-loop system were strictly restricted after the central and local governments started to implement groundwater laws to prevent land subsidence.

Installation of closed-loop system began in Hokkaido after the oil crisis in the early 1980s. Some domestic companies manufactured heat pumps for GSHP systems while others imported geothermal heat pumps and drilling machines for ground heat exchangers. Annual facility installation was less than ten during those years. Most Japanese people were not aware of the energy efficiency of GSHP systems.

Figure 3.3.6-1. GSHP Installations in Japan



Source: Ministry of Environment, 2016.

A renewed interest in GSHP systems arose after the World Geothermal Congress 2000 held in Japan. The private sector established the Geo-Heat Promotion Association of Japan in 2001. MOE began giving subsidies for installation of GSHP systems to reduce the urban heat island phenomenon in the beginning and, later, to reduce CO_2 emission. Following MOE, METI has also begun giving subsidies for energy-saving purpose. For example, Sky Tree, the highest tower in Tokyo, built in 2013, is air-conditioned by GSHP systems, making the systems better known. Figure 3.3.6-1 shows statistics of GSHP installations (MOE, 2016). Although still limited to a few thousand, GSHP installation is rapidly increasing in recent years.

In 2010, the Japanese government published *Basic Energy Plan,* describing ground source. In 2011, METI made a policy promoting the use of heat from renewable energy sources including grant of subsidies to municipalities and private companies. Thus, accelerated installation of GSHPs in Japan is expected in the coming years.

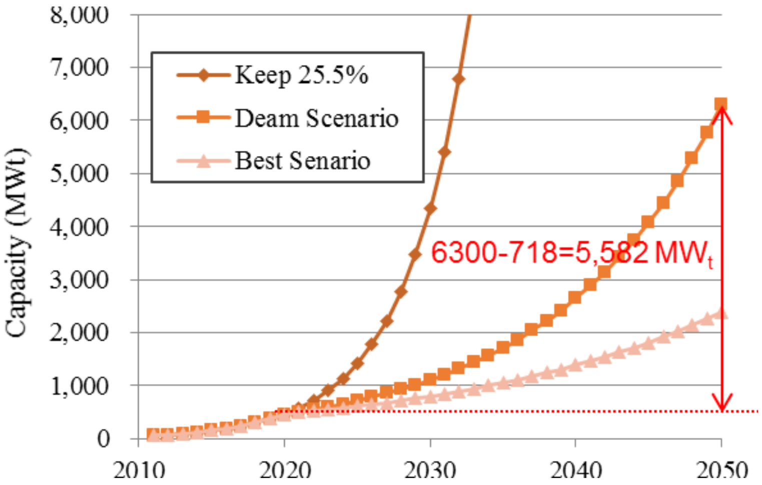
2) Target in 2025 and 2050

Yasukawa et al. (2010), with Ehara et al. (2008) as reference, show GSHP installation targets in Japan along three scenarios: base scenario, which should be done by people involved in GSHP businesses; best scenario, which may be fulfilled if the social system will be supportive of GSHP use; and dream scenario, which may be realised with drastic breakthrough in technical and/or social systems. Best scenario aims for GSHP capacity of 465 MW_t in 2020 and 2,384 MW_t in 2050 while dream scenario GSHP does 1200 MW_t and 6,300 MW_t for those years, respectively.

Through lobbying by related industry members such as the Geo-HP Association Japan, etc., MOE is giving subsidies for GSHP system installation to reduce CO_2 emission while METI is giving subsidies for energy saving. Thus, the present situation with government support is similar to the one described in best scenario. Therefore, the target value for 2050 by removal of barriers in this project should be the value of dream scenario, which is 6,300 MW_t.

To calculate our target for 2025, current trend was analysed based on Figure 3.3.6-1. Increasing trend of calculated curve matches the actual installation trend after 2000 with an increment rate of 25.5%. However, keeping the same increment after 2020 does not seem realistic because of its high value. Therefore, increment after 2020 was changed according to the target at 2050 in best or dream scenarios.

Figure 3.3.6-2. Estimation of GSHP Installation by 2050 with New Increment Curves



MW_t = megawatt thermal.

Source: Authors.

The increment after 2020 is 9.07% for dream scenario and 5.6% for best scenario. Since the current increment already satisfies the best scenario in 2020, our target should be the dream scenario, which is 6,300 MW_t in 2050. According to the new increment curve for dream scenario, installation in 2025 is 718 MW_t. It means installation in 2025–2050 would be 5,582 MW_t.

In summary,

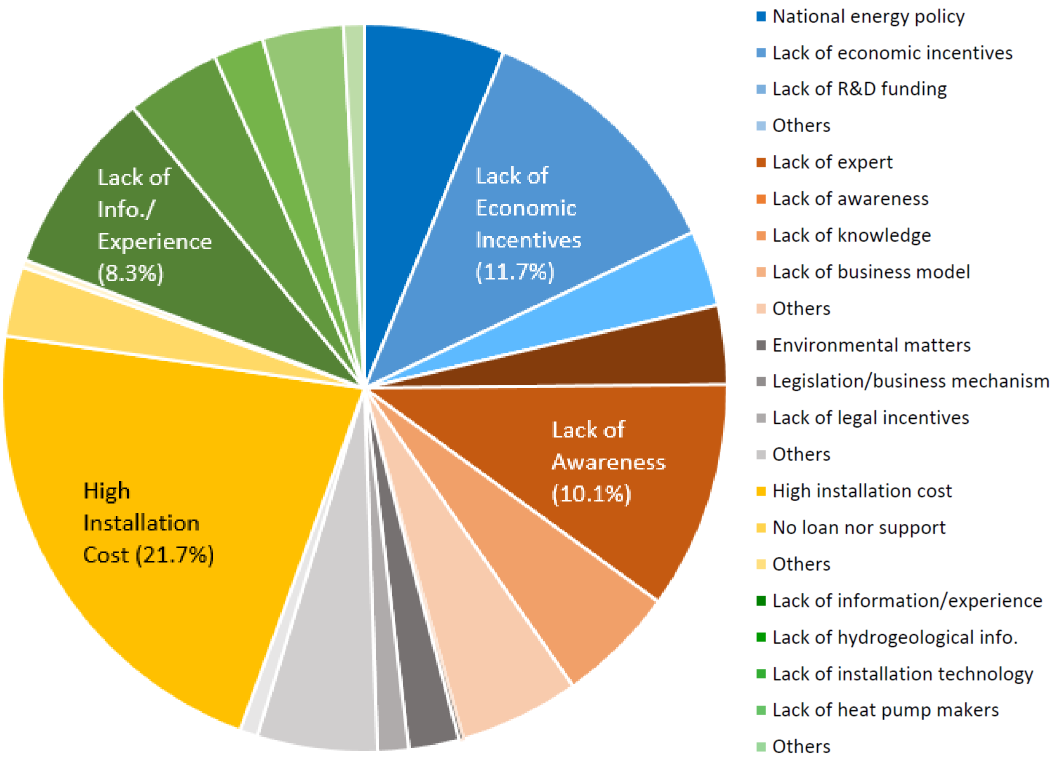
- Ehara et al. (2008) estimated installation in 2050 for three scenarios: base scenario, best scenario, and dream scenario.
- With the current increment rate of 25.5%, capacity in 2020 satisfies the installation in the best scenario (465 MW_t).
- Since the current increment already satisfies the best scenario in 2020, our target by removal of barriers should be the dream scenario, which is 6,300 MW_t in 2050.
- According to the new increment curve for dream scenario made in this study, installation target in 2025 is 718 MW_t.

3) Barriers

Figure 3.3.6-3 shows the results of domestic inquiry to local experts on barriers to GSHP during the symposium on GSHP and direct use held in March 2017 in Tokyo. The inquiry was answered by 76 experts and stakeholders. The highest score is for high installation cost (21.7%), followed by lack of economic incentives (11.7%), lack of awareness (10.1%), and lack of information and experience (8.3%). In both foreign and domestic inquiries, the highest barrier is high installation cost. Its percentage, however, is higher in domestic inquiry. Main difference between domestic and foreign inquiries' results is, in domestic inquiry, lack of economic incentives has second highest score, while it is not listed in foreign inquiry. Similarly, lack of experts scored 7.9% in foreign inquiry while it is not listed in domestic inquiry. As domestic experts have more experience, knowledge, and information, the result of domestic inquiry is given more preference in this report.

A few experts put forth some specific barriers in the 'Others' category, which are not listed in the inquiry. These barriers are 1) regulation of groundwater pumping for open-loop system, which can be categorised as legal barrier, 2) cost cutting by general contractors and sub-contractors, 3) standardisation of preliminary calculation of costs, which also falls under fiscal barrier, 4) absence of financial cooperation by leasing companies, 5) difficulty in technical design due to complex geology, 6) difficulty in evaluating superiority of heat pump from technical viewpoint, and 7) lack of information on operation and maintenance as a technical barrier. Amongst these specific barriers, 1), 5), and 7) are thought to be of primary importance.

Figure 3.3.6-3. Result of Inquiry to Domestic Experts on Barriers to GSHP in Japan



Source: Authors.

Regarding higher installation cost, drilling boreholes is very expensive as it costs about ¥15,000 (about US$123) per metre. The reason is, compared with those of other countries, the geological structure of Japan is heterogeneous, thus precise information on subsurface parameters such as thermal conductivity is hard to determine. Major human settlements (basins, plains) have thick quaternary deposits, with depth extending more than 100 metres in some places. As quaternary system is mainly consists of softer materials such as sand, gravel, silt, and clay, groundwater actively flows in this system. Below this system, tertiary system or Neogene exists which mainly consists of rocks. Hence, the consideration of geology as well as groundwater – in other words, hydrogeology – is very essential in Japan's context. If these factors are not considered, then cost gets higher. In some cases, cost increases because of an oversized design of ground heat exchangers due to lack of reliable estimates for heat exchange rates.

Economic incentives in the form of subsidies, tax reduction, etc. from the government are still insufficient for research and development. Hydrogeological and thermal properties of subsurface such as groundwater level, temperature distribution, thermal conductivity, etc. are hard to predict as measured data are not abundant in Japan. More research funds are essential for hydrogeological field surveys, case studies, and long-term monitoring. Moreover, subsidies for new installations of GSHP system in private residential buildings are also expected to consistently promote the system.

Lack of awareness and lack of information and experience fall under social and technical barriers, respectively. However, they can be linked with policy barriers as well, because incorporation of the GSHP systems into Japan's energy policy was delayed. It was only in 2010 that the GSHP systems were recognised in the Energy Master Plan. Still, people are not aware of the advantages offered by the systems and the difference that geothermal energy provides is unclear. Likewise, information and general experience from technical point of view are not sufficient enough. Nevertheless, the development of GSHP systems in Japan is gradually rising and it is expected that related experience and information will also be gradually accumulated with development and promotion of the systems.

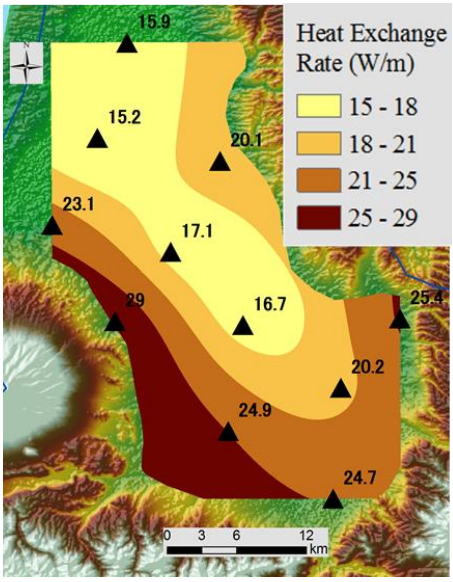
3.6.2 Innovative ideas to remove barriers

1) Suitability mapping

For the sustainable use and growth of the GSHP system, including the low cost, assessing its development potential in a regional scale (plain or basin) is of utmost necessity. Compiling suitability maps for the installation of GSHP system can be beneficial for this purpose. The term 'suitability' is mainly related to heat exchange with subsurface, heat extraction, and discharge from and to the subsurface, which depend on geology, groundwater and its flow, and subsurface temperature distribution. Therefore, assessment must be done based on hydrogeological and thermal information of the study area.

Geological and groundwater surveys are generally performed to collect data on geology, groundwater table (hydraulic heads), subsurface temperature, thermal gradients, etc. From these data, related parameters such as hydraulic and thermal conductivity can be predicted and thus contribute to hydrogeological database. Based on geological and groundwater data and predicted parameters, numerical modelling is done to comprehend groundwater flow system and heat transport in regional scale. By numerical analysis, three-dimensional groundwater flow, its velocity, and subsurface temperature distribution are estimated since they cannot be measured by field surveys. With all of the observed and calculated data, suitability maps (Figure 3.3.6-4) showing the distribution of heat exchange rate and depth of ground heat exchangers can be prepared. By using the suitability map, areas with higher, medium, or lower suitability can be distinguished clearly even by the general people. In areas with higher suitability, the installation of GSHP is favourable in terms of hydrogeology and thermal condition, and ground heat exchanger can be shorter than general case. Hence, installation cost can be reduced because drilling cost will be lower. As this suitability map incorporates the detailed hydrogeology and thermal information of the target area, it can contribute to accurate design of the GSHP system, reduction of cost, as well as raising awareness and promoting the system in Japan.

Figure 3.3.6-4. Suitability Map Showing the Distribution of Heat Exchange Rate in Tsugaru Plain, Japan



Source: Shrestha et al., 2015.

2) System optimisation technology

Optimisation of the GSHP system that can meet the local hydrogeological and thermal condition of the study area can contribute in increasing the efficiency of the system. Increasing the system efficiency leads to total cost reduction as well as energy saving. Comparison of GSHP systems installed in different regions with varying hydrogeological conditions and analysing the modifications needed for the better performance can be a good option to innovate new technologies. Collaboration with local universities, research institutes, and private local companies can be useful for this purpose because they may have detailed data, research results, and local technologies that can be best utilised to improve system efficiency. These optimisation technologies can then be expanded nationwide.

3.7 Benefits of GSHP use in Japan

3.7.1 Electricity saving

The GSHP system consumes less electricity than air conditioners (ACs). By saving electricity, the national energy security can be consistently maintained. Once the domestic energy is secured, the use of fossil fuels can be minimised and energy cost can be saved. Hence, electricity saving can also indirectly contribute to CO_2 mitigation.

Electricity saving by GSHP system for space cooling compared to ACs

This calculation is based on the assumption that space cooling by ACs in the whole Japan is completely replaced by the GSHP system.

For the same load of space cooling, AC and GSHP system can produce the same amount of coolness. Hence, annual electricity consumption (E) by AC and GSHP system can be related as;

$$\boxed{E_{GSHP} \times COP_{GSHP} = E_{AC} \times COP_{AC}}$$

…………Equation (1)

Table 3.3.7-1. Electricity Consumption of Air Conditioner

Electricity Demand in Peak Hours of Summer (MW)	Ratio of AC Use for Cooling in Electricity Demand (%)	Operation Hours per Year (hour)	Electricity Consumption by AC per Year (GWh)
156,050[a]	45[b]	1000[c]	70,223

AC = air conditioner, GWh = gigawatt hour, MW = megawatt.

[a] Sum of electricity demand in each of 10 power operators' region in Japan.

[b] Based on usage of AC for cooling in the Tokyo area.

[c] Operation scenario is assumed for 100 days in a year with 10 hours of operation per day.

Source: Agency Natural Resources and Energy, 2011, 2015.

System coefficient of performance (COP) of GSHP and AC for space cooling are taken as 4.5 and 3, respectively, based on available data of case studies in Japan.

Then, electricity consumption of GSHP system can be calculated from Equation (1) as follows:

$E_{GSHP} = E_{AC} \times COP_{AC} / COP_{GSHP} = 70{,}223 \times 3 / 4.5 = 46{,}815$ GWh per year

The annual electricity saving by GSHP is 23,408 GWh, which is about 33% compared to AC.

Likewise, other direct benefit is mitigation of urban heat island phenomenon, because in GSHP system, the exhaust heat during space cooling is thrown to the subsurface, not to the atmosphere as in AC. GSHP system can also contribute to CO_2 mitigation by replacing the conventional boilers and heaters that use fossil fuels for space heating.

3.7.2 CO_2 mitigation by GSHP system

In the 2015–2016 annual report of this project, installation capacity in 2025 was estimated to be 718 MWt (Original of this project, June 2016).

Equivalent full load hours for heating were considered as 840 hours based on Tokyo's case study. For cooling, equivalent full load hours were taken as 520 hours based on Spandagos and Ng (2017).

COP for heating and cooling by GSHP were considered as 3.5 and 4.5, respectively, based on the case studies in Japan, while COP of AC was taken as 2.

Table 3.3.7-2. Calculation of CO_2 Mitigation By GSHP Compared to Conventional Air Conditioner (heating mode)

Installed capacity/ Installation capacity (MW) A	Equivalent full load hours (EFLH) per year (h) B	System COP of GSHP for heating C	System COP of AC for heating D	Heating effect (GWh) E	Electricity consumed by GSHP (GWh) F	Electricity consumed by AC (GWh) G	Electricity saving (GWh) H	National average CO_2 emission factor (kg-CO_2/kWh) I	CO_2 mitigation (tonne-CO_2) J
718	840	3.5	2	2110.9	603.1	1055.5	452.3	0.5	226170.0

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GWh = gigawatt hour, GSHP = ground source heat pump, kg = kilogramme, kWh = kilowatt-hour, MW = megawatt.
Note: In the table, E= AxBxC/1000, F= E/C, G= FxC/D
Source: The study team.

Table 3.3.7-3. Calculation of CO_2 Mitigation by GSHP Compared to Oil Boiler (heating mode)

Installed capacity/ Installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Net heat energy production (GWh)	CO_2 saving factor (tonne/GWh)	CO_2 mitigation (tonne-CO_2)
718	840	3.5	2	430.8	409	176197.2

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour.
Source: The study team.

The CO_2 saving factors used in IEA Geothermal (http://www.iea-gia.org) and International Geothermal Association (Lund and Boyd, 2015) are shown in Table 3.3-8.

Table 3.3.7-4. CO_2 Saving Factor for Geothermal Direct Use Compared to Conventional Boilers

With Respect to Boiler (with 70% thermal efficiency)	CO_2 Saving Factor (tonne/GWh)
natural gas	97
oil	409
coal	477

CO_2 = carbon dioxide, GWh = gigawatt hour.
Source: Lund and Boyd, 2015.

With the estimated installation capacity of 718 MW of GSHP system in 2025, CO_2 mitigation for heating is estimated at 226,170 tonnes-CO_2 per year compared to conventional air conditioner and 176,197 tonnes-CO_2 per year compared to oil boiler. Additionally, CO_2 mitigation for cooling is estimated to be 93,340 tonnes-CO_2 per year.

Table 3.3.7-5. Calculation of CO_2 Mitigation by GSHP Compared to Air Conditioner (cooling mode)

Installed capacity/ Installation capacity (MW) A	Equivalent full load hours (EFLH) per year (h) B	System COP of GSHP for cooling C	System COP of AC for cooling D	Cooling effect (GWh) E	Electricity consumed by GSHP (GWh) F	Electricity consumed by AC (GWh) G	Electricity saving (GWh) H	National average CO_2 emission factor (kg-CO_2/kWh) I	CO_2 mitigation (tonne-CO_2) J
718	520	4.5	3	1680.1	373.4	560.0	186.7	0.5	93340.0

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, kWh = kilowatt-hour, MW = megawatt.
Source: The study team.

3.8 Summary of barriers to and benefits of GSHP use

➢ The major barriers to GSHP use in Japan are lack of economic incentives, lack of awareness, high installation cost, and lack of information and/or experience.

➢ To remove barriers, the following are necessary:

- ✓ Compilation of suitability maps on a regional scale can contribute to accurate design of the GSHP system, reduction of installation cost as well as running cost, also to raising awareness and promoting the growth of GSHP system in Japan. Overall, it can contribute to the sustainable use of GSHP system.
- ✓ Development and optimisation of the GSHP system based on the local hydrogeological and thermal condition of the area can contribute to the increment of system efficiency, reduction in total cost, and energy saving.
- ✓ Economic incentives from the government are essential for hydrogeological field surveys, case studies, and long-term monitoring. Subsidies for new installations of GSHP system in private residential buildings are also expected for consistent promotion of the system.

➢ Direct benefits automatically obtained by GSHP installation are:

- ✓ Saving electricity
- ✓ National energy security (domestic energy)
- ✓ Saving fossil fuels
- ✓ Saving energy cost
- ✓ Reduction of urban heat island phenomenon
- ✓ CO_2 mitigation by replacement of heater using fossil fuels (direct) and by saving electricity (indirect)

➢ Indirect benefits obtained by additional economic activity are new businesses such as greenhouse agriculture, fish farming, sports facilities (swimming pools).

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4. Korea

Korea's geological features are of relatively old rocks and various formations from the Precambrian era to the Quaternary period. Thick Cenozoic sedimentary layers are not common except in limited regions in the southeastern part. Although Korea has two distinct volcanoes (Jeju and Ulleung islands), there has not been any volcanic activity for more than a thousand years, so that one can hardly expect high-temperature geothermal resources near the surface in the country. Thus, deeper development is essential to get high-temperature geothermal resources for power generation. This relates directly to high exploration costs, weak economic feasibility, and various technological barriers. Because there have been no industries that relate to deep subsurface development or exploration in Korea, infrastructures, technologies, and legislations for securing rights of developers are far from being ready.

4.1 Current situation of geothermal energy use and national policy

4.1.1 Brief history, current energy policy, and energy mix

1) Brief history

Korea does not have high enthalpy geothermal energy related to volcanic or tectonic activities. Some anomalous regions, however, show high geothermal gradient. Pohang is one of such regions that show high heat flow and geothermal gradient. Geothermal anomaly in Pohang area was reported in the 1960s from several deep drillings for oil exploration. Based on the anomalous geothermal regime, a low-temperature geothermal development project in Pohang was done by Korea Institute of Geoscience and Mineral Resources in 2003–2008 (Lee and Song, 2008).

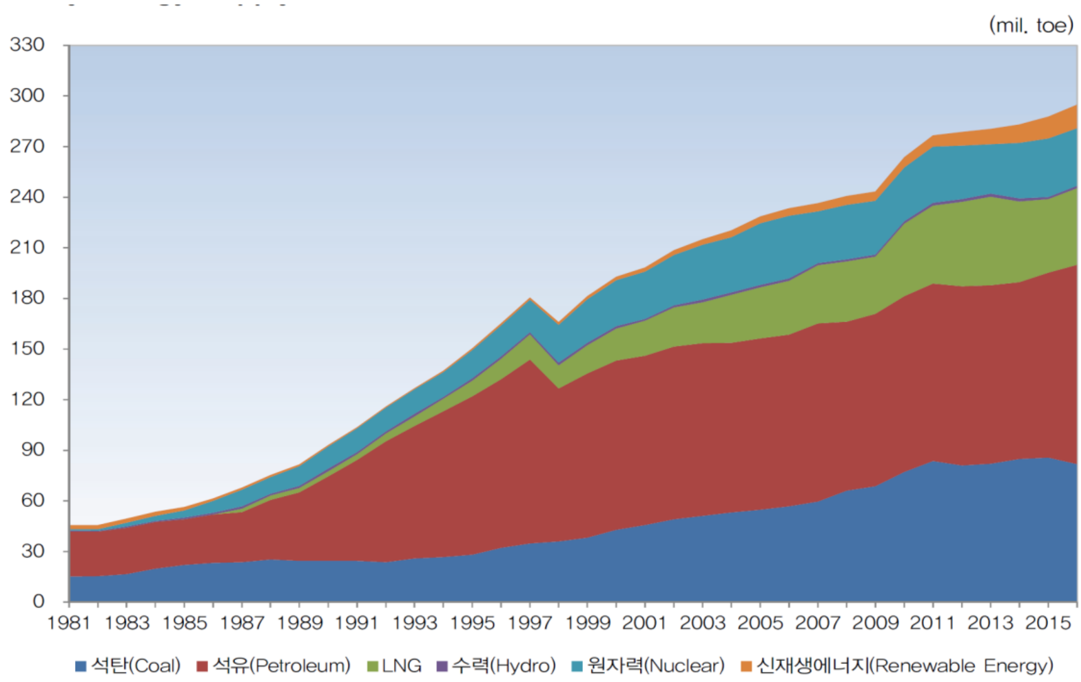
Intensive geological and geophysical surveys such as airborne gravity and magnetic surveys; radioactive, geochemistry, and magnetotelluric surveys were conducted to delineate possible fractures that could carry deep geothermal water to near surface. Four wells were drilled to figure out the geological and geothermal structure of the target area. Well logging from the four wells showed common geothermal gradient higher than 30°C/km (national average of geothermal gradient is about 25°C/km) (Lee and Song, 2008). Assessment of geothermal resources in Korea showed that the temperature at 5 km deep in the Pohang area is expected to be about 180°C and the enhanced/engineered geothermal system (EGS) technical potential for geothermal power generation is about 20 GW_e (Song et al., 2011).

In 2010, the first geothermal power generation project was launched by Enhanced Geothermal Technology. It was supposed to be a 5-year-term, government-funded and industry-matching project, with Pohang field as target area of higher heat flow in the southeastern part of the Korean Peninsula. The project was to be of two phases: I) site preparation, drilling a 3-km deep well and confirming the temperature anomaly in two years, and II) extending the 3-km deep well down to 4.5–5 km, hydraulic stimulation and reservoir creation, drilling another well and completing doublet system, and finally installing a MW_e class binary power plant in another three years (Song et al., 2015). The overall progress of the project was quite slow than what was originally planned due to extra budget demand for the unexpectedly high cost of procurements and mostly due to lack of experience. The project was suspended immediately after the Pohang earthquake that occurred in the vicinity of the EGS site.

2) Current energy policy and energy mix

The total primary energy supply (TPES) in Korea in 2016 was recorded at 294.8 million tonnes of oil equivalent (see Figure 3.4.1-1). Fossil fuels, including oil, coal, and liquefied natural gas (LNG) cover 83.3% of TPES in Korea, while only 4.8% is covered by new and renewable energy (See Table 3.4.1-1).

Figure 3.4.1-1. Yearly TPES Changes in the Last 36 Years in Korea



LNG = liquefied natural gas, toe = tonne of oil equivalent.
Source: Korea Energy Economics Institute, 2017.

Korea's total electricity generation in 2016 was 540 billion kWh (Table 3.4.1-1). Major sources for power generation are coal, nuclear power, and LNG, covering more than 90% of total electricity generation.

Table 3.4.1-1. Share of TPES and Power Generation in Korea in 2016

Source	Oil	LNG	Coal	Nuclear	Hydro	New & Renewable
TPES	40.1%	15.4%	27.8%	11.6%	0.4%	4.8%
Power	2.6%	22.4%	39.6%	30.0%	1.2%	4.2%

LNG = liquefied natural gas, TPES = total primary energy supply.
Source: Korea Energy Economics Institute, 2017.

Following the Second National Energy Master Plan, which was officially announced at the beginning of 2014, the 4th Basic Plan for New and Renewable Energy was fixed in September 2014. The new and renewable energy supply target by 2035 is 11% of TPES (Table 3.4.1-2).

Table 3.4.1-2. Target of New and Renewable Energy Supply by 2035

Year	2012	2014	2020	2025	2030	2035
Target	3.2%	3.6%	5.0%	7.7%	9.7%	11%

Source: Korea Energy Economics Institute, 2017.

Table 3.4.1-3 shows the target share of each new and renewable source to achieve the 11% of renewable energy goal by 2035, where the average increase rate of TPES is assumed at 0.88% annually. Photovoltaic and wind power are the main drivers of renewable power generation. Note that their average annual increases are 11.7% and 16.5%, respectively. Geothermal power, mainly GSHP system, and solar thermal power are expected to be two major sources for thermal energy supply. Target is 18.0% average annual growth of geothermal energy (GSHP).

Table 3.4.1-3. Target Share of New and Renewable Energy Sources in Korea

Year	2012	2014	2020	2025	2030	2035	Annual Increase
Solar Thermal	0.3	0.5	1.4	3.7	5.6	7.9	21.
Photovoltaic	2.7	4.9	11.7	12.9	13.7	14.1	11.7
Wind	2.2	2.6	6.3	15.6	18.7	18.2	16.5
Bio	15.2	13.3	18.8	19.0	18.5	18.0	7.7
Hydro	9.3	9.7	6.6	4.1	3.3	2.9	0.3
Geothermal	0.7	0.9	2.7	4.4	6.4	8.5	18.0
Ocean	1.1	1.1	2.5	1.6	1.4	1.3	6.7
Waste	68.4	6.70	49.8	38.8	32.4	29.2	2.0

Source: Korea Energy Agency, 2017.

On 10 May 2017, the newly installed government declared ‘Sustainable KOREA!’ and on 29 December 2017 announced the 8th Basic Plan of Long-term Electricity Supply and Demand (2017–2031). The key issue of the plan is energy transition to clean energy from nuclear power and fossil fuels. According to the plan, 20% of electricity will be generated by renewables by 2030. The following six major action plans were set up to achieve 20% of the target by 2030.

1) Increasing by 28% the mandatory rate of renewable portfolio standard (RPS) by 2030; currently at 10% by 2024.

2) Promoting large-scale renewable projects, including offshore wind farm and so on.

3) Local community participation; agricultural solar villages, etc.

4) Investment for grid stability.

5) Efficient demand side management using smart grid infrastructures.

6) R&D investment of US$1.4 billion, including US$1.0 billion for renewables (2016–2020)

4.1.2 Geothermal energy use in Korea

Despite the 19.6-GW_e geothermal technical potential across the country, there is no geothermal power generation in Korea (Table 3.4.1-4). A pilot EGS project had been performed since 2010 until an earthquake with a magnitude of 5.4 occurred on 15 November 2017 in the vicinity of the EGS site. It occurred two months after injection and subsequent bleeding-off had been done, but the local community were strongly concerned about possible link between the earthquake and the stimulation process, and the government eventually decided to stop the project temporarily to be able to conduct a scientific investigation.

Table 3.4.1-4. Geothermal Energy Utilisation in Korea by 2017

Electricity		**Direct Use**	
Total installed capacity (MW_e)	-	Total installed capacity (MW_{th}) (GSHP excluded)	**43.6**
Total running capacity (MW_e)	-	Total heat used (PJ/year) [GWh/year] (GSHP excluded)	**0.594** **[164.9]**
Total generation (GWh)	-	GSHP total installed capacity (MW_t)	**1,210.3***
Target (MW_e)	**200**	**GSHP total net use [GWh/year]**	**678.8***

GSHP = ground source heat pump, GWh = gigawatt hour, MW_e = megawatt electric, MW_t = megawatt thermal, PJ = petajoule.
Note: * indicates estimated values.
Source: Song and Lee, 2018.

On the other hand, GSHP installation in Korea has increased rapidly since the middle of the 2000s, with more than 100 MW_t new installations annually. Total installed capacity was estimated to have exceeded 1,200 MW_t at the end of 2017 (See Table 3.4.1-4). Geothermal direct use, excluding GSHP, is mainly hot spring water for bathing and space heating.

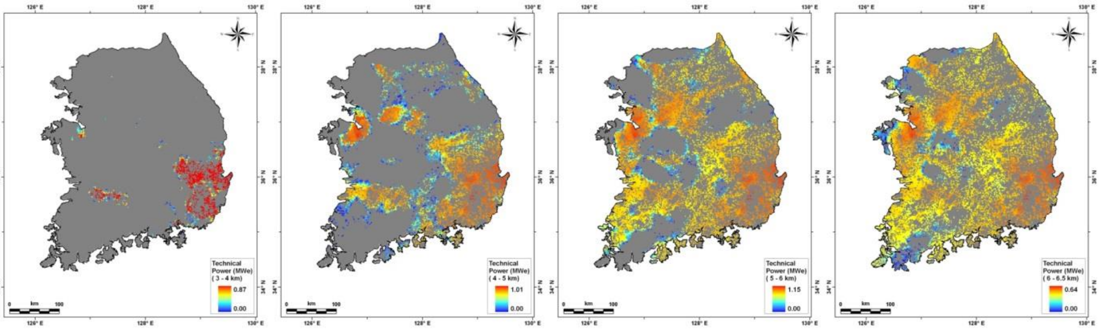
The main drivers of the rapid increase in GSHP installation are the active government subsidy programmes and a special Act for new and renewable energy (‘Mandatory Act’). The subsidy programmes include Deployment Subsidy Program, Rural Deployment Program, and 1 Million Green Home by 2020 Program. For the latter programme, the government subsidises 50% of total installation cost based on competition with pre-determined budget each year. Another powerful subsidy programme, established in 2010, is the Greenhouse Deployment Program wherein the central government subsidises 60% and local governments cover 20%, which means that rural farmers pay only 20% of GSHP installation cost for greenhouses and aquaculture. In 2012, the Mandatory Public Renewable Energy Use Act (Mandatory Act) was amended to state that ‘[i]n all public buildings bigger than 1,000 m^2 in area, more than 10% of annual energy uses should be from new and renewable energy sources’. The minimum percentage is to increase annually: 11% in 2013, 12% in 2014, and so on.

4.2 Target capacity estimation for geothermal power generation and direct use

4.2.1. Target for geothermal power generation in Korea

The technical potential for geothermal power generation by EGS technology was calculated by Song et al. (2011), adopting the protocol for EGS potential proposed by Beardsmore et al. (2010), which is endorsed by International Geothermal Association (2011) and International Energy Agency Geothermal Implementation Agreement (2011). The technical potential considers the technological depth limit (down to 6.5 km deep), land accessibility, and recovery ratio of 0.14. Total technical potential is calculated at 19,567 MW_e.

Fig. 3.4.2-1. EGS Technical Potential at Various Depths in Korea



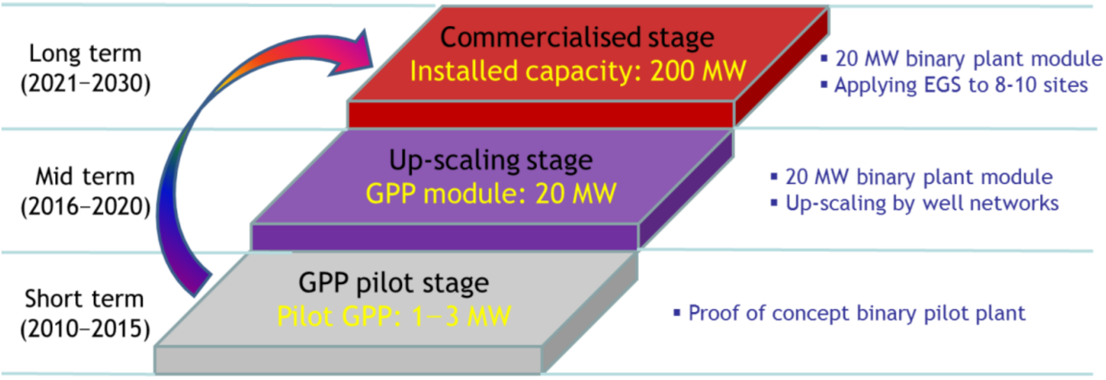
(a) 3~4 km (b) 4~5 km (c) 5~6 km (d) 6~6.5 km

Source: Song et al. 2011.

A national technological roadmap was set up in 2011, right after the start of the pilot EGS project. The scenario is to build a 1~3-MW_e pilot plant by 2015 as proof of a concept pilot plant. The next move is to scale up the plant to about 20 MW_e by 2020 using the well network concept. A geothermal power plant with total capacity of 200 MW_e is to be installed by applying 20-MW_e module to about 10 sites by 2030. It is, however, already behind the schedule and delay of at least 5 years is expected.

The target geothermal power generation in Korea can be estimated from the EGS technical potential and the national technological roadmap. Assuming delay of 5 years for the national technological roadmap, 20 MW of installed capacity can be a target geothermal power plant potential by 2025 and 200 MW by 2035. Assuming a double geothermal power plant capacity every 10 years, a total of 800 MW can be achieved by 2050, which corresponds to about 4% of total technical potential in Korea.

Figure 3.4.2-2. National Technological Roadmap for Geothermal Power Generation in Korea



EGS = enhanced/engineered geothermal system, MW = megawatt, GPP = geothermal power plant.
Source: Original figure of this project.

4.2.2. Target GSHP use in Korea

The annual increase of GSHP installations in Korea in the last 5 years was more than 100 MW_t (Song and Lee, 2015). However, installations due to subsidy programmes are slightly decreasing, and installations due to the mandatory Act are expected to decrease as well because of reduced activities in construction of public buildings.

- The estimated total installed capacity at the end of 2015 using the business-as-usual model is 900 MW_t.
- If we assume an annual decrease of installations of as much as 5 MW_t supported by subsidy programmes and the mandatory Act, then the expected installation by 2025 will be

$900 + 10 \times (100 + 55) / 2 = 1{,}675\ MW_t$

- Thus, we can say that expected GSHP installation by 2025 with the business-as-usual scenario is 1.675 GW_t.

Socio-economic and technical barriers are main hurdles for active GSHP installation for the residential sector. Installations for residential houses as a result of the subsidy programmes peaked at 11 MW_t in 2012 and decreased afterwards due to reduced subsidies. However, according to a government plan (called 1 Million Green Home Program), each GSHP installation should have covered at least 100,000 residential houses with 17.5 kW_t. Thus, we can expect 10,000 new annual installations until 2025 by removing barriers and by encouraging private business to enter the residential market. As potential GSHP installation is expected to be as much as 1,750 MW_t (= 0.0175 MW_t/house × 100,000 houses) by 2025, our target value in that year would be 1675 + 1750 = 3425 MW_t.

4.3 Barriers to geothermal power generation, and necessary innovations

4.3.1 Barriers

Thirty-two domestic experts including professors, researchers, students, and experts from energy authority and geothermal industry replied to the inquiry. Excluding six students, most have longer than 10 years of experience in geothermal business. Figure 3.4.3-1 and Table 3.4.3-1 show the results of inquiry on barriers to geothermal power generation in Korea. Since these experts cover all aspects of geothermal power generation and know the current situation well, the authors take these results (not those from foreign experts in AGS11) for barrier contribution analysis.

Based on these results, the major barriers in geothermal power generation in Korea are high exploration cost (14.3%), drilling technology (9.7%), lack of experts (8.7 %), and national energy policies (8.3 %).

Most of the major barriers to geothermal power generation in Korea are mainly related to the geological situation in Korea. It is essential to explore deeper to get high-temperature geothermal water for power generation. This directly relates to economic feasibility and various kinds of technological barriers, such as high exploration cost, drilling technology, lack of experts, and so on.

Due to the social debate that ensued regarding the possibility that the Pohang earthquake was triggered/induced by the geothermal exploration in the area, public acceptance became another big barrier for geothermal power generation.

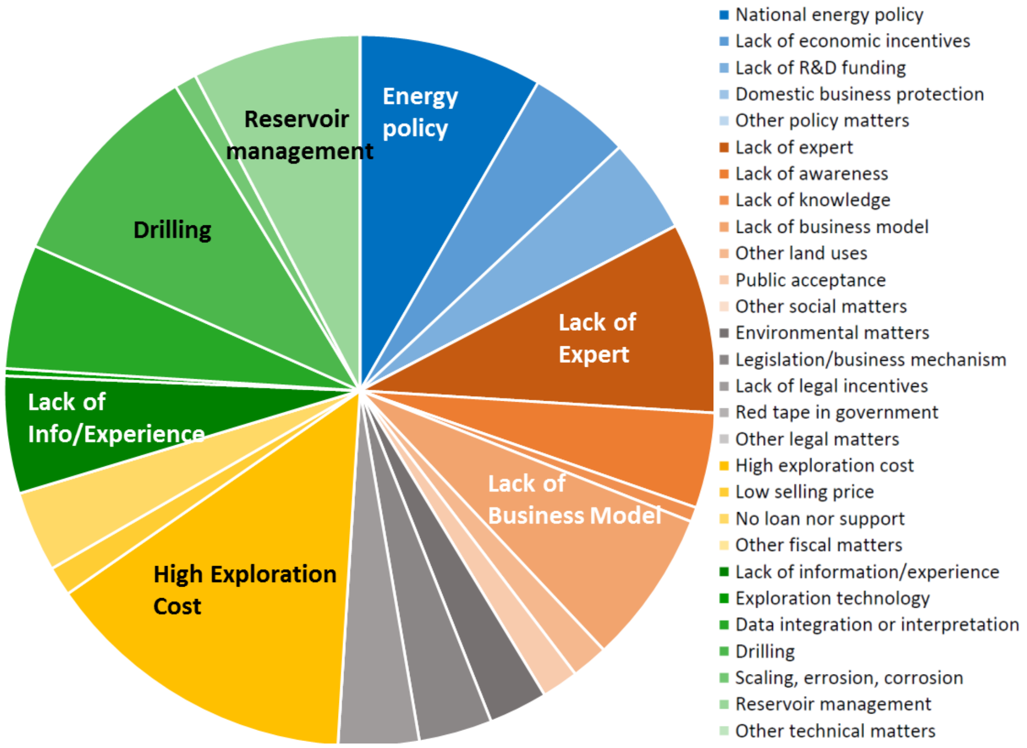
Table 3.4.3-1. Summary of Results of Inquiry on Barriers to Geothermal Power Generation in Korea

Policy	17%	National energy policy	8.3%
		Lack of economic incentives	4.7%
		Lack of R&D funding	4.3%
		Other policy matters	0.0%
Social	24%	**Lack of expert**	8.7%
		Lack of awareness	4.3%
		Lack of knowledge	0.7%
		Lack of business Model	7.0%
		Other land uses	1.7%
		Public acceptance	1.7%
		Other social matters	0.0%
Legal	10%	Environmntal matters	2.7%
		Legislation/business mechanism	3.3%
		Lack of legal Incentives	3.7%
		Other legal matters	0.0%
Fiscal	19%	**High exploration cost**	14.3%
		Low selling price	1.3%
		No loan nor support	3.7%
		Other fiscal matters	0.0%
Technical	30%	**Lack of information/experience**	5.3%
		Exploration technology	0.3%
		Data integration or interpretation	5.7%
		Drilling	9.7%
		Scaling, errosion, corrosion	1.0%
		Reservoir management	7.7%
		Other technical matters	0.0%
TOTAL (%)	100%		100.0%

R&D = research and development.

Source: Authors.

Figure 3.4.3-1. Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in Korea



R&D = research and development.
Source: Authors.

4.3.2 Necessary innovations

The main technical huddles or barriers to power generation in Korea are economic feasibility, and various kinds of technological barriers such as drilling and reservoir creation at depths, and legal and supporting schemes.

1) Renewable portfolio standard system

Geothermal power generation is now included in renewable portfolio standard (RPS) with renewable energy certificate of 2.0, the highest value in Korea. RPS is a kind of obligation where power companies with more than 500 MW of installed capacity are required to generate a certain percentage of power from renewable energy sources. The percentage gets bigger annually from 2012 until 2024 (Table 3.4.3-2).

Table 3.4.3-2. Yearly Renewable Energy Contributions in the RPS System

Year	**2012**	**2013**	**2014**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Renewable EnergyRatio (%)	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0

RPS = renewable portfolio standard.
Source: Korea Energy Agency, 2017.

Renewable energy sources are in different stages of technological development or economic feasibility. To cope with the difference, renewable energy credit (REC, a kind of weighing factor, was set up. Power companies can get the credit certificate by multiplying their power generation (MWh) with REC of corresponding renewable source. Table 3.4.3-3 shows the REC scheme that has been activated since 2015. Excluding energy storage system + wind which will be supported only for 3 years, geothermal energy has the highest value along with offshore wind and tidal energy.

In fact, studies on the economic feasibility of geothermal power generation in Korea are yet to be enough. But unit price for electricity generated from geothermal energy should be higher than those from the countries in volcanic zones. Considering costs for exploring such depths and the fact that the technologies for geothermal power generation are far from maturity, stronger incentives and more active R&D investments are needed for the industry to actively invest in geothermal power generation.

Table 3.4.3-3. Renewable Energy Certificate for Various Renewable Energy Sources

Category	REC	Type	Remarks
Solar	1.2	Utilisation on land	< 100 kW
	1.0		> 100 kW
	0.7		> 3,000 kW
	1.5	Utilisation on structures including buildings, houses, etc.	< 3,000 kW
	1.0		> 3,000 kW
	1.5	Utilisation on surface of water of dams or rivers	
Other Renewables	0.25	IGCC	
	0.5	Waste, gas from waste disposal	
	1.0	Hydro, wind, bio, tidal (embankment)	
	1.5	Biomass (wood), wind (offshore, less than 5 km)	
	2.0	Fuel cell, tidal current	
	2.0	Wind (offshore, farther than 5 km),	Constant
	1.0~2.5	Geothermal Tidal (without embankment)	Variable
	5.5~4.5	ESS + Wind	2015~2017

ESS = energy storage system, IGCC = integrated gasification combined cycle, kW = kilowatt, REC = renewable energy certificate.
Source: Korea Energy Agency, 2017.

2) R&D investments

Lack of experience and technologies is another obstacle to geothermal power generation in Korea. As an example, a pilot geothermal power generation plant project was started at the end of 2010, targeting 1 MW_e capacity from a doublet system from the depth of about 4.5 km. Most of the development technologies used came from abroad including deep drilling technologies, stimulations at depth, well loggings, etc.

One of the most critical technical barriers is reservoir creation to commercial scale. Reservoir creation in EGS technology depends upon the success of hydraulic stimulation by massive injection of water accompanying real-time monitoring of induced seismicity along with injection pressure. Injection strategy based on in-situ hydraulic parameters is not mature enough and there is not enough experience to go with it. Thus, a novel approach of enhancing injectivity as a result of hydraulic stimulation should be a main focus of technology innovation. Target injectivity or productivity is an order of 1.0 L/sec/bar or 10.0 L/sec/MPa while magnitude of induced seismicity should remain lower than 2.0 in M_L scale. Investment in infrastructure for those technologies is also needed such as drilling tools and logging tools for high pressure and high temperatures.

Table 3.4.3-4. Geothermal R&D Expenditures in 2012–2017 (in *US$1,000)

	2012	2013	2014	2015	2016	2017
Government	11,056	7,259	11,603	9,232	6,464	**5,842**
Industry	3,577	1,628	15,171	5,772	2,530	**2,073**
Total	**14,633**	**8,887**	**26,775**	**15,004**	**8,994**	**7,915**

*Exchange rates (in W–US$) are as of 01 July each year such as W1,174 (2012), W1,165 (2013), W1,029 (2014), W1,140 (2015), W1,168 (2016), and W1,165 (2017).
Source: Song and Lee, 2018.

Table 3.4.3-4 shows the geothermal R&D expenditures for the past six years (Song and Lee, 2018). One can see a considerable decrease of R&D investment in 2016 due to the government’s decision to end funding to the Pohang EGS project in 2015. R&D funding for geothermal power development was further decreased in 2017. Unfortunately, geothermal power exploration may not be expected for the time being due to the Pohang earthquake.

3) Legal and supporting schemes

There is no legal framework or supportive measures for geothermal power generation other than the RPS system. This lack of legal framework is a major barrier hindering active industry participation in geothermal business. Depending on sites and situations, geothermal power development in Korea is related to various laws on groundwater, hot spring, construction and environment, and mining. A separate geothermal law is yet to be set up but is expected to be part of mining laws.

The geothermal industries are continuously asking the government to provide stronger incentives or supporting schemes for geothermal power generation. Geothermal resource exploration for prospective regions over the country, risk sharing, or insurance schemes for deep drilling or exploration drilling can promote the geothermal business.

4.4 Benefits of geothermal power generation in Korea

4.4.1 CO_2 emission reduction (kg-CO_2/kW)

So far, enhanced/engineered geothermal system (EGS) is the only way of generating geothermal power in Korea. The capacity factor of the EGS binary system is assumed to be 85%, slightly higher than conventional geothermal power plant. The CO_2 emission factor of electricity generation in Korea is 0.443 tonne-CO_2/MWh (Korea Power Exchange, 2011), which is the average for all power sources. Assuming that the CO_2 emission factor by EGS geothermal is 0.038 tonne-CO_2/MWh (https://en.wikipedia.org/wiki/Life-cycle greenhouse - gas emissions of energy sources) and applying the short-term target of 20 MW_e and the long-term target of 800 MW_e additional capacity with estimated EGS capacity factor of 85%, the annual CO_2 reduction is:

For short-term target: $405 \times 20 \times 24 \times 365.25 \times 0.85 = 60{,}353{,}910$ kg-CO_2/year.

For long-term target: $405 \times 800 \times 24 \times 365.25 \times 0.85 = 2{,}414{,}156{,}400$ kg-CO_2/year.

4.4.2 Other direct and indirect effects to local economy

Because Korea does not have an operational geothermal power plant, no data are available for new employment as well as other direct or indirect effects to local economy of geothermal power generation. Thus, benefits of geothermal power generation in Korea has been calculated using common reference data as described in Chapter 2 except electricity sales price. In Korea, electricity sales price (system marginal price) fluctuates all the time depending on world oil price and domestic electricity consumption. The average system marginal price for 2017 was W81.5/kw-h, which is about US$0.076/kw-h. Sales tax is fixed to 10%.

4.4.3 Summary of barriers to and benefits of geothermal power generation

Table 3.4.4-1 and 3.4.4-2 show barriers to geothermal energy use in Korea and expected benefits for short-term and long-term targets if barriers are removed.

Table 3.4.4-1. Barriers to Geothermal Power Generation in Korea and Expected Benefits for Short-term Target by 2025

item		unit	Policy	Social	Legal	Fiscal	Technical	Total	remarks		
Barrier		%	17	24	10	19	30	100			
Target capacity		MW	3.4	4.8	2	3.8	6	20	from "CO2-Cost" Table		
Target power generation		MW-h/year	25,334	35,765	14,902	28,314	44,707	149,022	85%	capacity factor	
	electiricity	J(elect)/year	9.12E+13	1.29E+14	5.36E+13	1.02E+14	1.61E+14	5.36E+14		kWh= 3.6×10^6J	
	equivalent	J(heat)/year	2.28E+14	3.22E+14	1.34E+14	2.55E+14	4.02E+14	1.34E+15	suming 40% efficiency		
Saving land (compared to same power by PV)		m^2	4.53E+05	6.40E+05	2.67E+05	5.06E+05	8.00E+05	2.67E+06	from "Land" Table		
Electricity sales	developer's benefit	USD/year	1,950,698	2,753,927	1,147,469	2,180,192	3,442,408	11,474,694	0.08	USD/kW-h	USD
Electricity sales tax	government's benefit	USD/year	195,070	275,393	114,747	218,019	344,241	1,147,469	10%		
Saving oil (barrel of oil equivalent)		boe/year	37,256	52,596	21,915	41,639	65,745	219,150	1boe≈ 6.12×10^9J(heat)		
CO2 mitigation		(kg-CO2/yr)	10,260,165	14,484,938	6,035,391	11,467,243	18,106,173	60,353,910	from "CO2-Cost" Table		
Saving energy cost compared to PV	Factor	USD/MWh	5.100	7.200	3.000	5.700	9.000	30			compared to PV
	Total saving	USD	760,012	1,072,958	447,066	849,425	1,341,198	4,470,660			
Saving CO2 reduction cost compared to PV	Factor	USD/kg-CO2	0.013	0.018	0.008	0.014	0.023	0.08			
	Total cost	USD	772,422	1,090,478	454,366	863,295	1,363,098	4,543,659			
Land Saving for CO_2 reduction compared to	Factor	m2/kg-CO2	-	-	-	-	-	30.34	from "Land" Table		
	Toal saving	m2	311,252,851	439,415,789	183,089,912	347,870,833	549,269,737	1,830,899,122	for mitigation of 19I		
Benefit for local economy											
new employment			22	31	13	24	38	127		2.71x+73	
new business profit		USD	6,081	8,585	3,577	6,796	10,731	35,769	1,788	1788.47x	NZ example
new business sales tax		USD	608	858	358	680	1,073	3,577	10%		
new business economic effect		USD	7,602	10,733	4,472	8,497	13,416	44,720	2,236	2236x	NZ example

boe = barrel of oil equivalent, CO_2 = carbon dioxide, kWh = kilowatt-hour, m^2 = square metre, MW = megawatt, MWh = megawatt hour, NZ = New Zealand, PV = photovoltaics.
Source: The study team.

Table 3.4.4-2. Barriers to Geothermal Power Generation in Korea and Expected Benefits for Long-term Target by 2050

item		unit	Policy	Social	Legal	Fiscal	Technical	Total	remarks		
Barrier		%	17	24	10	19	30	100			
Target capacity		MW	136	192	80	152	240	800	from "CO2-Cost" Table		
Target power generation		MW-h/year	1,013,350	1,430,611	596,088	1,132,567	1,788,264	5,960,880	85%	capacity factor	
	electiricity	J(elect)/year	3.65E+15	5.15E+15	2.15E+15	4.08E+15	6.44E+15	2.15E+16		kWh= 3.6×10^6J	
	equivalent	J(heat)/year	9.12E+15	1.29E+16	5.36E+15	1.02E+16	1.61E+16	5.36E+16	suming 40% efficiency		
Saving land (compared to same power by PV)		m^2	1.81E+07	2.56E+07	1.07E+07	2.03E+07	3.20E+07	1.07E+08	from "Land" Table		
Electricity sales	developer's benefit	USD/year	78,027,919	110,157,062	45,898,776	87,207,674	137,696,328	458,987,760	0.08	USD/kW-h	USD
Electricity sales tax	government's benefit	USD/year	7,802,792	11,015,706	4,589,878	8,720,767	13,769,633	45,898,776	10%		
Saving oil (barrel of oil equivalent)		boe/year	1,490,220	2,103,840	876,600	1,665,540	2,629,800	8,766,000	1boe≈ 6.12×10^9J(heat)		
CO2 mitigation		(kg-CO2/yr)	410,406,588	579,397,536	241,415,640	458,689,716	724,246,920	2,414,156,400	from "CO2-Cost" Table		
Saving energy cost compared to PV	Factor	USD/MWh	5.100	7.200	3.000	5.700	9.000	30			compared to PV
	Total saving	USD	30,400,488	42,918,336	17,882,640	33,977,016	53,647,920	178,826,400			
Saving CO2 reduction cost compared to PV	Factor	USD/kg-CO2	0.013	0.018	0.008	0.014	0.023	0.08			
	Total cost	USD	30,896,883	43,619,130	18,174,637	34,531,811	54,523,912	181,746,373			
Land Saving for CO_2 reduction compared to	Factor	m2/kg-CO2	-	-	-	-	-	30.34	from "Land" Table		
	Toal saving	m2	12,450,114,031	17,576,631,573	7,323,596,489	13,914,833,328	21,970,789,466	73,235,964,886	for mitigation of 19I		
Benefit for local economy											
new employment			381	538	224	426	672	2,241		2.71x+73	
new business profit		USD	243,232	343,386	143,078	271,847	429,233	1,430,776	1,788	1788.47x	NZ example
new business sales tax		USD	24,323	34,339	14,308	27,185	42,923	143,078	10%		
new business economic effect		USD	304,096	429,312	178,880	339,872	536,640	1,788,800	2,236	2236x	NZ example

boe = barrel of oil equivalent, CO_2 = carbon dioxide, kWh = kilowatt-hour, m^2 = square metre, MW = megawatt, MWh = megawatt hour, NZ = New Zealand, PV = photovoltaics.
Source: The study team.

4.5 Summary of barriers to and benefits of geothermal power generation, and policy recommendations

Because high-enthalpy geothermal source cannot be expected near the surface in Korea, it is inevitable to go deeper to get high-temperature geothermal resources for power generation. Most major barriers to geothermal power generation in Korea directly relate to this fact, such as high exploration costs, weak economic feasibility, and various technological barriers. In terms of technology development for deep drilling and reservoir management, the top five barriers based on survey results are high exploration cost (14.3%), lack of drilling technology (9.7%), lack of experts (8.7 %), national energy policy (8.3 %), and reservoir management (7.7%).

According to the national roadmap, geothermal power's installed capacity will be 20 MW_e by 2030, which can generate 149.0 GWh of electricity and contribute 60,354 tonnes of CO_2 mitigation. To reach the goal, stronger governmental support is essential especially on infrastructure, technologies, and legislation for deep subsurface exploration and development.

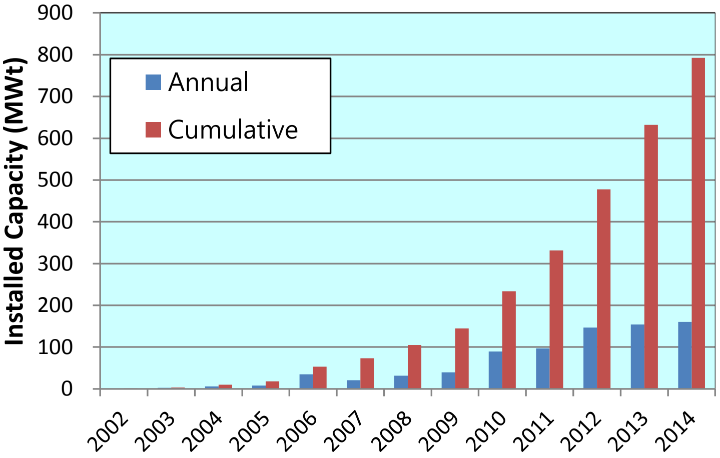
- Although the RPS system secures one of the highest RECs to geothermal power development, more incentives are needed until the EGS technology matures.
- Strong R&D investments are needed, especially to infrastructure for deep exploration and EGS technology such as reservoir creation in commercial scale.
- Legal framework and supportive schemes, such as separate geothermal law and risk sharing by insurance systems for deep drilling and exploration.
- Also needed is direct support for exploration in prospective regions and risk sharing or insurance schemes for exploration drilling.

4.6 Barriers to GSHP use, and necessary innovations

4.6.1. Brief history of GSHP use and barriers in Korea

Figure 3.4.6-1 shows the increasing trend of GSHP installation in Korea, with above than the average 50% annual increase up to 2010, and 100 MW_t installations per year since 2012, mainly due to the strong drive by the government through mandatory Acts and active subsidy programmes, such as the Deployment Subsidy Program, the Rural Deployment Program, the 1 Million Green home by 2020 Program, and the Greenhouse Deployment Program. About 75% of the installations use vertical closed loop system for ground heat exchanger, about 16% use groundwater source, mostly standing column well type, and 5.5 % use horizontal loop type (Kwon et al., 2012).

Figure 3.4.6-1. Trend of GSHP Installation in Korea



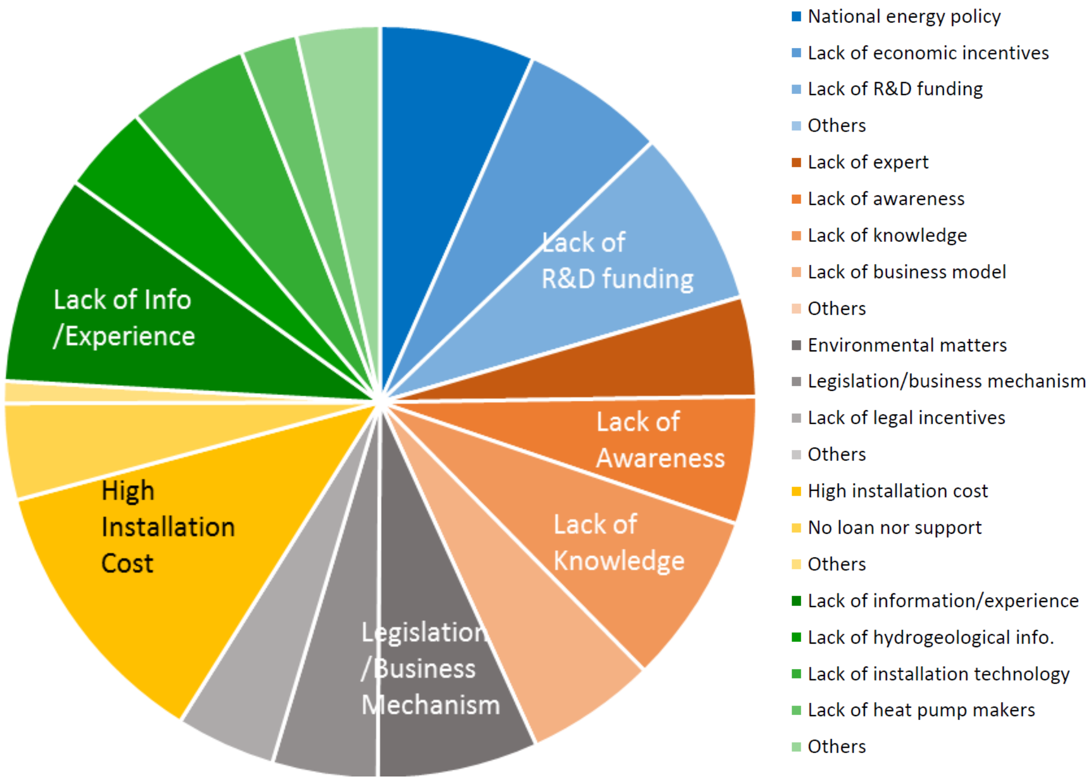
MW_t = megawatt thermal.
Source: Song and Lee, 2015.

4.6.2. Barriers

Figure 3.4.6-2 shows the results of survey among domestic experts on barriers to GSHP use in Korea. The results show that the major barriers to GSHP are high installation cost (11.9%), lack of information/experience (9.0%), lack of R&D funding (7.6%), lack of knowledge (7.4%), and environmental matters (6.9%).

Korea has seen remarkable increase of GSHP installation in the last ten years: more than 50% increase annually or more than 100 MW_t new annual installations since 2013. Such high increase is mainly due to legislation (renewable mandatory Act) and strong government subsidy programmes which may be terminated after some years although there is yet no clear target ending year. The government expects the private sector to be competent in the market without the supporting measures, but the business side is not mature enough in terms of either technology or business. This aspect may lead domestic experts to raise those issues as the most important barriers to be removed. High installation cost is the most common barrier to GSHP business and should be the top priority to be resolved. One thing to note is that domestic experts especially raise the issues of environmental matters (6.9%) including the leakage of circulation fluids within boreholes, and R&D funding (7.6%) for wider application of GSHP as well as reducing installation costs.

Figure 3.4.6-2. Results of Inquiry to Korean Experts on Barriers to GSHP



R&D = research and development.
Source: Authors.

4.6.3. Necessary innovations

The main technical barriers to GSHP systems in Korea are high installation cost, which relates to economic feasibility; and lack of knowledge, information, or awareness. Of the two major innovative ideas needed to hurdle such barriers, one must come from the government while the other one needs efforts from experts in GSHP.

1) Geothermal-specific policy

Amongst the various barriers to the GSHP system in Korea, one of the most significant is the lack of geothermal-specific policy that can drive more efficient installation accounting for climate condition, load characteristics of building type, and hydrogeologic situation. This affects business expansion to residential application.

2) Monitoring

Heating and cooling loads of buildings vary depending on their main functions or purposes. For example, residential houses generally need more heating than cooling and longer heating hours, which is not true for office buildings. Therefore, to estimate the environmental and economic benefits of GSHP and its potential, we must estimate how much loads a specific building type needs, measured as equivalent full load hours per annum.

Accurate monitoring of load factors and system COPs (or SPF_2) of major application types (residential houses, public and commercial buildings, greenhouses, etc.) is the most critical issue to be resolved both in terms of technical barriers and supportive schemes like renewable heat obligation, which is analogous to RPS in power generation. Monitoring of the system COP should include flow rates and temperature difference both at load side (building loops) and at source side (ground loops). In addition, there must be designed a standard procedure in proper installation of temperature sensors, flow meters and electricity (watt-hour) meter, and data logging system. Separate monitoring of electricity consumption of circulation pump for ground loop is critical in accurate estimation of the system COP.

4.7 Benefits of GSHP use in Korea

Adding the business-as-usual model estimate of 1,675 MW_t, the additional potential of GSHP installation by 2025 is expected to be as much as 1,750 MW_t if barriers are removed. Thus, considering the load factors of different applications as described in Table 3.4.7-1 using equivalent full load hours, annual heating energy production of geothermal energy for heating in 2025 becomes

$$1{,}750 \times 1{,}800 \times (1-3.73)/3.73 = 2{,}305.8 \text{ GWh } (= 8{,}300.9 \text{ TJ})$$

and annual cooling energy production of

$$1{,}750 \times 540 \times (1-4.75)/4.75 = 745.6 \text{ GWh } (= 2{,}684.2 \text{ TJ})$$

which corresponds to additional annual CO_2 saving of 1,207,064 tonnes-CO_2 (Table 3.4.7-2) compared to conventional air conditioners, and 942,948 tonnes-CO_2 compared to oil boilers (Table 3.4.7-3), plus 244,204 tonnes-CO_2 by cooling compared to conventional air conditioners (Table 3.4.7-4).

Table 3.4.7-1. Equivalent Full Load Hours and Nominal Coefficient of Performance for Heating and Cooling of Different Application Types of GSHP

		EFLH	COP
Residential House	Heating	1,800	3.73
	Cooling	540	4.75
Industry Application	Heating	570	3.73
	Cooling	590	4.75

COP = coefficient of performance, EFLH = equivalent full load hours, GSHP = ground source heat pump.

Source: Paek et al., 2015.

Table 3.4.7-2. Calculation of CO_2 Savings by GSHP Compared to Conventional Air Conditioner (heating mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Heating effect (GWh)	Electricity consumed by GSHP (GWh)	Electricity consumed by AC (GWh)	Electricity Saving (GWh)	National average CO_2 emission factor (kg-CO_2/kWh)	CO_2 mitigation (tonne-CO_2)
A	B	C	D	E	F	G	H	I	J
1750	1800	3.73	2	11749.5	3150.0	5874.8	2724.8	0.443	1,207,064

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, MW = megawatt.
Source: The study team.

Table 3.4.7-3. Calculation of CO_2 Savings by GSHP Compared to Oil Boiler (heating mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for heating	System COP of AC for heating	Net heat energy production (GWh)	CO_2 saving factor (tonne/GWh)	CO_2 mitigation (tonne-CO_2)
1750	1800	3.73	2	2305.5	409	942,948

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, MW = megawatt.
Source: The study team.

Table 3.4.7-4. Calculation of CO_2 Savings by GSHP Compared to Air Conditioner (cooling mode)

Installed capacity/ installation capacity (MW)	Equivalent full load hours (EFLH) per year (h)	System COP of GSHP for cooling	System COP of AC for cooling	Heating effect (GWh)	Electricity consumed by GSHP (GWh)	Electricity consumed by AC (GWh)	Electricity Saving (GWh)	National average CO_2 emission factor (kg-CO_2/kWh)	CO_2 mitigation (tonne-CO_2)
A	B	C	D	E	F	G	H	I	J
1750	540	4.75	3	4488.8	945.0	1496.3	551.3	0.4	244,204

AC = air conditioner, CO_2 = carbon dioxide, COP = coefficient of performance, GSHP = ground source heat pump, GWh = gigawatt hour, kg = kilogramme, MW = megawatt.
Source: The study team.

4.8 Summary of barriers to and benefits of GSHP use in Korea, and policy recommendations.

GSHP system installation in Korea increased remarkably in the last 10 years, mainly due to legislation and strong government subsidy programmes such as New and Renewable Energy Development Act, Greenhouse Subsidy Program, Mandatory Public New and Renewable Energy Use Act, as well as the support on the electricity price system. With those supporting schemes, the Korean government expects the private sector to be competent in the market without the supporting measures, but the business side is still not mature in terms of either technology or business.

Major barriers to GSHP in Korea that came from survey results are listed below. High installation cost is the most common barrier in GSHP business and should be the top priority to be resolved. It is worth noting that domestic experts especially raise the issues of environmental matters (6.9%) including the leakage of circulation fluids within boreholes, and R&D funding (7.6%) for wider application of GSHP as well as reduction of installation costs.

Also, according to domestic experts, most GSHP companies do not have long-term perspectives regarding their business. It is absolutely necessary that GSHP business show actual benefits or actual COP of GSHP based on the long-term monitoring to request the followings to the government:

- geothermal-specific policy to give high incentives to more efficient installation, accounting for the geological, hydrological, and load characteristics of the target building; and
- accurate monitoring schemes of load factors and the system COPs for both technical and social awareness of GSHP’s benefits and supportive schemes such as renewable heat obligation.

Business-as-usual model estimates that total installation of GSHP systems in 2025 will be 1,675 MW_t that is equivalent to 1,226.7 GWh (= 4,416.2 TJ) of annual geothermal energy use for heating. Additional potential of GSHP installation by 2025 is expected to be as much as 1,750 MW_t, which corresponds to installation in 100,000 houses and annual heating energy production of 2,305.8 GWh (= 8,300.9 TJ). Total annual heating energy production can thus be 3,532.5 GWh in 2025. Noting the fact that Korea imports 95% of TPES, domestic energy production is very important. Additional GSHP installation by 2025 can mitigate 1.45 million tonnes of CO_2 emission (1.2 million tonnes from heating and 0.24 million tonnes from cooling) compared to conventional air conditioners.

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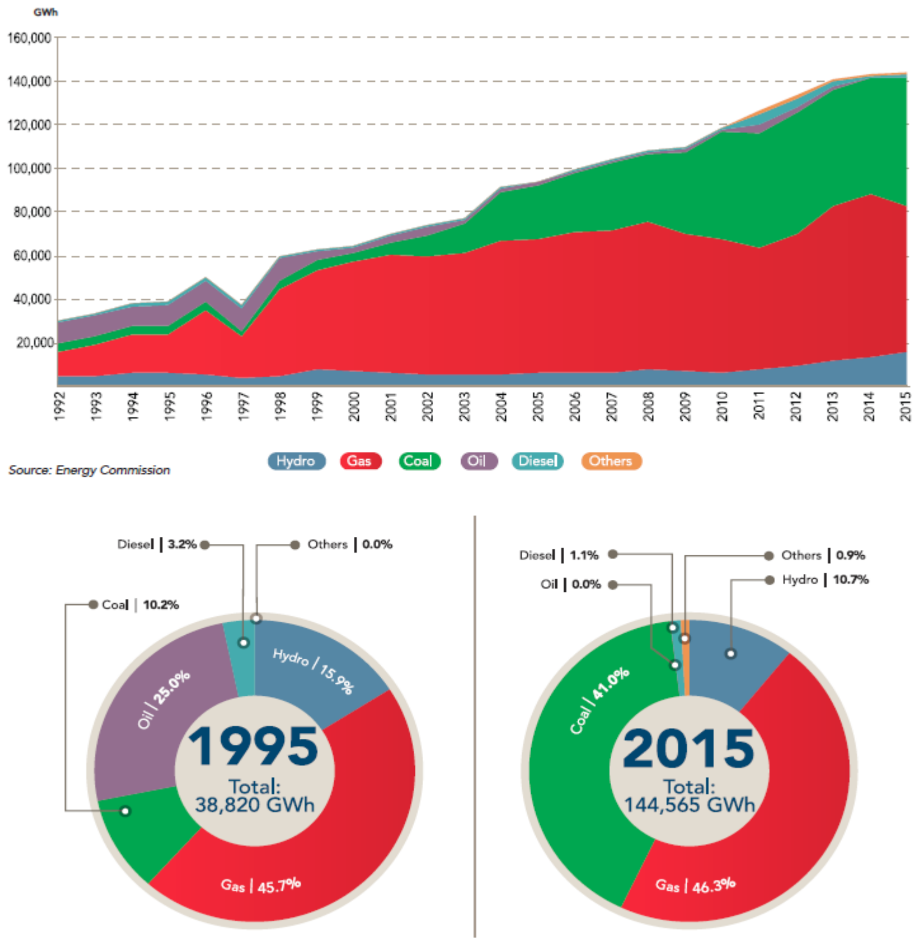
5. Malaysia

5.1 Current situation of geothermal energy use and national policy

5.1.1 Current energy policy and energy mix

Malaysia's energy sector has matured considerably in the last 30 years, from merely relying on fossil fuels to diversifying its energy mix with renewable energy. The country is working towards the new era of sustainable energy in line with the commitment expressed in its intended nationally determined contribution report to the United Nations Framework Convention on Climate Change in November 2015. The intended nationally determined contribution report stipulates Malaysia's intent to reduce its greenhouse gas emissions intensity of gross domestic product by 45% by 2030 relative to the emissions intensity of GDP in 2005. This consists of 35% on an unconditional basis and a further 10% conditional upon receipt of climate finance, technology transfer, and capacity building from developed countries. The country's electricity generation mix in 1992–2015 is shown in Figure 3.5.1-1.

Figure 3.5.1-1. Electricity Energy Mix in Malaysia, 1992–2015



Source: Energy Commission

GWh = gigawatt hour.

Source: Malaysia Energy Statistic Handbook, 2016.

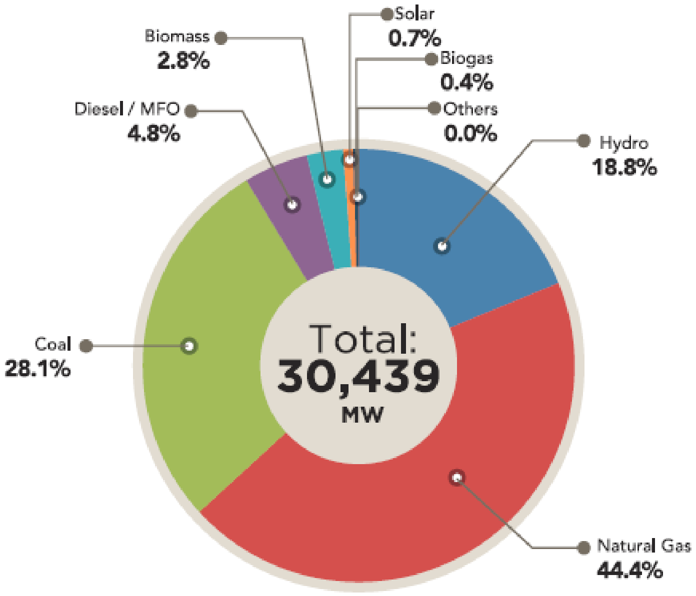
Renewable energy debuted in Malaysia in 2011 with the Renewable Energy Act, 2011 (Act

725), which provides a legal framework for feed-in tariff (FiT) to operate, and the Sustainable Energy Development Authority Act 2011 (Act 726), which provides the legal framework for the establishment of the Sustainable Energy Development Authority of Malaysia (SEDA Malaysia).

The FiT mechanism allows electricity produced from an indigenous renewable energy source to be sold to authorised power utility companies at a fixed premium price for a specific duration. The primary goal of FiT is to offer cost-based compensation to renewable energy producers, provide price certainty, and establish long-term contracts that would improve the bankability of renewable energy projects. Currently, five renewable sources are eligible for the FiT mechanism: biomass (including solid waste), biogas (including landfill gas and sewage), small hydro, solar photovoltaic, and geothermal resource.

Malaysia's total installed capacity as of the end of 2015 was 30,439 MW, an increase of 1.5% from 29,974 MW in 2014 **(**Figure 3.5.1-2). Today, the generation of electricity from renewables such as solar, biomass, and biogas has expanded in scale, attaining about 1% in the energy generation mix in 2015. Moving forward, the percentage of renewables is expected to increase gradually to address environmental and climate change concerns.

Figure 3.5.1-2. Malaysia's Installed Capacity as of 31 December 2015



MFO = marine fuel oil, MW = megawatt.

Source: National Energy Balance, 2015.

As of 31 December 2017, SEDA Malaysia approved a cumulative 12,143 feed-in tariff approval applications with a total capacity of 1,632.87 MW. Table 3.5.1-1 shows the approved projects and operational plants in Malaysia as of 31 December 2017.

Table 3.5.1-1. Approved Renewable Energy Projects in Malaysia Under FiT Mechanism as of 31 December 2017

No.	Renewable Energy Source	No. of Projects	Capacity (MW)	Percentage (%)
1	Biogas	125	220.86	13.53
2	Biomass	44	396.19	24.26
3	Small hydro	60	538.48	32.98
4	Geothermal	1	37.00	2.27
5	Solar PV	11,863	440.19	26.96
	Total	12,143	1,632.87	100.00

MW = megawatt, PV = photovoltaics.

Note: The project timeline for the approved projects is until 2019.

Source: SEDA Malaysia, 2017.

Table 3.5.1-2. Operational Plants in Malaysia Under FiT Mechanism as of 31 December 2017

No.	Renewable Energy Source	No. of Projects	Capacity (MW)
1	Biogas	30	55.83
2	Biomass	8	87.90
3	Small hydro	6	30.30
4	Geothermal	-	-
5	Solar PV	8,993	354.03
	Total	9,037	528.06

MW = megawatt, PV = photovoltaics.

Source: SEDA Malaysia, 2017.

3.5.1.2 Geothermal energy potential in Malaysia

a) Peninsular Malaysia Region

The geothermal survey at Ulu Slim, Perak, conducted from January 2014 to April 2016, was a collaboration of SEDA Malaysia and Department of Mineral & Geoscience. Based on the survey, the estimated resource potential is 148 MW.

The remaining sites (hot springs) in Peninsular Malaysia that need to be further explored to determine their geothermal resource potential are Lojing in Kelantan, Ulu Langat and Batang Kali in Selangor, and Sungai Denak in Perak.

Figure 3.5.1-3. Potential Geothermal Resource in Peninsular Malaysia

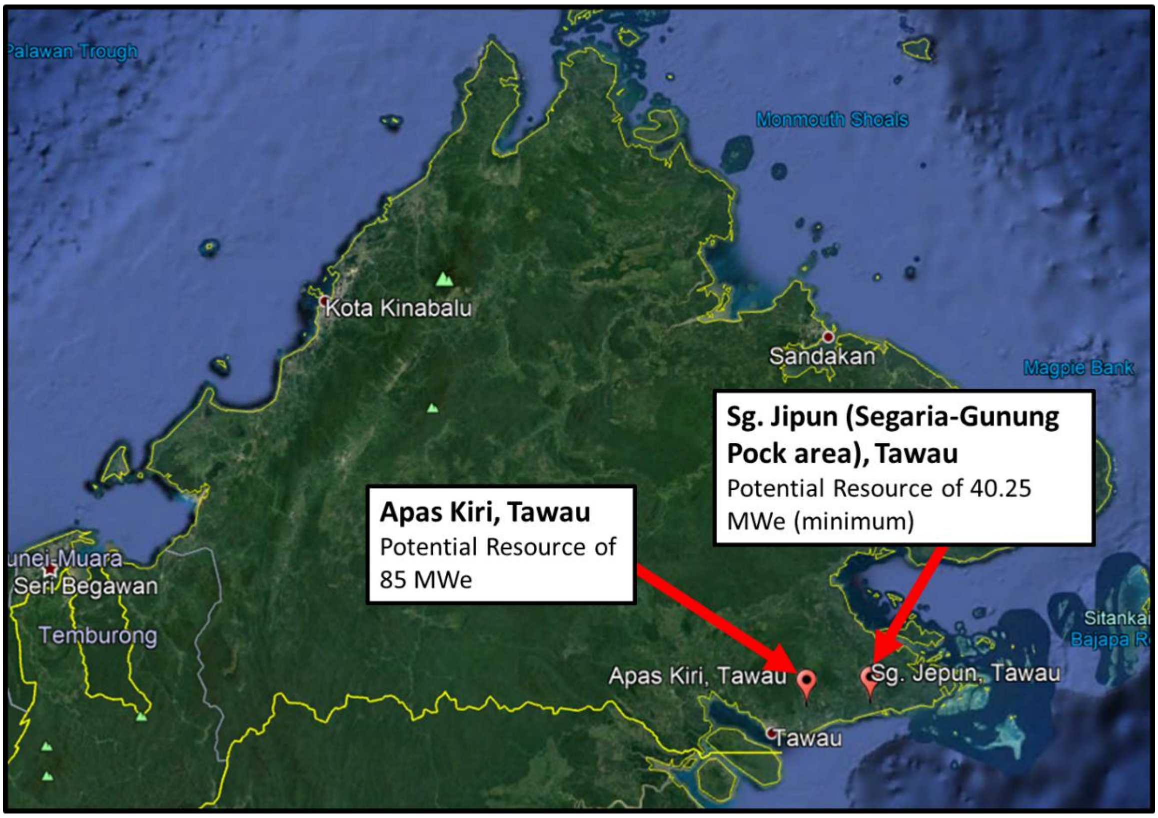
MW =megawatt
Source: Google Maps.

b) Sabah/Labuan Region

Based on a geothermal survey by Department of Mineral and Geoscience Malaysia (2009), the initial estimated resource potential in Apas Kiri, Tawau, Sabah, was 67 MW$_e$, but recalculated by Tawau Green Energy Sdn Bhd to be 85 MW$_e$ (Barnett, 2010). Tawau Green Energy Sdn Bhd is developing a 37-MW geothermal power plant under SEDA Malaysia's FiT scheme, which will be operational by 2019.

Another area surveyed by Department of Mineral and Geoscience Malaysia (JMG) for geothermal potential is the Segaria–Sungai Jipun–Gunung Pock area in Kunak. Based on preliminary calculation, this area has a minimum capacity of 40.25 MW$_e$ (JMG, 2014).

Figure 3.5.1-4. Potential Resource in East Malaysia (Sabah)



MWe= megawatt electric

Note: The volume of geothermal resource potential in Peninsular Malaysia and Sabah/Labuan is based on preliminary study. Further exploration is needed to get more accurate data.

Source: Google Maps.

5.2 Target geothermal power generation in Malaysia

Table 3.5.2-1 shows geothermal potential of three regions in Malaysia.

Only the Apas Kiri, Tawau, site has obtained approval from SEDA Malaysia under the FiT scheme to build a 37-MW geothermal power plant which is scheduled to operate in 2019. Increasing the capacity to about 30 MW every 4 years is planned until the plant has reached its full resource potential.

As for the other sites, the Apas Kiri, Tawau, site is being developed and, if successful, can be a benchmark to develop other potential sites. It is assumed that by 2050, all potential geothermal resources in Malaysia could be developed once the Apas Kiri, Tawau, project becomes successful and all barriers are removed. In addition, a total of 902 new employment (estimation) may be available for the local population.

Table 3.5.2-1. Geothermal Resource Potential in Malaysia

	Potential (MW)	Achievable by 2025 (MW)	Achievable by 2050 (if all barriers are removed) (MW)
Ulu Slim, Perak (Peninsular Malaysia)	148.00	148	148.00
Apas Kiri, Tawau (Sabah)	85.00	85.00	85.00
Sg. Jipun, Tawau (Sabah)	40.25	40.25	40.25
Total	273.25	273.25	273.25

MW = megawatt.

Note: Figures are calculated based on potential reserve estimation and the assumption of zero barrier.

Source: The study team.

The values shown as 'Achievable by 2025' are considered to be achievable in the current situation. Therefore, if the existing barriers are removed, we assume that the geothermal resources ready to be developed by 2025 would be about 250 MW.

5.3 Barriers to geothermal energy use, and necessary innovations

5.3.1 Analysis of the results of inquiry on barriers

This study aims to identify barriers that hinder geothermal development in Malaysia. To determine the type of barriers, a survey was conducted among domestic experts, which include energy producers, developers, university professors, consultants, and other stakeholders.

Although 60 survey forms were distributed, only 13 people responded (21.7%). Although considered very low, the response covered a wide range of professions, which include the developers of the Apas Kiri Geothermal Resource. The other respondents include an officer of the Tenaga Nasional Berhad, a university professor, private consultants, and others.

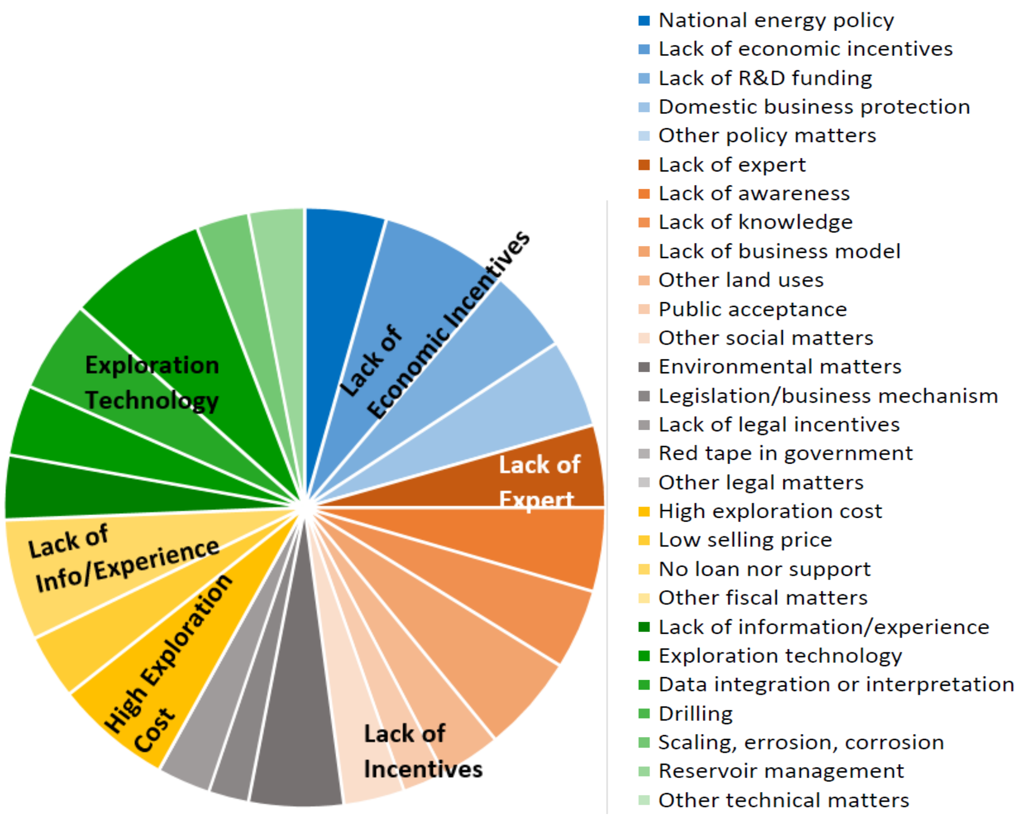
Table 3.5.3-1 shows the results of inquiry among domestic experts on barriers to geothermal power generation in Malaysia. Based on the results, all barriers are similar in percentages. Nonetheless, the greatest barriers are drilling, lack of economic incentives, no loan nor support, high exploration cost, and lack of business models (Figure 3.5.3-1). This indicates that all the relevant barriers have been considered and there is a need to address the problems.

Table 3.5.3-1. Results of Inquiry to Domestic Experts and Stakeholders in Malaysia

Barrier Category	Percentage	Barriers	Result
Policy	19%	National energy policy	6.7%
		Lack of economic incentives	10.5%
		Lack of R&D funding	6.9%
		Domestic business protection	7.3%
		Other policy matters	0.0%
Social	25%	Lack of experts	6.8%
		Lack of awareness	6.9%
		Lack of knowledge	6.6%
		Lack of business models	8.0%
		Other land uses	5.0%
		Public acceptance	3.5%
		Other social matters	5.0%
Legal	11%	Environmental matters	7.8%
		Legislation/Business mechanism	3.3%
		Lack of legal incentives	4.4%
		Red tape in government	0.0%
		Other legal matters	0.0%
Fiscal	17%	High exploration cost	9.6%
		Low selling price	5.3%
		No loan nor support	10.0%
		Other fiscal matters	0.0%
Technical	28%	Lack of information/experience	5.3%
		Exploration technology	5.8%
		Data integration or interpretation	7.6%
		Drilling	11.6%
		Scaling, erosion, corrosion	4.3%
		Reservoir management	4.6%
		Other technical matters	0.0%
TOTAL	100%		100.0%

Source: Authors.

Figure 3.5.3-1. Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in Malaysia



Source: Original figure of this project.

Of the inquiries, selections of samples were carefully made. The survey was developed with inputs from geothermal developers, exploration consultants, policymakers, investment authorities, energy-related personnel, university lecturers, and scientists. The results obtained reflect the current situation in Malaysia.

Based on the results, technical and social barriers are highest. Note that two barriers in fiscal barriers – high exploration cost and no load nor support – are biggest barriers although the fiscal barriers category is not dominant.

Barriers in the technical category include lack of information, lack of experience, lack of exploration technology, lack of data integration or interpretation, and cost of drilling. Barriers under the social category include lack of experts, lack of awareness, lack of knowledge and, most importantly, lack of business models.

5.3.2 Innovative ideas to remove barriers

Based on the analyses of barriers, the top four barriers fall under different categories as follows:

a) Technical: Drilling

b) Policy: Lack of economic incentives

c) Fiscal: No loan nor support

d) Social: Lack of business models

In offering an innovative economic support system for geothermal power generation business, the government can adopt a method used in Japan. To remove or offset the high drilling costs, the Japanese government gives drilling incentives, low-interest loans, feed-in tariff, and tax-reduction incentives to investors to encourage them to develop geothermal energy sources. Japan also initiates preliminary model/good data capture, which is sufficient for investors to decide on whether a geothermal resource reservoir is worth investing in. Other than that, technical expertise and technology transfer are needed for capacity building and attaining independence in the development of geothermal energy resource in the country.

a) Drilling incentives

Drilling incentives from the government may encourage investors to participate in the development of geothermal plants in the country. These may be given from the exploration stage and up to the development and power generation stages.

The government should take some of the risks by co-funding drilling activities. In the event of failed wells, the government absorbs the losses. In the case of successful wells, the developer pays its portion of the drilling costs.

JMG may assist investors with technical know-how during the initial stages of exploration such as geophysical surveys, water samplings, and analyses. As JMG has the capabilities, it is worth for investors to use JMG expertise to help reduce drilling costs.

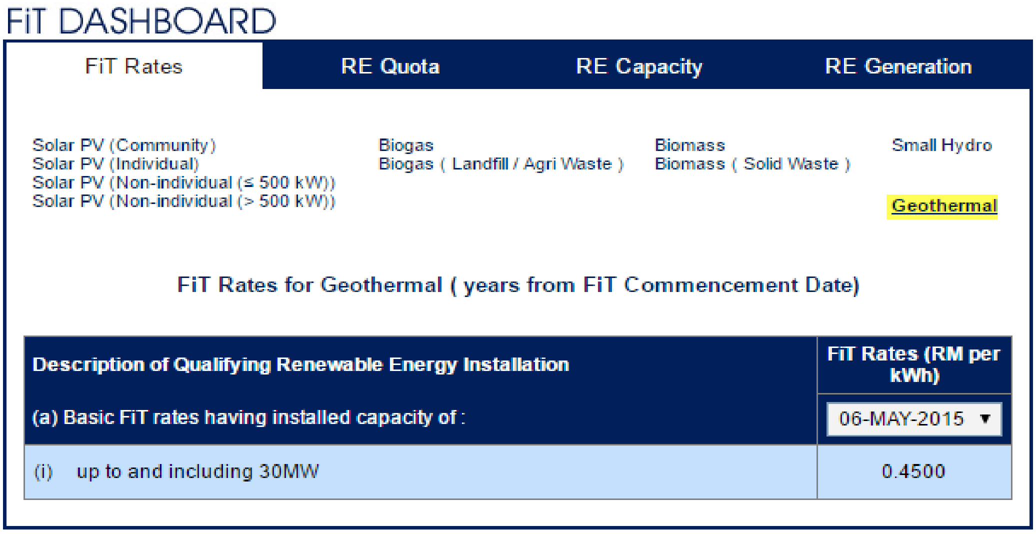
b) Low-interest loans

With the government’s support and assurance, low-interest loans should be provided by local banks to help the development of geothermal power plants. In turn, should the project be successful, banks will benefit by recovering their loans plus additional cumulative interests. The outcome of more renewable energy supplies is a country that will benefit in energy security and environmental preservation.

c) Feed-in tariff for geothermal power

The FiT mechanism obliges distribution licensees to buy renewable energy from feed-in approval holders via the Renewable Energy Power Purchase Agreement. The rates to be paid are as set out in the schedule of the Renewable Energy Act 2011. The FiT rate for geothermal energy is RM0.45/kWh (approximately US$0.12) (Figure 3.5-5).

Figure 3.5.3-2. FiT Dashboard by SEDA Malaysia



FiT Rates for Geothermal (years from FiT Commencement Date)

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)
(a) Basic FiT rates having installed capacity of :	06-MAY-2015 ▼
(i) up to and including 30MW	0.4500

FiT = feed-in-tariff, RE = renewable energy, PV = photovoltaics, MW = megawatt, kWh = kilowatt-hour.

Source: Sustainable Energy Development Authority Malaysia, 2018.

d) Tax reduction

Import duty exemptions for geothermal power projects should be introduced as most of the equipment and materials for drilling and power plants will be imported.

e) Technical expertise and technology transfer

To reduce technical barriers, various methods can be explored such as:

- Providing scholarships or research grants on geothermal energy to graduates (either local or abroad).
- Setting up geothermal centres of excellence or research centres in local universities to encourage collaboration with other universities (local and abroad) on research and development of geothermal energy.

- Encouraging the government to collaborate with other governments (Japan, USA, Philippines, etc.) and other international agencies that are well versed in geothermal energy regarding transfer of technology and policymaking

5.4. Benefits of geothermal use in Malaysia

5.4.1 Positive aspects of geothermal power

Geothermal power has positive aspects such as:

○ Relatively high capital expenditures (65%) but low operating expenses (35%) compared to fossil-fuel generated energy (e.g. CAPEX = 35%; OPEX = 65%);

○ Baseload generation with capacity factor averaging 90%

(Cf. nuclear = 90%, coal = 71%, hydro = 35%, solar = 20%);

○ Very small carbon footprint @ 0.09 kg CO_2/kWh

(Cf. coal=1.13 kg, fuel oils = 0.895 kg, natural gas = 0.60kg);

○ Readily coexists with natural habitat.

In Tawau, Sabah, a 37-MW_e electrical generation is equivalent to a 56 million tonnes of carbon equivalent eliminated annually, 13.5 trillion trees planted annually, and 45 million cars off the roads annually (refer to website portal of Tawau Green Energy (TGE) Sdn. Bhd. at www.tge.com.my).

5.4.2 CO_2 emission reduction

A study by Malaysia Green Technology Corporation entitled 'Study on Grid Connected Electricity Baselines in Malaysia (Year 2012, 2013 & 2014)' assessed the overall average emission factor for Peninsular Malaysia, Sabah, and Wilayah Persekutuan Labuan. CO_2 emission factor is calculated by year through energy production (MWh) baseline (Table 3.5.4-1).

Table 3.5.4-1. Overall Average Emission Factor for Peninsular Malaysia and Sabah

Year	Peninsular Malaysia (tCO_2/MWh)	Sabah/Labuan (tCO_2/MWh)
2012	0.741	0.546
2013	0.742	0.533
2014	0.694	0.536

MWh = megawatt hour, tCO_2 = total carbon dioxide.
Source: Malaysian Green Technology Corporation, 2014.

Based on CO_2 emission factor in the Peninsular Malaysia and Sabah/Labuan regions, CO_2 mitigation by geothermal power was calculated as follows.

Peninsular Malaysia Region

The estimated resource potential at Ulu Slim, Perak, is 148 MW. The annual power generation at this area can be calculated (assuming an 85% capacity factor) as follows:

148MW x 24h x 365d x 0.85 = 1,102,008 MWh

Considering the 0.013 tCO_2/MWh geothermal power plant emission factor (based on Japan studies), the emission factor for the Peninsular Malaysia region is 0.694 tCO_2/MWh. Hence,

(0.694 tCO_2/MWh - 0.013 tCO_2/MWh) x 1,102,008 MWh = 750,467.4 tonne-CO_2.

Sabah/Labuan Region

The estimated resource potential at Apas Kiri, Tawau, Sabah, is 85 MW. The annual power generation at this area can be calculated (assuming an 85% capacity factor) as follows:

85MW x 24h x 365d x 0.85 = 632,910 MWh.

Considering the 0.013 tCO_2/MWh geothermal power plant emission factor (based on Japan studies), the emission factor for the Sabah/Labuan region is 0.536 tCO_2/MWh. Hence,

(0.536 tCO_2/MWh - 0.013 tCO_2/MWh) x 632,910 MWh = 331,011.93 tonnes-CO_2.

Therefore, annual CO_2 mitigation of 750,467.4 + 331,011.93 = 1,081,479 tonnes-CO_2.

5.4.3 Other benefits

Other benefits are calculated following the procedures in Section 2.4.2.1 for the target capacity. The expected benefits by removal of each barrier category are calculated based on the barrier contributions shown in Table 3.5.3-1**.** The capacity factor of 70% is used in this calculation, taking global current mode of flush type geothermal power plants, although we expect higher capacity factor in the future. Again, note that these barriers are interrelated and removal of one barrier may stop further geothermal development. Nevertheless, this estimation gives insights to policymakers on the significance of benefits to be gained by barrier removal. Table 3.5.4-2 summarises the calculated benefits.

Table 3.5.4-2. Direct and (Expected) Indirect Benefits of Geothermal Power Generation by Removal of Barriers

Item		Unit	Barriers significance and benefits by removal of each barrier					Total benefit	Remarks
			Policy	Social	Legal	Fiscal	Technical		
Barrier significance		%	19	25	11	17	28	100	
Target capacity		MW	47.5	62.5	27.5	42.5	70	250	*W*
Target capacity factor		%						70%	*Cf*
a) Power generation		MWh/year	291,470	383,513	168,746	260,789	429,534	1,534,050	*W* x 24 x 365.25 x *Cf*
b) Annual fuel saving	by oil	barrel/year	368,932	485,437	213,592	330,097	543,689	1,941,748	11,096 *W x Cf*
	by LNG	kg/year	43,795,005	57,625,006	25,355,003	39,185,004	64,540,007	230,500,025	1,317,143 *W x Cf*
		Million Btu/year	2,157,250	2,838,487	1,248,934	1,930,171	3,179,105	11,353,947	0.04926 *W*
c) Saving foreign currency	by oil	US$/year	22,135,922	29,126,213	12,815,534	19,805,825	32,621,358	116,504,850	60.0 US$/Barrel
	by LNG	US$/year	10,786,250	14,192,434	6,244,671	9,650,855	15,895,526	56,769,735	5.0 US$/Btu
d) CO_2 mitigation		(tons-CO_2/yr)	205,481	270,370	118,963	183,851	302,814	1,081,479	from "CO_2" Table
e) Local employment		persons	143	188	83	128	210	751	2.71*W*+73
f) Saving lands compared to solar PV		m^2	5,297,105	6,969,875	3,066,745	4,739,515	7,806,260	27,879,500	111,518 *W*
(g) Expected profit of additional businesses		US$/year	84,953	111,780	49,183	76,010	125,194	447,120	1,788 *W*
(h) Expected local employee by additional businesses		persons	24	31	14	21	35	125	0.5 *W*
(i) Expected local economic effect of the additional		US$/year	106,210	139,750	61,490	95,030	156,520	559,000	2,236 *W*

Btu = British thermal unit, CO_2 = carbon dioxide, kg = kilogramme, LNG = liquefied natural gas, MW = megawatt, MWh = megawatt hour, PV = photovoltaics. For symbols *Cf* and *W*, please refer equation (1) in section 2.4.2.1.
Source: Authors.

5.5. Summary for policymakers

a) A total of 273.25 MW of potential geothermal resource can be developed for energy in Malaysia. A 37-MW geothermal power plant at Apas Kiri, Tawau, has been approved by SEDA Malaysia under the FiT scheme which is scheduled to operate in 2019 (expected).

b) The barriers hindering geothermal resource development in the country are identified as drilling, lack of economic incentives, no loan nor support, high exploration cost, and lack of business models.

c) Innovative ideas to tackle the barriers are drilling incentives, low-interest loans, feed-in tariff, tax reduction, technical expertise, and technology transfer.

d) The FiT mechanism has made significant contribution to two primary national issues faced by many countries: energy security and climate change mitigation. FiT also provides economic benefits such as increased employment and strengthened gross national income. Other positive impacts of FiT include improving social health, empowering and providing fairer wealth distribution, and environmental conservation.

e) It is estimated that 1,081,479.33 tonnes of CO_2 could be eliminated yearly when all the geothermal power plants are fully developed.

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6. Philippines

6.1 Current situation of geothermal energy use and national policy

The energy crisis in the early 1970s provided the impetus to initiate geothermal resource development in the Philippines. From 1976 to 1983, the geothermal power industry grew from zero to 981 MW_e. However, the growth of the geothermal power industry remained relatively stagnant until the 1990s when Republic Act 6957 or the Build–Operate–Transfer Law (BOT Law) was enacted, allowing the private sector to invest in infrastructure. The law provides assurance of cost recovery and ample profits. With the passage of the BOT Law, an additional 924 MW_e of geothermal power capacity was added to the Philippine grid system from 1996 to 2000.

Despite additional government interventions through the enactment of Republic Act 9136 or the Electric Power Industry Reform Act (EPIRA Law) in 2001, which was designed to bring down power rates and open the electricity sector to the private sector, and the Renewable Energy Act, enacted in 2008 to promote the development of renewable energy by granting fiscal incentives and feed-in tariff rates, the geothermal power industry grew only to its present installed capacity of 1906 MW_e.

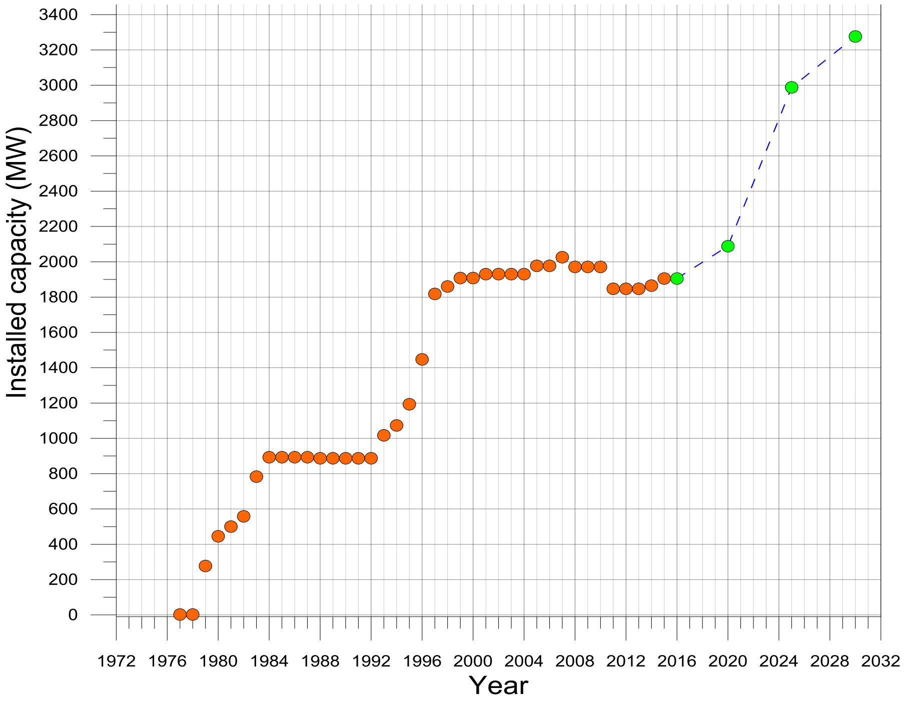
As of 2013, the Department of Energy (DOE) of the Philippines projected the installation of an additional 1090 MW_e through 2020, 1040 MW_e of which will come from the development of new areas while the remaining 50 MW_e will come from the expansion of existing geothermal production areas. To date, however, the target may not be met, judging from the current pace of geothermal resource development and power plant construction. Power plant construction to power plant commissioning normally takes two years, thus development and construction should have been actively started by now.

Geothermal resource concessions with estimated power potential of 1,124 MW_e were granted by DOE from 2010 to 2014. Despite this, only two of several concessions areas – Biliran and Naujan – have progressed to exploration drilling activities.

6.2 Target capacity estimation for geothermal power and direct use

Figure 3.6-3 shows the growth of installed geothermal capacities in the Philippines, comprising of trends of rapid growth, then stagnations that required policy reforms and interventions.

Figure 3.6-3. Trend of Installed Geothermal Capacity in the Philippines (1976–2016) and Projections to 2032



MW = megawatt.
Source: Philippine Department of Energy, 2016.

1973–1976: Creation of Unocal–Philippine Geothermal Inc. and Philippine National Oil Company–Energy Development Corporation with a mandate to develop indigenous energy resources as government response to the oil crisis;

1977–1984: Rapid increase in geothermal resource development with the commissioning of the Tiwi, Makban, Tongonan, and Palinpinon geothermal power stations;

1985–1992: Stagnation as newly commissioned fields and operations mature;

1993–1997: Additional capacities brought online through the efforts of Philippine National Oil Company–Energy Development Corporation with the build–operate–transfer partnerships with various companies as government response to the 1991 power crisis that resulted in electricity shortage and long power outages;

1998–2016: Stagnation as build–operate–transfer plants awaited transfer of ownership, and developers and investors await interventions from government to spur the next wave of geothermal resource development in the country;

2017–2032: The overall target growth by DOE is for an additional 1,371 MW (for a total of 3,277 MW) installed capacity by 2030. This is broken down into an additional 183 MW by 2020, then a rapid increase of 900 MW by 2025, and an additional 288 MW by 2030.

These targets can be achieved through initiatives highlighted in the Philippine geothermal roadmap such as development of low-enthalpy resources, small-sized systems (<50MW), acidic reservoirs, enhanced geothermal systems, and geothermal heat pumps. However, these will not materialise without innovative ideas and measures to remove the barriers to geothermal power generation development in the Philippines. The geothermal energy industry will need government support to develop additional capacity and achieve the target of 3,280 MW by 2030, especially if fossil fuel prices remain low. Policy and regulatory platforms, including government incentives, will be the spark to drive the third wave of geothermal development to fully realise the significant geothermal resource potential in the country.

The target geothermal power capacity in this project, which may be achieved by removal of all barriers, is projected from the trend shown in Figure 3.6-3. The 1,360 MW target is set as additional capacity, which is ready to be developed by 2025 if all barriers are removed.

6.3 Barriers to geothermal power generation and necessary innovations

6.3.1 Barriers to geothermal power generation

A survey of domestic experts on barriers to geothermal power generation in the Philippines was conducted and the result are shown in Table 3.6.3-1 and Figure 3.6.3-1.

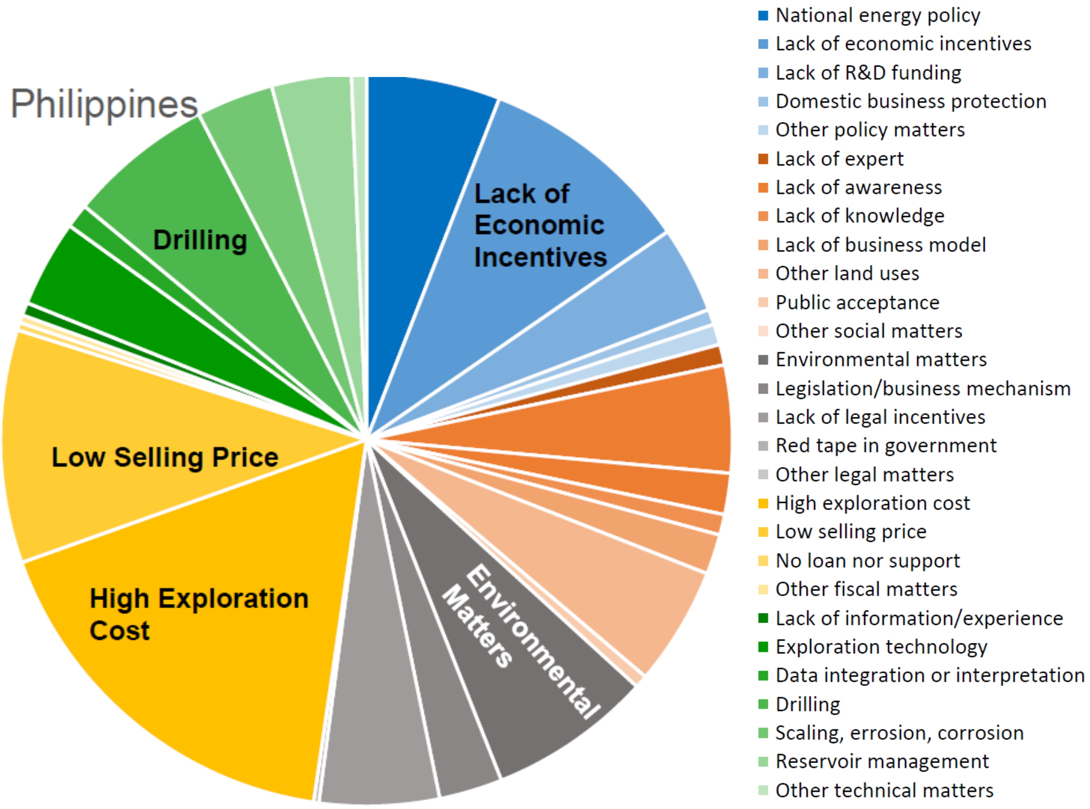
Table 3.6.3-1 Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in the Philippines

Policy	21%	National energy policy	5.93%
		Lack of economic incentives	9.48%
		Lack of R&D funding	3.84%
		Domestic business protection	0.68%
		Other policy matters	0.91%
Social	16%	Lack of experts	0.91%
		Lack of awareness	4.75%
		Lack of knowledge	1.82%
		Lack of business models	0.91%
		Other land uses	1.77%
		Public acceptance	5.25%
		Other social matters	0.57%
Legal	16%	Environmental matters	7.23%
		Legislation/Business mechanism	2.80%
		Lack of legal incentives	5.30%
		Red tape in government	0.23%
		Other legal matters	0.00%

Fiscal	28%	High exploration cost	17.27%
		Low selling price	10.30%
		No loan nor support	0.34%
		Other fiscal matters	0.34%
Technical	20%	Lack of information/experience	0.57%
		Exploration technology	3.84%
		Data integration or interpretation	1.07%
		Drilling	6.43%
		Scaling, erosion, corrosion	3.41%
		Reservoir management	3.52%
		Other technical matters	0.66%
TOTAL (%)	100%		100.1%

Source: Authors.

Figure 3.6.3-1. Results of Inquiry to Domestic Experts on Barriers to Geothermal Power Generation in the Philippines



Source:Authors.

The major barriers in each category are explained below.

1) Policy: Lack of economic incentives

The Philippines has no feed-in tariff (FiT) incentive for geothermal electricity producers, unlike the FiT incentives provided by the Renewable Energy Act to the other renewable energy technologies like solar, wind, hydro, and tidal energy, because when the Act was crafted by Congress, geothermal energy technology was considered a mature technology that does not need additional incentives. In contrast, the other renewable energy technologies were considered new and emergent technologies that require incentives for developers and investors.

2) Legal: Red tape in government

As a result of the inquiry, environmental matters appear as the biggest legal barrier. However, when considering underlying problems, red tape in government delays processes. Instead of spurring interest from investors and developers, government regulations tend to become major barriers in the exploration and development of geothermal resource areas. Five government institutions supervise geothermal power generation development in the Philippines:

(1) Department of Energy. Selects, awards, and monitors geothermal development activities.

(2) Department of Trade and Industry. Issues tax incentives for renewable energy commercialisation.

(3) Local government units. Issue permits and licences specific to geothermal reservation areas.

(4) Department of Environment and Natural Resources. Issues Environment Impact Assessments for Environmental Compliance Certificate and tree-cutting permits.

(5) National Commission on Indigenous People. Issues permits in areas within ancestral domains.

The usual problems encountered by geothermal resource developers with these government agencies/institutions are: (1) prior and periodic consultations which developers must conduct with local governments; (2) approval from the Indigenous People Council that must be obtained before work within ancestral domains can be undertaken; (3) absence of clear-cut rules; (4) obtaining environmental compliance certificate prior to commencement of the project and repetitive tree cutting permits; (4) obtaining passage of law from Congress to undertake exploitation and utilisation of geothermal resources located inside protected areas. These multiple requirements from different government agencies result in significant delays in the start of exploration and/or expansion projects. For the 150–200 permit requirements alone, processing could take anywhere between 3 to 5 years.

3) Fiscal: High exploration cost and low selling price

Despite improvements in exploration technology, the cost of developing geothermal energy is not competitive especially with the declining oil and coal prices. High-surface development (steep and difficult terrain, pipeline routes, roads and pads, power plant location, far off-grid transmission) and drilling cost with attendant high risk on greenfield projects deter investors and developers from embarking on geothermal exploration, drilling, and development. Moreover, with almost all bigger-sized resources in the Philippines discovered and developed already, the next prospects are the low- to medium-enthalpy systems and high-enthalpy, acidic reservoirs that require higher development and operating costs due to higher drilling and well costs, use of special materials to mitigate corrosive effects of acid fluids, and less conversion efficiency for binary power plants in low- to medium-enthalpy developments.

Electricity price from geothermal power producers is also being steeply challenged by low-selling electricity from coal power plant operators. With oil and coal prices at a record low in the world market, coal-plant power producers are able to sell their output at low price, pushing geothermal power producers to compete for markets and forcing them to reduce their electricity selling price, thus affecting the profitability and sustainability of their operations. Since there is no mandate from the government to prioritise renewable energy in the energy mix and in the priority dispatch, every producer has to compete for market based on selling price, which is artificially low for coal plants as externalities are not being considered (like impact to environment and air pollution).

4) Technical: Exploration technology; scaling, erosion, corrosion; and reservoir management

Exploration technologies, techniques, and methods still need to advance to de-risk geothermal prospects and make them attractive for developers and investors. Some of these technical barriers result in higher operation and maintenance costs on existing and new geothermal fields due to resource management issues and climate change. These deter existing operators and developers from embarking on future expansion and development plans.

Some geothermal fields in the Philippines experience these technical resource management challenges: (1) injection returns (from brine and power plant condensates), (2) cold peripheral and groundwater inflow, (3) pressure drawdown and boiling that increase operation and maintenance drilling requirements, (4) well feed sharing and production interference, (5) well integrity issues on old and damaged wells (making workover and well repair costs escalate), (6) acid fluids causing well and line corrosion damage, (7) mineral scaling (calcite, silica, etc.), (8) erosion from fine solids entrained in high-velocity steam from drawn-down dry fields, and (9) effects from extreme weather (e.g. recurring super-typhoons) that result in landslides and damage to surface and power plant facilities.

6.3.2 Innovative ideas and measures to remove barriers

1) Legal barriers

<u>Simplify the permit and authorisation requirements and process</u>

To reduce or eliminate red tape in government, there is a need to simplify the permit and authorisation requirements and process. This would hopefully reduce the 150–200 permits that need to be processed and secured from various government agencies before exploration and development works can commence. Some of these permit and authorisation requirements might be overlapping in jurisdictions, particularly those required by local government units with those of national government agencies. By simplifying and reducing the permit and authorisation requirements and process, the soonest can geothermal projects start exploration and development works. This would also reduce the gestation period to commercial operations.

<u>Establish a one-stop shop for permit and authorisation processing and filing</u>

With five government agencies supervising the geothermal development in the country, there is a need to set-up a one-stop shop for the permit and authorisation filing and processing. As these government agencies hold office at national and local levels, transacting with them is already a major effort and cause of delays. If their geothermal resource development permitting sections/divisions are placed under one roof, the process will be shortened.

Declare geothermal development as a project of national interest

DOE should declare renewable energy projects, including geothermal resource development, as projects of national interest, to imbue them with a sense of national importance and urgency and insulate them from government red tape, corruption, court injunctions and challenges, and other causes of delays. Right of way acquisitions for roads, pipeline routes and pads, and transmission line routes should not be hampered by delays.

The provisions on the National Integrated Protected Areas Systems and the Indigenous Peoples' Rights Act should also be harmonised with the Renewable Energy Act so that geothermal resource development inside protected areas and indigenous peoples' lands could still proceed.

2) Policy barriers

Provide feed-in tariff support for electricity produced from geothermal energy

Geothermal power developers and investors will need market and tariff support from the government in the form of FiT, given the high costs and risks of exploration and development and market uncertainties and volatilities. Congressional amendments to the Renewable Energy Act are required for geothermal energy to be included in the renewable energy technologies qualified for FiT award (similar to solar, wind, hydro, and tidal energy technologies). There is a debate if large-scale geothermal energy projects should be awarded FiT given that geothermal technology is already an established and mature one and not anymore needing incentives for large-scale commercial utilisation (as has been practised in the Philippines since the 1970s). The proposal is to award FiT only to emerging technologies such as low-enthalpy utilisation, acid resource development, and small-scaled geothermal development (<50 MW). With this proposal, the full-scale inventory of geothermal resources in the Philippines needs to be updated and classified to further quantify the overall potential of conventional (large scale vs small scale) and non-conventional (low enthalpy) resources, as well as acid resources, to be able to determine the installation targets and quantify the FiT rate that can be awarded.

Provide for the right energy mix with emphasis on renewable energy

The Electric Power Industry Reform Act provides the right energy mix in the energy policy of the country. The initial proposal was to allocate 30% of the total installed capacity to renewable energy technologies (to include geothermal energy). However, this was challenged by some developers (particularly coal power operators). Thus, the government has not been able to implement the rules and regulations pertaining to this provision of the EPIRA law. It would serve the interest of geothermal resource development in the country if this barrier is removed and the EPIRA Law is fully implemented.

Priority dispatch for geothermal power plants generation outputs

With electricity supply currently in excess of peak demand, the national grid operator follows a protocol allocating dispatch for all generators. Some electricity output is also traded in the Wholesale Electricity Spot Market. While solar and wind energy are already priority dispatch, geothermal output, having no FiT allowance, has no such priority. Thus, DOE and Philippine Electric Market Corporation should classify geothermal power plant generation outputs as priority dispatch since they are capable of baseload generation and have very low CO_2 emission.

Priority interconnection of geothermal projects to the national grid

Most geothermal resource prospects are located in mountainous areas and are off the current grid infrastructure. Thus, DOE should compel the national grid operator to prioritise the interconnection of geothermal resource projects to the national grid. This will free the geothermal energy developers of the burden of connecting their projects to the grid and thus lower their development costs. The national grid operator is allowed to recover its capital expenditures for transmission projects from its wheeling fee charged to electric distribution utilities, which also pass this on to consumers.

3) Fiscal barriers

Government to assume initial exploration activities

One of the major challenges in bidding for geothermal resource concessions in the Philippines is the lack of available exploration data. With resources spread thin amongst developers and bidders, some get unpromising prospects, thus lowering their appetite to explore and spend more in other prospects after failing initial exploration results. If the government undertakes or spends for the initial exploration activities, developers and bidders will have more data to base their decisions on when bidding for concessions. The more promising prospects (based on data from initial exploration activities) get selected, the earlier will advanced exploration activities and drilling happen. This will also shorten the time to development and commercial operations.

Provide fiscal support to exploration drilling from green funds

One of the most expensive costs in geothermal resource development is drilling, and more so if it is still exploration drilling because of the high risks involved that may lead to failure in investment. Thus, if the government can give support and concessional loans from some green funds and even share the risks of exploration drilling, then more developers will be aggressive enough to explore.

Fiscal support against fluctuation in energy prices in the international market

Geothermal energy development needs policies that would manage energy price risks specifically price of geothermal steam and electricity as it is currently benchmarked with international price of coal. With market volatility and low coal prices, sales of geothermal steam and electricity are at a disadvantage since fixed costs in geothermal power are high, and margins are squeezed every time coal and oil prices fluctuate down. If the government can provide price stabilisation fund, then developers and investors will be protected of their investments and more will be encouraged to invest in geothermal resource development.

Award additional tax incentives

Geothermal power developers and operators enjoy the 10% income tax rate as afforded by the Renewable Energy Act. However, with coal price at all time low at current competitive markets, the geothermal power industry will need tax holidays and tax exemptions on capital equipment importation. There are provisions for these; the incentives will just have to be reviewed and strengthened.

Tax carbon emission from coal plants

Coal power plant operators can offer their electricity at low price because externalities are not considered in their pricing. Thus, the government, in compliance to the provisions of the Clean Air Act, should initiate taxation of carbon emission from coal power plants. Its harmful effects to the environment and community should also be considered and levied on the operations of these power plants. Provisioning and including these costs in electricity pricing of coal power plants will make geothermal power cost-competitive with coal. With a level playing field, consumers will have better choices and can opt for the electricity source (green energy option) that does not harm the environment and is available at baseload whole year round.

4) Technical barriers

Develop new technologies for exploration surveys

Since exploration survey is one of the key determinants in the success or failure of a geothermal prospect, advanced methods of appraisal should be developed to increase the likelihood of finding promising resources. Technologies that use micro-earthquakes and soil gas compositions to explore permeable areas are already being used in the Philippines. Surveying methods using light detection and ranging and even unmanned aerial vehicles or drones can refine or prepare structural maps, detect thermal manifestations, and point to geohazards or areas unsuitable for road and pipeline routes and pad developments.

Collaborative research on scaling, erosion, and corrosion

Common problems in steam fields in the Philippines and other Asian countries are scaling (calcite, silica, etc.), erosion from formation particles (from drawn-down high-enthalpy dry fields), and corrosion from acidic or low-pH resources. Thus, Asian countries engaged in geothermal power generation should work together and invest in industry-collaborative research in optimising resource and steam-field management with available technologies or, when needed, to specifically develop technologies for these resources. Needed solutions include specialty alloys (e.g. corrosion-resistant alloys) or chemical mitigation (NaOH or corrosion inhibitors) that can withstand the fluid characteristics. Acid resources will require reinforcement of surface facilities for safety and reliability, and an intensive asset reliability monitoring programme will require more frequent workovers, downhole monitoring, and use of scrubbers for the acid steam.

Other fronts on Asian collaborative research will be on devices (two-phase flow metres and sensors for big data capture), robotics (for intrusive inspections), materials for corrosive environment (e.g. metal alloys and advanced polymers), and well workover and maintenance technologies without using rigs (e.g. broaching, coiled tubing unit, bullhead acidising, etc.).

Share best practices on reservoir management

Asian countries generating geothermal energy also experience common resource-related issues that are managed adequately and properly by reservoir management scientists and engineers. It would be beneficial to all if these best practices on reservoir management are shared so countries do not have to ‘reinvent the wheel’, and to shorten the learning curves of geothermal power operators.

Some best reservoir management practices that can be shared are managing (1) injection returns (from brine and power plant condensates), (2) cold peripheral and groundwater inflow, (3) pressure drawdown and boiling, (4) well feed sharing and production interference, (5) well integrity issues on old and damaged wells, (6) acid fluids causing well and line corrosion damage, (7) mineral scaling (calcite, silica, etc.), and (8) erosion from fine solids entrained in high-velocity steam from drawn-down dry fields.

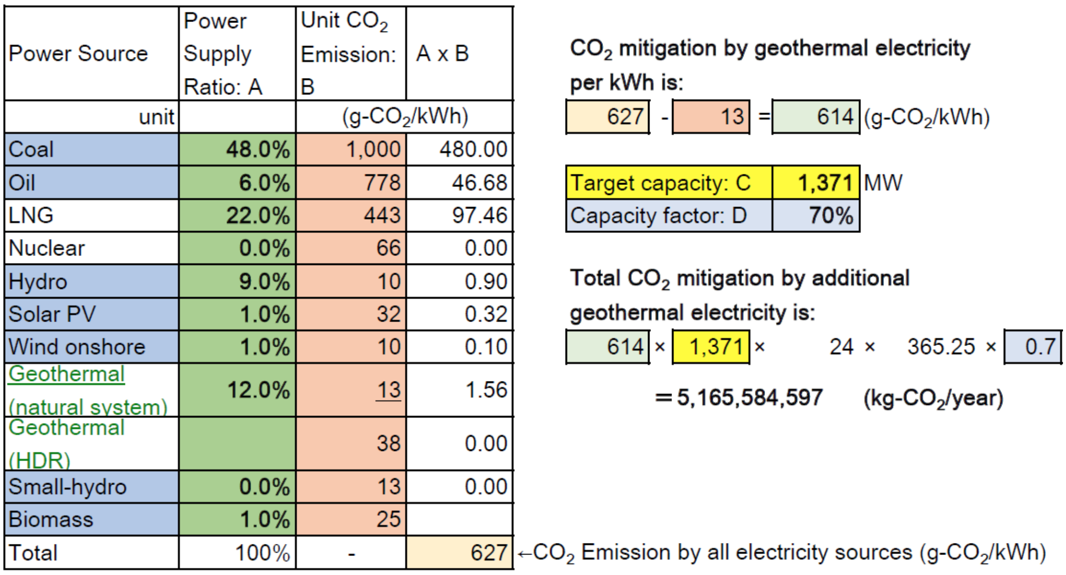
6.4 Benefits of geothermal power generation use in the Philippines

The benefits of geothermal energy use in the Philippines include a) baseload generation, b) low CO_2 emission, c) local employment generation, and d) driving local economic development. These were quantitatively analysed following the procedure shown in Section 2.4.2.1 b.

1) CO_2 mitigation

CO_2 mitigation by additional geothermal capacity of 1371 MW was calculated at 5,165,584,597 kg-CO_2/year (Figure 3.6.4-1).

Figure 3.6.4-1. CO_2 Mitigation by Additional Geothermal Power



Power Source	Power Supply Ratio: A	Unit CO_2 Emission: B	A x B
unit		(g-CO_2/kWh)	
Coal	48.0%	1,000	480.00
Oil	6.0%	778	46.68
LNG	22.0%	443	97.46
Nuclear	0.0%	66	0.00
Hydro	9.0%	10	0.90
Solar PV	1.0%	32	0.32
Wind onshore	1.0%	10	0.10
Geothermal (natural system)	12.0%	13	1.56
Geothermal (HDR)		38	0.00
Small-hydro	0.0%	13	0.00
Biomass	1.0%	25	
Total	100%	-	627

←CO_2 Emission by all electricity sources (g-CO_2/kWh)

CO_2 mitigation by geothermal electricity per kWh is:

627 - 13 = 614 (g-CO_2/kWh)

Target capacity: C	1,371	MW
Capacity factor: D	70%	

Total CO_2 mitigation by additional geothermal electricity is:

614 × 1,371 × 24 × 365.25 × 0.7

= 5,165,584,597 (kg-CO_2/year)

CO_2 = carbon dioxide, g-CO2 = gramme of carbon dioxide, HDR = hot dry rock, kWh = kilowatt-hour, LNG = liquefied natural gas, PV = photovoltaics.

Source: Authors. Data source for column A: Department of Energy, Philippines, 2017; B: Benjamin K. Savacool, 2008.

2) Other benefits

Other benefits are calculated following the procedure in Section 2.4.2.1 for the target capacity. Expected benefits by removal of each barrier category are calculated based on barrier contributions shown in Table 3.6.3-1**.** Again, note that these barriers are interrelated and removal of one barrier may stop further geothermal development. Nevertheless, this estimation gives insights to policymakers on the significance of benefits by barrier removal. Table 3.6.4-1 summarises the calculated benefits.

Table 3.6.4-1. Direct Benefits and (Expected) Indirect Benefits of Geothermal Power Generation by Removal of Barriers

Item		Unit	Barriers significance and benefits by removal of each barrier					Total benefit	Remarks
			Policy	Social	Legal	Fiscal	Technical		
Barrier significance		%	**14**	**32**	**22**	**15**	**17**	**100**	
Target capacity		MW	191.94	438.72	301.62	205.65	233.07	1,371	*W*
Target capacity factor		%						70%	*Cf*
a) Power generation		MWh/year	1,177,782	2,692,074	1,850,801	1,261,910	1,430,164	8,412,730	*W* x 24 x 365.25 x *Cf*
b) Annual fuel saving	by oil	barrel/year	1,490,796	3,407,534	2,342,680	1,597,281	1,810,252	10,648,543	11,096 *W x Cf*
	by LNG	kg/year	176,968,699	404,499,884	278,093,670	189,609,321	214,890,563	1,264,062,137	1,317,143 *W x Cf*
		Million Btu/year	8,717,106	19,924,814	13,698,310	9,339,757	10,585,058	62,265,045	0.04926 *W*
c) Saving foreign currency	by oil	US$/year	89,447,764	204,452,031	140,560,771	95,836,890	108,615,142	638,912,597	60.0 US$/Barrel
	by LNG	US$/year	43,585,532	99,624,072	68,491,550	46,698,784	52,925,288	311,325,225	5.0 US$/Btu
d) CO_2 mitigation		(tonne-CO_2/year)	723,182	1,652,987	1,136,429	774,838	878,149	5,165,585	from "CO_2" Table
e) Local employment		persons	530	1,212	833	568	644	3,788	2.71*W*+73
f) Saving lands compared to solar PV		m^2	21,404,765	48,925,177	33,636,059	22,933,677	25,991,500	152,891,178	111,518 *W*
(g) Expected profit of additional businesses		US$/year	343,281	784,642	539,441	367,801	416,841	2,452,006	1,788 *W*
(h) Expected local employee by additional businesses		persons	96	219	151	103	117	686	0.5 *W*
(i) Expected local economic effect of the additional		US$/year	429,178	980,978	674,422	459,833	521,145	3,065,556	2,236 *W*

Btu = British thermal unit, CO_2 = carbon dioxide, cf = coefficient factor, kg = kilogramme, LNG = liquefied natural gas, MW = megawatt, MWh = megawatt hour, PV = photovoltaics. For symbols *Cf* and *W*, please refer to equation (1) in section 2.4.2.1.

Source: Authors.

6.5 Summary of barriers to and benefits of geothermal power generation

The most significant barriers to geothermal power use in the Philippines are environmental matters and red tape in the government (legal); lack of economic incentives (policy); high exploration cost and low selling price (fiscal); and exploration technology, scaling, erosion, corrosion, and reservoir management (technical). Innovative ideas and measures to remove the barriers are as follows:

Legal aspect

- Simplify the permit and authorisation requirements and process
- Establish a one-stop shop for permit and authorisation processing and filing
- Declare geothermal energy development as a project of national interest

Policy aspect

- Provide FiT for electricity produced from geothermal energy
- Provide for the right energy mix with emphasis on renewable energy
- Prioritise dispatch for geothermal power plants generation outputs
- Prioritise interconnection of geothermal projects to the national grid

Fiscal aspect

- Urge government to assume initial exploration activities
- Provide fiscal support to exploration drilling from green funds
- Provide fiscal support against fluctuation in energy prices in the international market
- Award additional tax incentives
- Tax carbon emission of coal plants

Technical aspect

- Develop new technologies for exploration surveys
- Undertake collaborative research on scaling, erosion, and corrosion
- Share best practices on reservoir management

Note that the benefits of geothermal energy use in the Philippines include baseload generation, low CO_2 emission, generation of local employment, and driving local economic development.

Reference

Department of Energy, Philippines (2017), 2016 Philippine Power Situation Report.

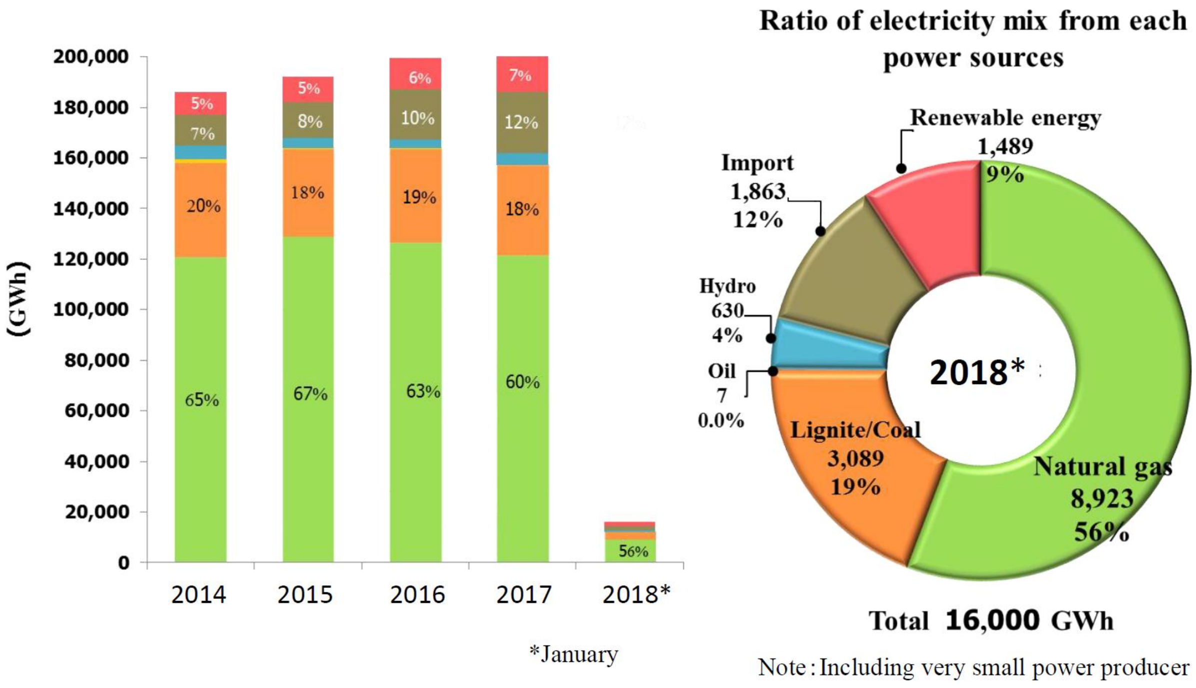
7. Thailand

7.1 Current situation of geothermal energy use and national policy

7.1.1 Current energy policy and energy mix

Thailand produces electricity from five power sources: natural gas, lignite/coal, renewable energy, hydropower, and oil. The ratio of each power source is shown in Figure 3.7.1-1 (updated: January 2018).

Figure 3.7.1-1. Ratio of Electricity Mix in Thailand



GWh = gigawatt hour.

Source: Ministry of Energy, 2018.

Thailand's renewable energy policy

Thailand's renewable energy policy started in 2006 as manifested in the 6th National Economic and Social Development Plan (Plan 6: 1987–1991) (Renewable 2011 Global Status Report). In the same year, the country introduced renewable electricity feed-in tariff (FiT). Thailand also introduced non-financial support mechanisms, including standard power purchase agreements, preferential arrangements for small generators, and information support. In 2008, Thailand, seriously concerned of the renewable energy policy of the Ministry of Energy, published the Renewable Energy Development Plan, setting targets for the deployment of renewable energy for 2008–2022. It set as main target the increase to 20% of renewable energy's share in total final energy demand in 2022 (Asia–Pacific Economic Cooperation, 2018). The Renewable Energy Development Plan targets are divided in three phases. The target for phase I is an increase of 15.6% in the renewable energy's share in the energy mix of total energy consumption in 2011. At the end of phase II (2012–2016), renewable energy is expected to represent 19.1% of total energy consumption. In the third phase (2017–2022), the share of renewables is expected to have developed to 20.3% of total final energy consumption (Olz and Beerepoot, 2010). Table 3.7.1.-1 shows the renewable energy targets in Thailand as indicated in the Renewables 2011 Global Status Report (REN, 2011). There are no data on geothermal energy.

Table 3.7.1.1-1. Renewable Energy Targets in Thailand

Renewable Energy Target	2011	2016	2022
Biomass	2,800 MW	3,220 MW	3,700 MW
Wind energy	115 MW	375 MW	800 MW
Hydro	185 MW	281 MW	324 MW
Solar PV	55 MW	375 MW	800 MW

MW = megawatt, PV = photovoltaics.
Source: Renewable Energy Policy Network for the 21st Century, 2011.

In 2015, the Ministry of Energy published the Alternative Energy Development Plan, which focused on promoting energy production within the full potential of domestic renewable energy resources, and with consideration to appropriateness and benefits to the social and environmental dimensions of the community.

In the formulation of the Alternative Energy Development Plan, the final energy consumption demands from the Energy Efficiency Plan 2015 are used especially in energy intensity which is reduced by 30% in 2036 compared to the figure in 2010. This indicates that demand of final energy consumption in 2036 will be 131,000 tonnes of oil equivalent (ktoe). The electricity demand forecast from the power development plan is also used to set the target of Alternative Energy Development Plan. This power development plan indicates that in 2036, net electricity demand will be 326,119 units or equivalent to 27,789 ktoe. The heat demand forecast in 2036 will be 68,413 ktoe and the forecast demand for fuel in the transportation sector from the fuel management plan for 2036 is 34,798 ktoe. The target of other plan as shown above, including consideration of the potential of renewable energy sources that can be developed, was used to formulate the target of Alternative Energy Development Plan 2015 to replace 30% of final energy consumption (in the form of electricity, heat, and bio-fuel) by 2036 (Ministry of Energy, 2017).

Table 3.7.1.1-2. Targets of Electricity, Heat, and Bio-fuel from Renewable Energy

Energy	Share of Renewable Energy (%)		Final Energy Consumption at 2036 (tonnes of oil equivalent, ktoe)
	Status As of 2014	Target by 2036	
Electricity: Electricity	9	15– 20	27,789
Heat: Heat	17	30– 35	68,413
Bio-fuels: Fuels	12	20– 25	34,798
RE : Final Energy Consumption	**12**	**30**	**131,000**

ktoe = kilotonne of oil equivalent, RE = renewable energy.
Source: Alternative Energy Development Plan 2015.

The target electricity production from various types of renewable sources was set up using the renewable energy supply–demand matching principle. The available renewable energy resource potential will be sorted and sequenced by the merit order of renewable energy technologies in accordance with the demand for electricity in the area and the limitation of the transmission system. Going by the merit order, it seems that geothermal energy is last in the order of renewable energy technologies (Table 3.7.1.1-3).

Table 3.7.1.1-3. Merit Order of Various Types of Renewable Energy Sources for Generating Power

1	2	3	4	5	6	7	8
Municipal solid waste	Biomass	Biogas	Small hydro	Biogas (energy crop)	Wind	Solar	Geothermal

Source: Alternative Energy Development Plan 2015.

The Alternative Energy Development Plan 2015 has set a target of electricity from all renewable energy to 20% of the net electrical energy demand, which complies with the fuel diversification ratio in the power development plan for 2015–2036, indicating the proportion of electricity generated from renewables in the range of 15–20 years in 2036.

Table 3.7.1.1-4. Status and Target of Electricity Generation by Type of Fuel

Fuel	Status by End of 2014* (MW)	Target by 2036 (MW)
1. Municipal solid waste	65.72	500
2. Industrial waste	-	50
3. Biomass	2,451.82	5,570
4. Biogas	311.5	600
5. Small hydro	142.01	376
6. Biogas (energy crop)	-	680
7. Wind	224.47	3,002
8. Solar	1,298.51	6,000
9. Large hydro	-	2,906.4**
Total installed capacity (MW)	4,494.03	19,684.40
Electrical energy (million units)	17,217	65,588.07
Total electrical energy demand (million units)	174,467	326,119.00
Share of renewable energy in electricity generation (%)	9.87	20.11

Note: * Including off-grid power generation and not including power generated from large hydro.
** The existing capacity and generation from large hydro was included in the target of AEDP2015.
MW = megawatt
Source: Alternative Energy Development Plan 2015.

For goals heat production from renewable energy targets at 68,413 ktoe in 2036 (Table 3.7.1.1-2): Demand for energy for heating is a significant portion of the energy consumption of the country, which has steadily increased and is proportional to the economic situation, such as expansion of cities and communities, tourism, industry, and agricultural sector adapting to agricultural industry.

Assessment of the potential to produce heat from renewable energy is based on four renewable energy groups (Table 3.7.1.1-5):

1) Production of heat from renewable feedstock such as residual waste, biomass, and biogas as fuel remaining after deducting the estimated potential to produce a different type of energy.

2) Production of heat from fast-growing trees.

3) Production of solar heat (solar hot water systems, solar drying system, and solar heating and cooling systems).

4) Production of heat by other sources of renewable energy. This is in the research and development of technology in the near future, such as geothermal energy, etc., that is competitive in price.

Table 3.7.1.1-5. Status and Target to Produce Heat by Type of Feedstock

Feedstock	Status by end of 2014* (ktoe)	Target by 2036 (ktoe)
1. Municipal solid waste	98.10	495.00
2. Biomass	5,144.00	22,100.00
3. Biogas	528.00	1,283.00
4. Solar	5.10	1,200.00
5. Alternatives heat source*	-	10.00
Total	5,775.20	25,088.00
Total heat demand	33,419.54	68,413.40
Share of renewable energy for heat production (%)	17.28	36.67

ktoe = kilotonne of oil equivalent.
*Geothermal, oil from tyre, etc.
Source: Alternative Energy Development Plan 2015.

7.1.2 Geothermal energy use in Thailand

According to a study by Department of Alternative Energy Development and Efficiency in 2006, 112 hot brine sources are found in regions of Thailand except in the northeastern part. Water temperatures on the surface level ranged 40°C–100°C and most of the hot springs originated from granite, especially along the fault line in the northern provinces such as Mae Chan in Chiang Rai and Fang in Chiang Mai.

The Department of Mineral Resources, in collaboration with Chiang Mai University and Electricity Generating Authority of Thailand, was reported to have test-run a 300-kW production from a geothermal project at Fang in Chiang Mai. The production cost of the project was eight times cheaper than the production cost of fossil fuel, and its maintenance is of longer durability while its cost is several times cheaper.

However, unlike in other countries, the geothermal energy potential in Thailand remains doubtful due to lack of expertise in assessing it. The Department of Alternative Energy Development and Efficiency states that the key success factors of geothermal resource development in Thailand include geothermal exploration, drilling cost, borehole characteristics, fluid collection and transmission, and geothermal by products.

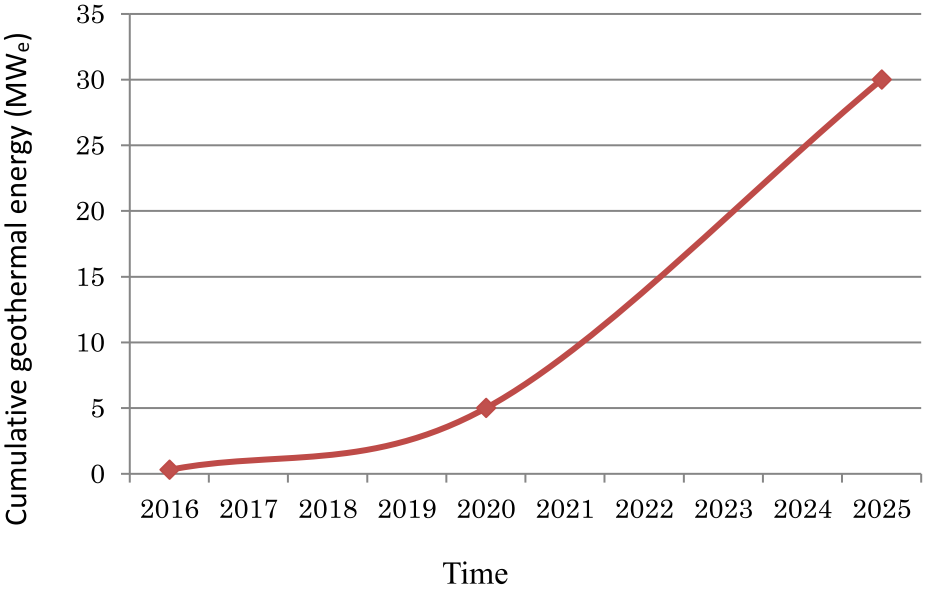
Aside from technical barriers, policy and legal barriers also hinder geothermal development in Thailand. Despite the many positive results of geothermal power utilisation, e.g. green energy, durability, etc., promoting geothermal energy development in Thailand is difficult because of the uncertainty of its potential, thus making policy and legal framework on its development equally difficult. At the moment, no specific legislation for geothermal development exists in Thailand.

7.2 Geothermal projects and target by 2025

In 2011, four memorandums of understanding on geothermal exploration, potential assessment, and development were signed among PTT Public Company Limited; Department of Groundwater Resources and Department of Groundwater Resources and Department of Mineral Resources, both of the Ministry of Natural Resources and Environment; and Department of Alternative Energy Development and Efficiency of the Ministry of Energy.

Figure 3.7.2 shows the target of geothermal energy development project as contained in the memorandums of understanding. The current power production from geothermal energy in the binary system is 0.3 MW_e. In the next 15 years, the project is set to produce up to 5 MW_e. If the project can produce the target volume, Thailand can produce up to 30 MW_e in 2025.

Figure 3.7.2. Expected Cumulative Geothermal Energy in Thailand



MW = megawatt.
Source: Authors.

If barriers are not removed, the generated geothermal power in Thailand will be 0.3 MW_e.

7.3 Barriers to geothermal energy use, and necessary innovations

7.3.1 Barrier to geothermal energy use in Thailand

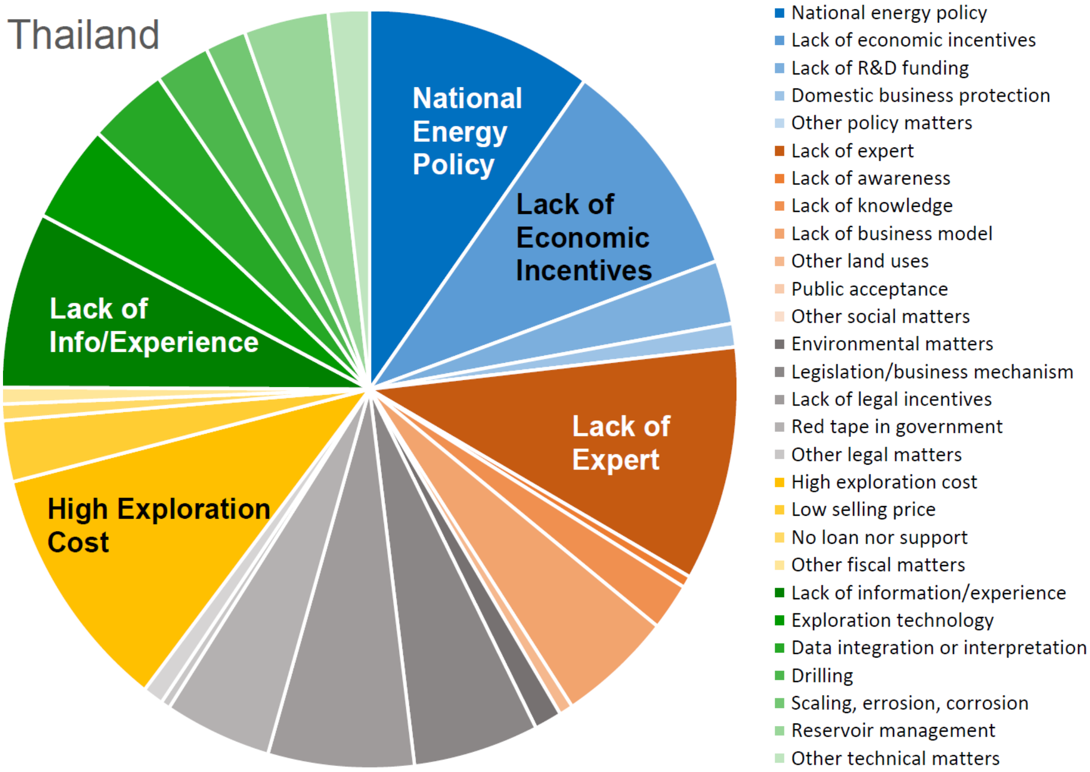
Table 3.7.3-1 and Figure 3.7.3-1 show the results of inquiry to domestic and foreign experts on barriers to geothermal power generation in Thailand, as presented by an ERIA working group member from Thailand at the 11th Asian Geothermal Symposium in Chiang Mai, Thailand, in November 2016.

Table 3.7.3-1. **Results of Inquiry on Barriers to Geothermal Power Generation in Thailand, as Obtained at the 11th Asian Geothermal Symposium**

Policy	23%	National energy policy	9.9%
		Lack of economic incentives	9.6%
		Lack of R&D funding	2.7%
		Domestic business protection	1.0%
		Other policy matters	0.0%
Social	19%	Lack of experts	10.0%
		Lack of awareness	0.5%
		Lack of knowledge	2.0%
		Lack of business models	5.0%
		Other land uses	0.6%
		Public acceptance	1.2%
		Other social matters	0.0%
Legal	18%	Environmental matters	5.5%
		Legislation/Business mechanism	6.4%
		Lack of legal incentives	4.7%
		Red tape in government	0.4%
		Other legal matters	0.9%
Fiscal	15%	High exploration cost	10.6%
		Low selling price	2.6%
		No loan nor support	0.7%
		Other fiscal matters	0.7%
Technical	25%	Lack of information/experience	7.5%
		Exploration technology	4.2%
		Data integration or interpretation	3.5%
		Drilling	2.4%
		Scaling, erosion, corrosion	1.8%
		Reservoir management	3.7%
		Other technical matters	1.8%
TOTAL (%)	100%		100.0%

Source: Authors.

Figure 3.7.3-1. Results of Inquiry to Experts from Foreign Countries on Barriers to Geothermal Power Production in Thailand



Source: Authors.

Based on results, the major barriers to geothermal power generation in Thailand are high exploration costs, lack of experts, lack of economic incentives, lack of information/experience, national energy policy, and legislation/business mechanism.

7.3.2 Innovative ideas to remove barriers in Thailand

Based on the study, the main barriers to geothermal energy use in Thailand are commonly legal and technical.

1) Legal barriers

The Thai government does not support renewable energy researches because no legislation promoting them has been made. Thus, there is a dearth of knowledge related to the development of renewable energy. The government should be compelled to enact laws on renewable energy so proper guidelines can be made for setting standard for production and preservation of renewable energy.

Proposed action plans for geothermal energy development:

1) Sign memorandums of understanding among entities previously cited on geothermal exploration, potential assessment, development, and their affects to the environment and local population.

2) Enact geothermal energy laws upon review of similar legislation from foreign countries.

3) Set period and target for geothermal energy development and set up a mechanism for transparency and accountability in its management.

4) Define feed-in tariff.

5) Introduce tax measures, and establish and manage geothermal energy fund.

6) Determine and establish legal rights of the various sectors such as producers, buyers, consumers, and affected communities. Determine the structure and price mechanism for hydrothermal energy, business licence application, and examine the effects of energy production and consumption.

7) Ease the process of applying for permission.

2) Knowledge and technique barriers

Thailand has few research efforts and limited knowledge on geothermal energy development. For deep geothermal exploration, we need more knowledge, techniques, machineries, and materials from foreign entities that are more experienced in geothermal development and have poured huge investments into it. To remove these barriers, the following have to be considered:

a) Material

Most hot springs of high potential in Thailand are located in nature parks, which are not the best place to set up power plants. Thus, to avoid problems and conflict, the Ministry of Natural Resources and Environment should first consider gaining knowledge from geothermal energy experts from other countries, and conduct training courses on exploration, assessment, and development of geothermal sources, including the construction of power plants, before starting any research or action plans.

b) Method

Aside from geology and structure analysis, we should use geophysical exploration to define exact geology and structure of reservoirs of geothermal energy such as resistivity, transient electro magnetic, and magneto telluric methods, which are the most commonly used today to define very deep structures; and geochemistry and specific isotope technique to classify temperature and water source.

We should also change geothermal power station system from binary system to Kalina system.

c) Budget

Thailand should look for foreign funds to support research on geothermal energy development. Since the Thai government is paying more attention to the well-being of the people than supporting research and development for geothermal energy, we have to show how geothermal energy is, on the long term, useful for people.

d) Machine

We need more high-potential machines for deep reservoirs.

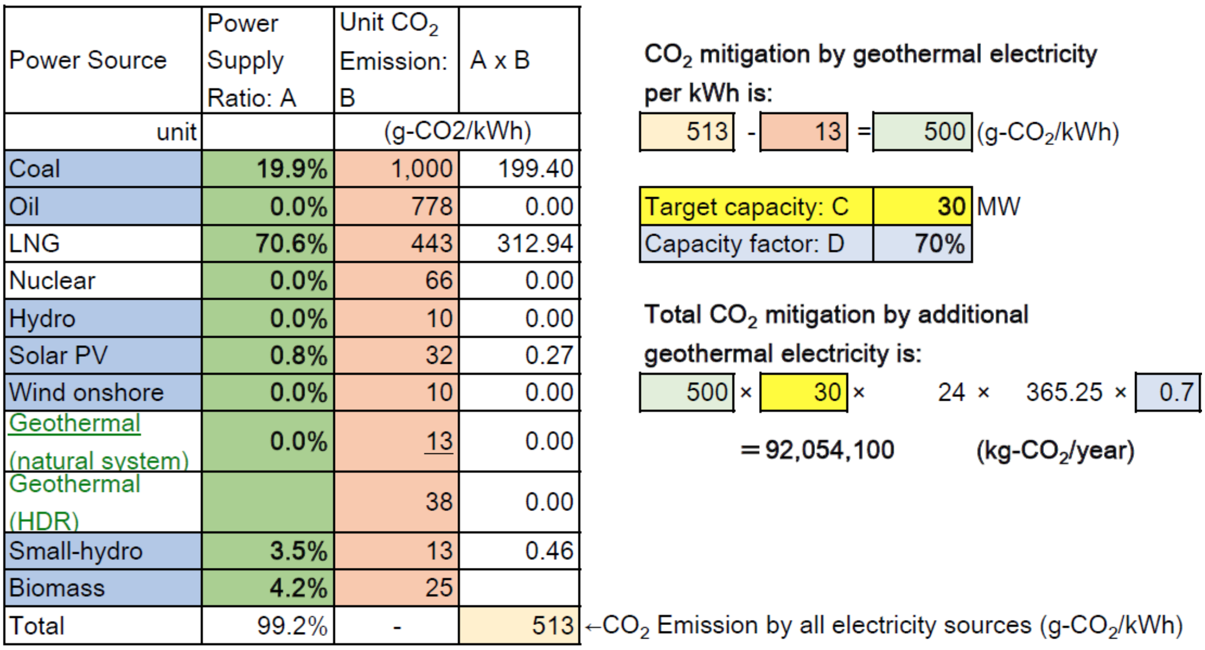
7.4 Benefits of geothermal energy use in Thailand

The benefits of geothermal power generation in Thailand include 1) local welfare, 2) local infrastructure, 3) local economy, 4) CO_2 emission mitigation in the power sector, and 5) energy security. Amongst them, items 3), 4), and 5) are quantified here.

1) CO_2 mitigation

CO_2 mitigation by additional geothermal capacity of 1371MW was calculated as 92,054,100 kg-CO_2/year (Figure 3.4.4-1).

Fig. 3.7.4-1. CO_2 Mitigation by Additional Geothermal Power



Power Source	Power Supply Ratio: A	Unit CO_2 Emission: B	A x B
unit		(g-CO2/kWh)	
Coal	19.9%	1,000	199.40
Oil	0.0%	778	0.00
LNG	70.6%	443	312.94
Nuclear	0.0%	66	0.00
Hydro	0.0%	10	0.00
Solar PV	0.8%	32	0.27
Wind onshore	0.0%	10	0.00
Geothermal (natural system)	0.0%	13	0.00
Geothermal (HDR)		38	0.00
Small-hydro	3.5%	13	0.46
Biomass	4.2%	25	
Total	99.2%	-	513

←CO_2 Emission by all electricity sources (g-CO_2/kWh)

CO_2 mitigation by geothermal electricity per kWh is:

513 - 13 = 500 (g-CO_2/kWh)

Target capacity: C 30 MW

Capacity factor: D 70%

Total CO_2 mitigation by additional geothermal electricity is:

500 × 30 × 24 × 365.25 × 0.7

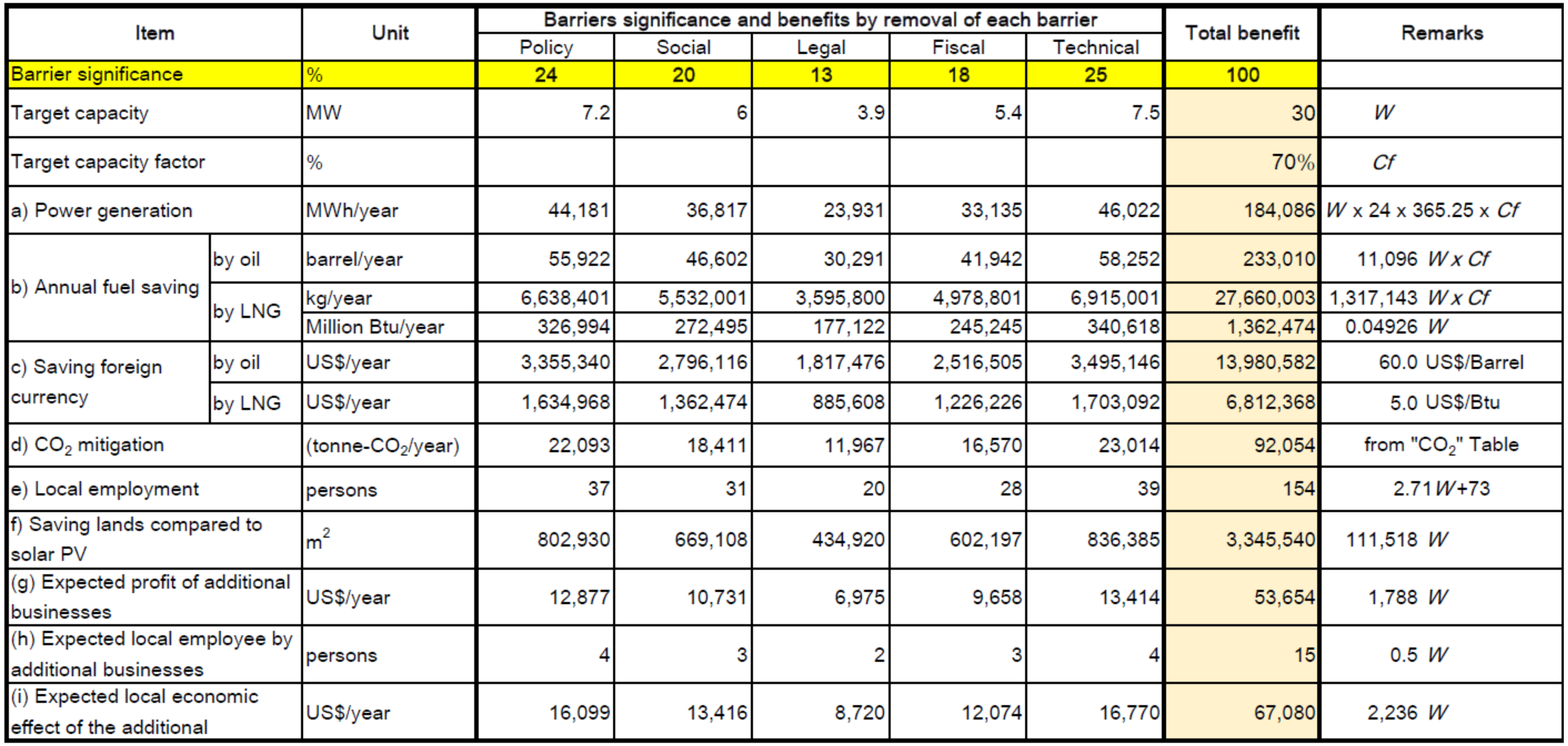
= 92,054,100 (kg-CO_2/year)

CO2 = carbon dioxide, HDR = hot dry rock, g-CO2 = gramme of carbon dioxide, kWh = kilowatt-hour, LNG = liquefied natural gas, PV = photovoltaics.
Sources: Original of this study. Data source for column A: International Energy Agency 2016; B: Benjamin K. Savacool, 2008.

2) Other benefits

Other benefits are calculated following the procedure in Section 2.4.2.1 for the target capacity. The expected benefits by removal of each barrier category are calculated based on the barrier contributions shown in Table 3.7.3-1. Again, note that these barriers are interrelated and removal of one barrier may stop further geothermal development. Nevertheless, this estimation gives insights to policymakers on the significance of benefits by barrier removal. Table 3.6.4-1 summarises the calculated benefits.

Table 3.7.4-1. Direct Benefits and (Expected) Indirect Benefits of Geothermal Power Generation by Removal of Barriers in Thailand



Item		Unit	Barriers significance and benefits by removal of each barrier					Total benefit	Remarks
			Policy	Social	Legal	Fiscal	Technical		
Barrier significance		%	24	20	13	18	25	100	
Target capacity		MW	7.2	6	3.9	5.4	7.5	30	W
Target capacity factor		%						70%	Cf
a) Power generation		MWh/year	44,181	36,817	23,931	33,135	46,022	184,086	W x 24 x 365.25 x Cf
b) Annual fuel saving	by oil	barrel/year	55,922	46,602	30,291	41,942	58,252	233,010	11,096 W x Cf
	by LNG	kg/year	6,638,401	5,532,001	3,595,800	4,978,801	6,915,001	27,660,003	1,317,143 W x Cf
		Million Btu/year	326,994	272,495	177,122	245,245	340,618	1,362,474	0.04926 W
c) Saving foreign currency	by oil	US$/year	3,355,340	2,796,116	1,817,476	2,516,505	3,495,146	13,980,582	60.0 US$/Barrel
	by LNG	US$/year	1,634,968	1,362,474	885,608	1,226,226	1,703,092	6,812,368	5.0 US$/Btu
d) CO_2 mitigation		(tonne-CO_2/year)	22,093	18,411	11,967	16,570	23,014	92,054	from "CO_2" Table
e) Local employment		persons	37	31	20	28	39	154	2.71W+73
f) Saving lands compared to solar PV		m^2	802,930	669,108	434,920	602,197	836,385	3,345,540	111,518 W
(g) Expected profit of additional businesses		US$/year	12,877	10,731	6,975	9,658	13,414	53,654	1,788 W
(h) Expected local employee by additional businesses		persons	4	3	2	3	4	15	0.5 W
(i) Expected local economic effect of the additional		US$/year	16,099	13,416	8,720	12,074	16,770	67,080	2,236 W

Btu = British thermal unit, CO_2 = carbon dioxide, cf = coefficient factor, kg = kilogramme, LNG = liquefied natural gas, MW = megawatt, MWh = megawatt hour, PV = photovoltaics. For symbols *Cf* and *W*, please refer to equation (1) in section 2.4.2.1.

Source: Authors.

7.5 Summary of barriers to and benefits of geothermal energy use

The most significant barriers to geothermal use in Thailand are high exploration costs, legislation/business mechanism, and national energy policy, followed by lack of legal incentives and lack of drilling technology. Innovative ideas and measures to remove the barriers are as follows:

National policy should include geothermal energy in the government's master plan of energy supply.

Legal barriers, including legislation/business mechanism, should be solved by setting up the following items:

1) Legislation on geothermal energy, aided by reviews of laws on the subject from foreign countries.
2) Target period for geothermal energy development, with corresponding transparency and accountability in management.
3) Feed-in tariff.
4) Tax and management measures in the set up of geothermal energy fund.
5) Legal rights of various sectors such as producers, buyers, consumers, and affected communities. Likewise, structure and price mechanism for geothermal energy, and processing of licence for geothermal energy business.
6) Process of permit application.

Barriers to knowledge and technology should be solved by:

- Collaboration with experts such as engineers and academics from foreign countries.
- Geothermal training in New Zealand, Iceland, and Japan for Thai geothermal experts.

Technical problems need solutions such as:

- Application of geological, geochemical, and geophysical (especially electro-magnetic) exploration methods.
- Improvement of binary cycle system such as changing from Organic Rankin Cycle to Kalina cycle.

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8. Viet Nam

8.1 Current situation of geothermal energy use and national policy

8.1.1 Current energy policy and energy mix

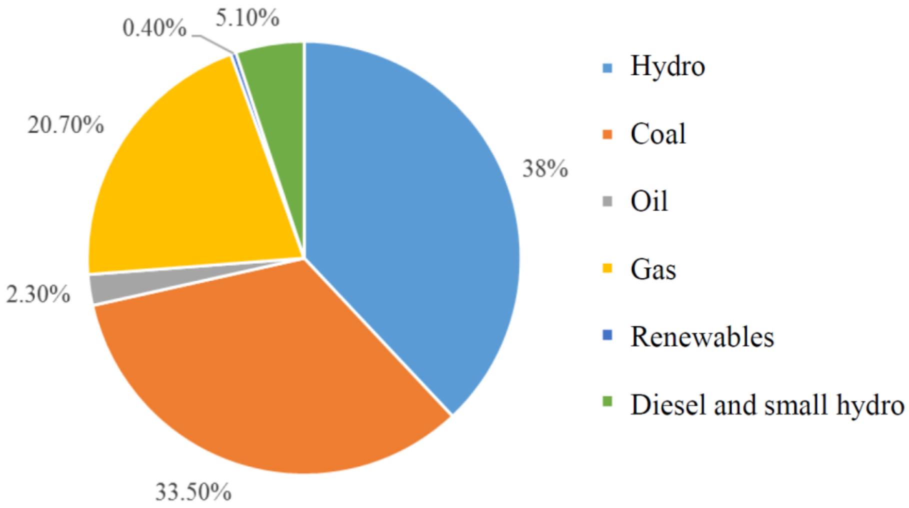
The total installed capacity of domestic and imported electricity in Viet Nam as of 31 December 2015 is shown in Table 3.8.1-1 and Figure 3.8.1-1 (Vietnam Electricity, 2016).

Table 3.8.1-1. Capacity of Viet Nam's Power Sources in 2016

Power Source	Capacity (MW)	Share (%)
Hydropower	14,636	38%
Coal	12,903	33.50%
Oil	875	2.30%
Gas	7,998	20.70%
Renewables	135	0.40%
Diesel and small hydropower	2,006	5.10%
Total	38,553	100%

Source: Vietnam Electricity, 2016.

Fig. 3.8.1-1. Power Capacity Mix of Viet Nam in 2016



Source: Vietnam Electricity, 2016.

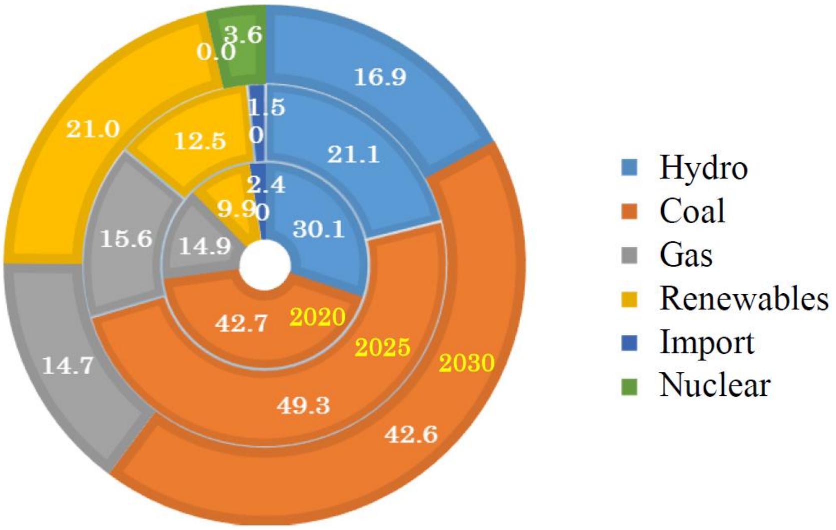
Taking into consideration the 7% annual economic growth of Viet Nam, the National Power Development Master Energy Plan (Electric Plan No. 7) was adjusted by Decision No. 428/QD-TTg in 2016 to signify the electric generation target for all kinds of energy sources (Table 3.8.1-2).

Table 3.8.1-2. Capacity Shares of Energy Generation as Adjusted by Plan No. 7

Year	Total Capacity (MW_e)	Energy Source	Share (%)
2020	60,000	Hydro	30.1
		Coal	42.7
		Gas	14.9
		Renewables	9.9
		Import	2.4
		Nuclear	0
2025	96,500	Hydro	21.1
		Coal	49.3
		Gas	15.6
		Renewables	12.5
		Import	1.5
		Nuclear	0
2030	129,500	Hydro	16.9
		Coal	42.6
		Gas	14.7
		Renewable	21
		Import	0
		Nuclear	3.6

MW_e = megawatt electric.
Source: Decision No. 428/QD-TTg, 2016.

Fig.3.8.1-2. Capacity Mix in 2020, 2025, and 2030 According to Plan No. 7



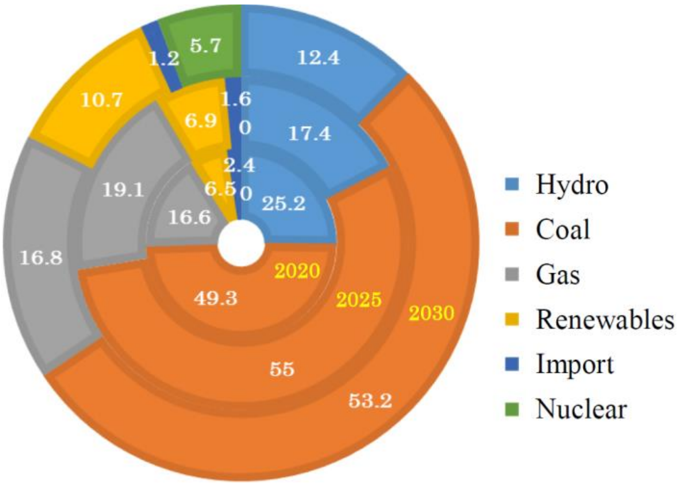
Source: Decision No. 428/QD-TTg, 2016.

Table 3.8.1-3. Energy Production Mix According to Adjusted Plan No.7

Year	Total Production (billion kWh)	Energy Source	Share (%)
2020	265	Hydro	25.2
		Coal	49.3
		Gas	16.6
		Renewables	6.5
		Import	2.4
		Nuclear	0
2025	400	Hydro	17.4
		Coal	55
		Gas	19.1
		Renewables	6.9
		Import	1.6
		Nuclear	0
2030	572	Hydro	12.4
		Coal	53.2
		Gas	16.8
		Renewables	10.7
		Import	1.2
		Nuclear	5.7

kWh = kilowatt-hour.
Source: Decision No. 428/QD-TTg, 2016.

Fig. 3.8.1-3. Energy Production Mix in 2020, 2025, and 2030 According to Plan No. 7



Source: Decision No. 428/QD-TTg, 2016.

Renewable energy is targeted with the capacity share of 9.9% in 2020, 12.5% in 2025, and 21% in 2030. Accordingly, the targeted share of electricity production is 6.5% in 2020, 6.9% in 2025, and 10.7% in 2030.

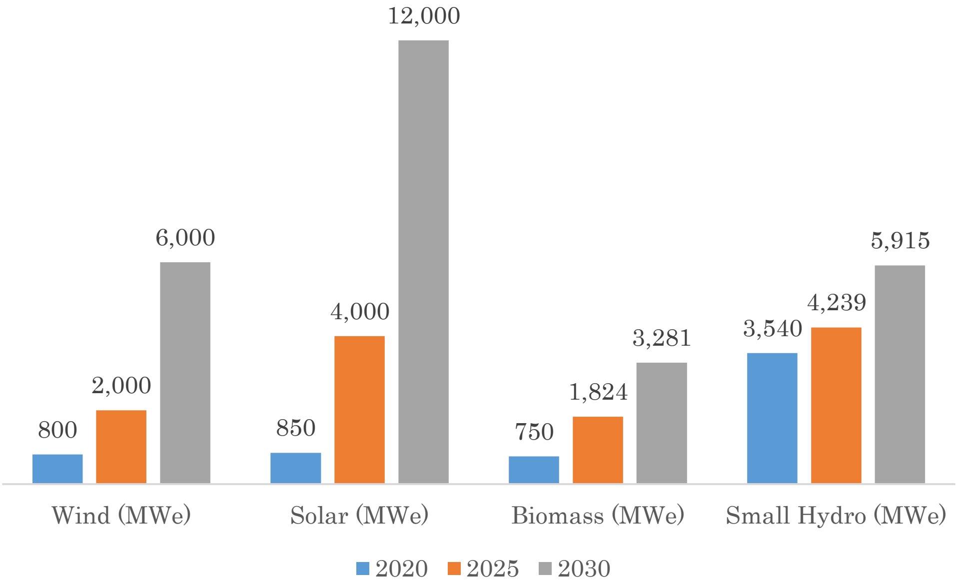
Although Decision No. 428/QD-TTg in 2016 set the targets for the development of renewable energy by the years mentioned, it did not include geothermal power (Table 3.8.1-4 and Figure 3.8.1-4).

Table 3.8.1-4. Summary of Renewable Energy Development Plan by 2030

Year	Wind (MW_e)	Solar (MW_e)	Biomass (MW_e)	Small Hydro (MW_e)
2020	800	850	750	3,540
2025	2,000	4,000	1,824	4,239
2030	6,000	12,000	3,281	5,915

MW_e = megawatt electric.
Source: Decision No. 428/QD-TTg, 2016.

Figure 3.8.1-4. Development Plan for Renewable Energy in Viet Nam



MW_e = megawatt electric.
Source: Decision 428/QĐ-TTg, 2016.

Even with the exclusion of geothermal energy in Power Plan No. 7, the Vietnamese government expects to attain the target for developing individual power sources of renewable energy by 2030. The vision for 2050, however, already includes geothermal energy (Table 3.8.1-5 and Figure 3.8.1-5).

Although the Energy Administration under the Ministry of Industry and Trade of Viet Nam is expecting geothermal energy capacity of 680 MW_e (EEP Mekong and Vietnam General Directorate of Energy, 2013), it has no timeline for this source of energy, unlike the rest of the mentioned renewable energy sources in Decision No. 428/QD-TTg.

With the goal set for the development of renewable energy in general, the government of Viet Nam has put in place policies to encourage the development of renewable energy sources. Policy for geothermal energy, however, has yet to be specified (Table 3.8.1-6).

Table 3.8.1-5. Installed and Potential Renewable Energy Capacity in Viet Nam

Type of Renewable Energy	**Expected Potential (MW)**	**Current and Development Trend**	
		Installed and under construction in 2016 (MW)	Potential could be exploited and invested in (MW)
Biomass/biogas	Approx.	375	8,125
Wind	Approx.	160	26,840
Solar	Approx.	5.6	129,944
Small hydro	Approx.	2,143	> 4,857
Municipal solid waste	Approx.	2.4	400
Geothermal	Approx.	0	680

Mw = megawatt.
Source: Decision No. 428/QD-TTg, 2016.

Table 3.8.1-6. Key Renewable Energy Policies

Year	Policy	Main Field Covered	Status
2007	• Financial mechanism for CDM projects	Financing, tariff	Effective
2008	• Regulations on electricity selling tariff and Small Power Purchase Agreement for small renewable energy-based power projects	Tariff (ACT)	Effective
2011	• Supporting mechanism for wind power projects	Tariff (FiT); taxes (income, import); land rent and use	Effective (under redesign)
2014	• Supporting mechanism for biomass co-generation projects	Tariff (FiT and ACT); land rent and use	Effective
	• Supporting mechanism for solid waste-based power projects	Tariff (FiT); taxes (income, import); land rent and use	Effective
2015	• Small Power Purchase Agreement for solid waste-based power projects	Tariff (FiT)	Effective
	• Small Power Purchase Agreement for biomass co-generation projects		
	• Viet Nam renewable energy development strategy.	Renewable energy targets; renewable energy development fund	
2016	• Price list of electricity selling tariff for 2016 for biomass-based power generation	Tariff (ACT)	Effective
	• The adjusted power development master plan No. 7.	Renewable energy targets	
	• Drafted: Supporting mechanism for solar PV (roof tops and ground mounted)	Tariff (FiT); taxes (income, import); land rent and use	Submitted Government

ACT = avoided cost tariff, CDM = clean development mechanism, FiT = feed-in tariff, PV = photovoltaics.
Sources: Danish Ministry of Energy; Ministry of Industry and Trade, Vietnam, 2017.

Regarding renewable energy pricing policy, there are pricing policies for renewables except for geothermal energy (Table 3.8.1-7).

Table 3.8.1-7. Price Tariffs of Electricity for Different Types of Renewable Power Projects

Generation Source	Technology	Capacity Limit	Tariff	Electricity Sale Price
Small hydro	Power generation	≤ 30 MW	Avoided cost tariff published annually	• D598 – 663/kWh for electricity sales (depending on time of use, season, and region) • D302 – 320/kWh for surplus electricity • D2 – 158/kWh for capacity sales (for whole country)
Wind	Power generation	No limit	FiT for 20 years	• US$0.78/kWh (on-shore) • US$0.98/kWh (near-shore) – not yet informed
Biomass	Co-generation	No limit	FiT for 20 years	• US$0.58/kWh for excess electricity
	Power generation	No limit	FiT for 20 years	• US$0.76/kWh for North region • US$0.74/kWh for Central region • US$0.75/kWh for South region
Municipal solid waste	Incineration	No limit	FiT for 20 years	• US$0.10/kWh
	Landfill gas	No limit	FiT for 20 years	• US$0.73/kWh
Solar power	Power generation	No limit	FiT for 20 years	• US$0.94/kWh

D = dong, FiT = feed-in tariff, MW = megawatt.
Source: Danish Ministry of Energy; Ministry of Industry and Trade, Vietnam, 2017.

8.2 Target capacity estimation for geothermal power in Viet Nam

In 1995, the American company ORMAT Inc. set up a pre-feasibility project to generate 50 MW of electricity from geothermal prospects in Bang (Quang Binh), Mo Duc and Nghia Thang (Quang Ngai), Hoi Van (Binh Dinh), Tu Bong, and Danh Thanh (Khanh Hoa), all in the central region. However, these projects have been unsuccessful due to various barriers.

In 2013, the Vietnamese government granted licence to LiOA Geothermal Joint Stock Company to explore Hoi Van geothermal prospect in South Central Viet Nam and develop a geothermal power plant with 10 MW–15 MW capacity. The project is still in the thermal gradient drilling stage.

Currently, Viet Nam's geothermal energy, with a total estimated capacity of 30 MW$_t$, is only used for drying iodine mixing salt, fish farming, bathing and swimming (including balneology), and animal farming (Nguyen et al., 2005).

According to 'Geothermal Potential for Power Generation for Viet Nam' in ERIA 2016 report (ERIA, 2016), a preliminary assessment indicates that the 11 most prospective geothermal potential sites in Viet Nam can be developed for 155 MW$_e$ capacity by 2025, and 680 MW$_e$ capacity can be attained in 2050 if all barriers are removed.

8.3 Barriers to geothermal energy use, and necessary innovations

Questionnaires were sent out to 11 geologists and 8 renewable energy engineers (Table 3.8.3-1) as inquiry survey on geothermal power generation and GSHP.

Table 3.8.3-1. Institutions and Number of Domestic Experts Respondents to the Survey

	Institution and Specialisation	Number	Sub-	Total
Geology Group	Exploration company engineer	2	11	19
	Research institution researcher	6		
	University researcher or teacher	3		
Energy Group	Renewable energy institute	4	8	
	Renewable energy company	4		

Source: Authors.

1) Geothermal power generation

Table 3.8.2-2 and Figure 3.8.2-1 show the results of interviews, indicating that the biggest category of barriers to geothermal energy development is technical (25%), followed by policy (24%). Social issues are also major barriers (20%), while financial and legal barriers represent 18% and 13%, respectively.

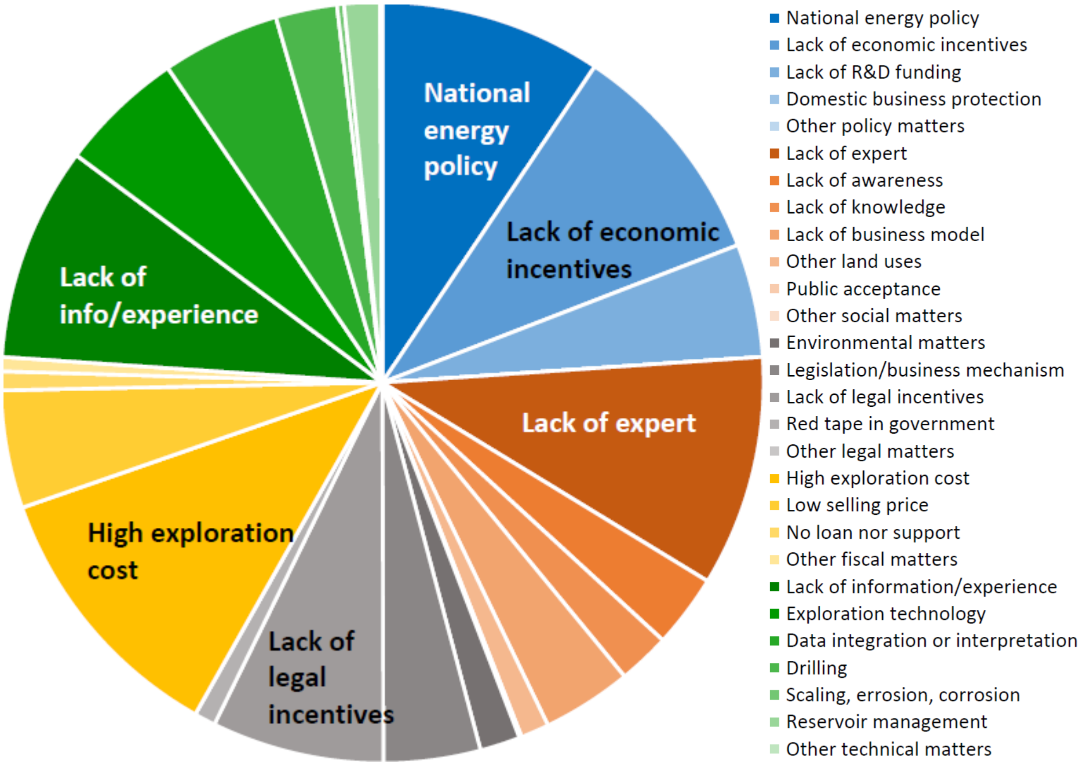
Considering specific barriers, the biggest is exploration costs (11.5%), followed by lack of expertise (9.8%) and economic incentives (9.7%). The fourth is the government's energy policy (see Section 3.8.1.1). There are small barriers that also contribute in diminishing the development of geothermal energy in Viet Nam.

Table 3.8.3-2. Degrees of Barriers Hindering Geothermal Power Generation Development in Viet Nam

CategoryBarriers	%	Barrier	%
Policy	**24**	National energy policy	9.4
		Lack of economic incentives	**9.7**
		Lack of R&D funding	4.8
		Domestic business protection	0.0
		Other policy matters	0.0
Social	**20**	Lack of experts	**9.8**
		Lack of awareness	3.1
		Lack of knowledge	2.2
		Lack of business models	3.8
		Other land uses	1.2
		Public acceptance	0.1
		Other social matters	0.0
Legal	**13**	Environmental matters	1.7
		Legislation/Business mechanism	4.1
		Lack of legal incentives	**7.3**
		Red tape in government	0.9
		Other legal matters	0.0
Fiscal	**18**	High exploration cost	**11.5**
		Low selling price	5.0
		No loan nor support	0.8
		Other fiscal matters	0.6
Technical	**25**	Lack of information/experience	**9.1**
		Exploration technology	5.3
		Data integration or interpretation	5.0
		Drilling	2.6
		Scaling, erosion, corrosion	0.3
		Reservoir management	1.5
		Other technical matters	0.1
TOTAL (%)	**100**		**100**

R&D = research and development.
Source: Authors.

Figure 3.8.3-1. Barriers to Geothermal Power Generation Development in Viet Nam



Source: Authors.

2) GSHP

Since there is no GSHP application in Viet Nam, technical barriers form the largest of barriers (27%), of which 12% corresponds to lack of installation experience. Although fiscal barriers are only 18% of the total, installation cost (14.7%) is the highest amongst all barriers in this category. Policy issues form the second largest category where national energy policy is the highest (10.6%).

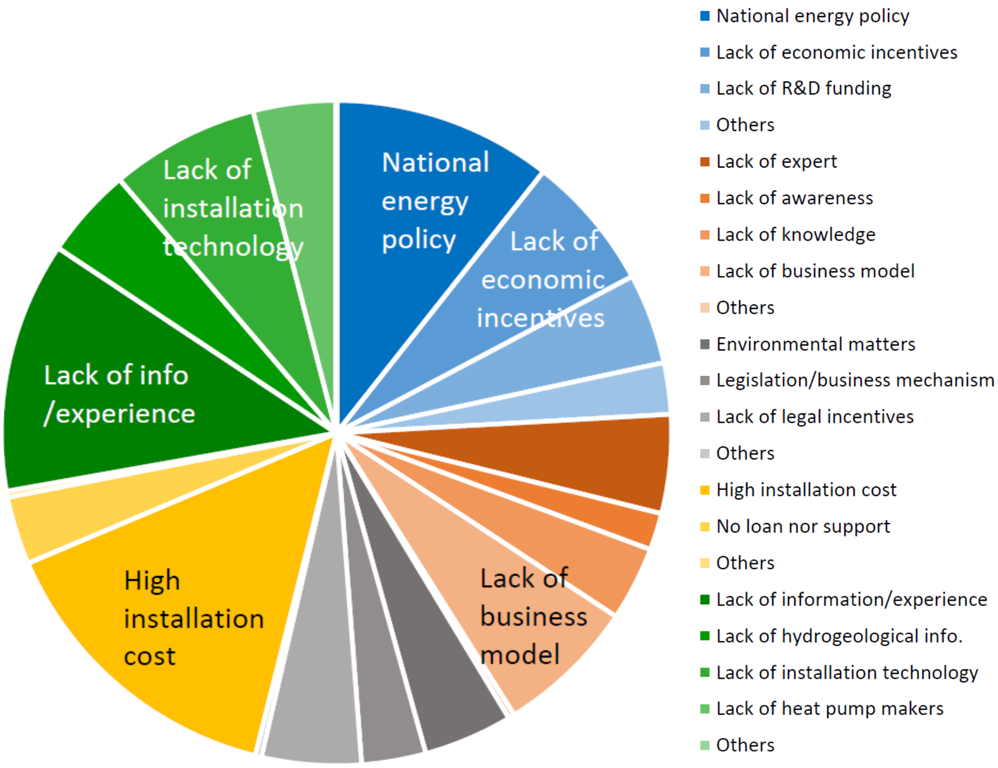
Table 3.8.3-3. Degrees of Barriers Hindering the Ground Source Heat Pump Installation in Viet Nam

Category	%	Barriers	%
Policy	**24%**	National energy policy	10.6%
		Lack of economic incentives	6.6%
		Lack of R&D funding	4.4%
		Others	2.5%
Social	**17%**	Lack of experts	4.8%
		Lack of awareness	1.8%
		Lack of knowledge	3.6%
		Lack of business models	6.8%
		Others	0.3%
Legal	**13%**	Environmental matters	4.3%
		Legislation/Business mechanism	3.1%
		Lack of legal incentives	4.8%
		Others	0.3%
Fiscal	**18%**	High installation cost	14.7%
		No loan nor support	3.3%
		Others	0.3%
Technical	**27%**	Lack of information/experience	12.2%
		Lack of hydrogeological information	4.4%
		Lack of installation technology	7.2%
		Lack of heat pump makers	4.0%
		Others	0.0%
TOTAL (%)	**100**		100

R&D = research and development.

Source: The study team.

Figure 3.8.3-2. Barriers to Ground Source Heat Pump Installation in Viet Nam



Source: The study team.

8.4 Benefits of geothermal energy use in Viet Nam

Viet Nam is expecting to generate 680 MW_e total geothermal power, 155 MW_e of which is expected to be available by 2025 (ERIA, 2016).

However, because of many barriers, the geothermal power generation target by 2025 is deemed to be not feasible. But assuming that by 2025, Viet Nam would have developed 155 MW_e with a capacity factor of 70%, the selling price would be US$0.09/kW-h, with electricity sales tax of 8%. The benefits drawn from it, shown in Table 3.8.3-1, are as follows:

- CO_2 reduction of 410,284 tonnes-CO_2/year
- New employment of 493.
- New business profit of US$277,214/year
- New business sales tax of 22,177 US$/year
- New business economic effects of 346,580 US$/year

In addition are direct benefits to local people, such as food provision for those directly involved in the exploration, construction, and operation of geothermal power plants. Restaurants, hotels, and recreation facilities will also be developed in areas with geothermal power plants. The larger the plant capacity is, the more will these services be available, thus enhancing the livelihood of local population.

The number of services that utilise surplus heat from power plants will also be significant. Large amount of water with temperature of 90°C can be extracted from the geothermal power plants, which local people can use for bathing, physiotherapy, recreation, etc. Roads, schools, and clinics will also be built in communities around power plants.

Table 3.8.4-1. Benefits if 155-MWe Geothermal Power Capacity is Developed in 2025

Item		Unit	Policy	Social	Legal	Fiscal	Technical	Total	Remark
Barrier		**%**	**24**	**20**	**13**	**18**	**25**	**100**	
Target capacity		MW	37.2	31	20.15	27.9	38.75	155	x
Target power		MWh/ye	277,1	230,9	150,1	207,8	288,7	1,154,	capacity factor
Electricity		US$/year	24,94	20,78	13,51	18,70	25,98	103,94	US$0.9/kW-h
Electricity		US$/year	1,995,	1,663,	1,081,	1,496,	2,078,	8,315,	8%
Saving oil		boe/yr	335,6	279,7	181,8	251,7	349,6	1,398,	1
CO_2 mitigation		(tonnes-	119,5	99,64	64,76	89,67	124,5	498,20	
Saving energy cost	Fac	US$/MW	7.200	6.000	3.900	5.400	7.500	30	
	Tot	US$	8,315,	6,929,	4,504,	6,236,	8,661,	34,647	
Saving CO_2 reduction	Fac	US$/ton	18.01	15.01	9.760	13.51	18.76	75.08	
	Tot	US$	8,976,	7,480,	4,862,	6,732,	9,351,	37,404	
Benefits to local									
New employment		Employe	118	99	64	89	123	493	2.71x+73
New business profit		US$	66,53	55,44	36,03	49,89	69,30	277,21	1788.47x
New business sales		US$	5,323	4,435	2,883	3,992	5,544	22,177	8%
New business		US$	83,17	69,31	45,05	62,38	86,64	346,58	2236x

boe = barrel of oil equivalent, CO_2 = carbon dioxide, J = joule, MW = megawatt, MWh = megawatt hour, PV = photovoltaics.
Source: Authors.

8.5 Summary of barriers to and benefits of geothermal energy use, and policy recommendations

8.5.1 Summary of barriers

Although the development of geothermal energy in Viet Nam has many barriers, the most important thing is for the country to first have a geothermal power plant. With this plant, investors can truly understand the technological and exploration processes involved, the advantages and disadvantages in developing geothermal energy as well as the necessary government policies needed for developing geothermal projects. As in the case of other forms of renewable energy, appropriate policies and legal frameworks are necessary for geothermal energy development as it has its own characteristics.

8.5.2 Summary of benefits

Developing geothermal energy in Viet Nam means creating a new renewable energy source with many benefits to be gained. In addition to creating new jobs, contributing to a stable electricity supply, and reducing CO_2 emission, geothermal power plants also occupy very small land areas. Given Viet Nam's large population, saving natural land areas is very important.

8.5.2 Recommendation to policymakers

Include geothermal energy in the national energy development plan as soon as possible.

As a new type of resource, geothermal energy should be added to the current mineral law so geothermal developers can be licenced for exploration and development. Like other types of minerals, geothermal resource also requires geological exploration area that is greater than the area of exploration for hot mineral water, which is only 2 km^2.

Exempt from import tax equipment for exploration and exploitation of geothermal resource and construction of geothermal power plants.

Appropriately reduce electricity tax.

Encourage research cooperation between geothermal scientists and experts of Viet Nam and scientists and experts from countries with geothermal development experience.

Set training subjects related to geology and energy as well as technology in universities such as Hanoi University of Mining and Geology, Vietnam National University, Hanoi University of Science and Technology, and Electric Power University.

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Chapter 4

Recommendations to Policy Makers

1. The Most Important Policy Relevant Findings

The most important barriers common for power generation and direct use/GSHP in many member countries are:

a) lack of knowledge on geothermal energy use,

b) lack of legislation/business mechanism,

c) lack of technical information and/or experience, and

d) lack of economic incentives and high exploration/installation cost.

- For a) and c), education of both experts and ordinary people is needed.
- For b), creation of decent legislation system is necessary.
- For d), cost problems in the short term should be solved by economic incentives given by the government with proper legislation system. That, in the long term, should be solved by technology development which also needs R&D support from the government.
- Since many important barriers are inter-related, systematic support by the government is essential.

Direct benefits automatically obtained from geothermal power/heat plant installation are:

- Electricity or heat production,
- National energy security (domestic energy),
- Saving fossil fuels,
- Saving energy cost (sales price of electricity or heat),
- Saving land (amongst renewable energy),
- CO_2 mitigation,
- Saving cost for CO_2 mitigation,
- Benefits for local economy: new employment, businesses with exploration and development staffs, and
- Development of the local region (in cases of rural areas).

In many cases, indirect benefits have much larger significance to the local economy than direct benefits. Indirect benefits obtained by additional economic activity using excess heat of geothermal power plant are:

- New businesses such as greenhouse agriculture, fish farming, sport facilities by cascade heat use or mineral extraction from geothermal fluid.

For GSHP, direct benefits automatically obtained by installation are:

- Saving electricity,
- National energy security (domestic energy),
- Saving fossil fuels,
- Saving energy cost,
- Reduction of urban heat island phenomenon, and
- CO_2 mitigation by replacement from heater by fossil fuels (direct) and by saving electricity (indirect).

Indirect benefits obtained by additional economic activity using GSHP are:

- New businesses such as greenhouse agriculture, fish farming, sport facilities (swimming pools), etc.

2. Recommendations

The followings innovations are recommended to remove barriers to geothermal power generation:

Policy aspect:

- Set target on geothermal development. It should be described in national policy with roadmap and bound to national energy policy.
- Give economic incentives to geothermal business. Note that although FiT or RPS is effective, in many cases FiT or RPS is not sufficient for the private sector because of high exploration risks and high initial cost of geothermal energy development. Government support in each stage, such as R&D, subsidies for exploration and drilling, low-interest loans, and/or tax reductions are recommended.
- Create systems for capacity building and open data access. International collaboration in information exchange, case studies, and technology transfer should be encouraged.
- Conduct the following, if not yet done:
  - ✓ National demonstration projects to show best practice to investors,
  - ✓ Cooperation with other countries on research projects, capacity building, and technical and economic cooperation,
  - ✓ Inter-ministry cooperation in the government, and
  - ✓ Tax exemption for importing materials and equipment for geothermal development.

Social aspect:

- Create a good business mechanism. A mechanism contributing to local economy and welfare, and national policy on environment and energy security would be recommended for business sustainability.
- Strengthen capacity building. Education programmes at university level or higher to strengthen expertise and a social system for sustainable human resources (to keep experts in technology fields) are necessary.
- Enhance geothermal publicity through social media for public acceptance.
- Zoning by the government is needed in case of controversy with other land uses and environmental matters.

Legal aspect:

- Set laws or regulations for geothermal resource management. Rights of developers and necessary legislation process should be described in laws or Acts (legal framework). Also, geothermal development towards other land uses from environmental aspects should be given priority.
- Set up one-stop shops for simple permit and authorisation process. Especially if comprehensive geothermal law does not exist, existence of official one-stop shops for faster permission process is essential to encourage the private sector.

Fiscal aspect:

- Set risk fund (insurance scheme) or low-interest loans for geothermal exploration.
- Give drilling support (subsidies and/or risk fund).
- Give economic incentives (FiT/RPS) especially for technically difficult resources, such as low-temperature, deep, small-scale, acid-fluid, etc., with effective duration and price.
- Give tax incentives such as environmental incentives for renewable energy.

Technical aspect:

- Conduct investigations on geothermal resource reserves as national project.
- Provide open data access to previous geological exploration achievements. If there are conflicts with existing regulations, give access at least for research purpose. Sharing data from other sites may largely reduce exploration risks.
- Give strong support for R&D especially for deep EGS reservoir creation.
- Conduct national demonstration projects to show best practice for technology development to investors and to find real problems at the site.
- Promote international cooperation especially on:
  - ✓ Development of new technologies for exploration surveys

- ✓ Collaborative research on scaling, erosion, and corrosion
- ✓ Sharing best practices on reservoir management
- ✓ Capacity building: training of experts abroad

For ground source heat pump (GHSP), the followings innovations are recommended:

Policy aspect:

- ➢ Give geothermal-specific policy to drive expansion of residential applications.

Legal aspect:

- ➢ Give legal incentives for green energy (not penalty but reward) to GSHP.
- ➢ Set accurate monitoring schemes of load factors and system COPs for both technical and social awareness of GSHP benefits.
- ➢ Set government supervision of reservoir management (especially on injection) for sustainable use of reservoirs for direct use by the community.

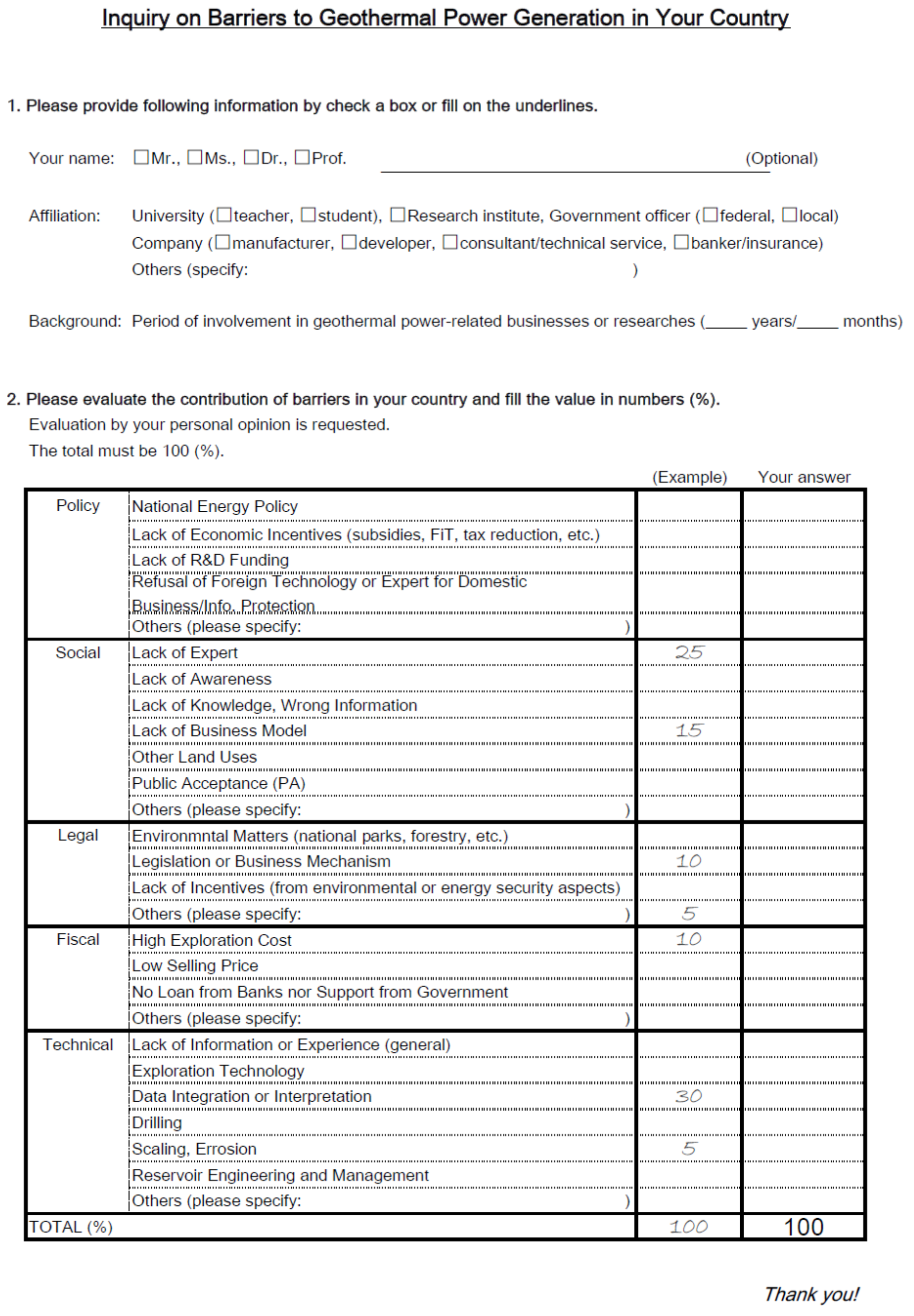
Technical aspect:

- ➢ Conduct research to 1) compile suitability maps in a regional scale and 2) optimise GSHP system based on the local hydrogeological and thermal condition, targeting a) accurate GSHP system design (reduction of installation/running cost), b) sustainable use of GSHP, and c) raising awareness of GSHP.
- ➢ For direct use, conduct R&D of technical part of injection especially into sandstone range.

Fiscal aspect:

- ➢ Support R&D for hydrogeological field surveys, case studies, and long-term monitoring.
- ➢ Subsidise new installations of GSHP system in private residential buildings.

Appendix 1 (Form of the inquiry surveys for geothermal power generation)



Inquiry on Barriers to Geothermal Power Generation in Your Country

1. Please provide following information by check a box or fill on the underlines.

Your name: ☐Mr., ☐Ms., ☐Dr., ☐Prof. ______________________________ (Optional)

Affiliation: University (☐teacher, ☐student), ☐Research institute, Government officer (☐federal, ☐local)
Company (☐manufacturer, ☐developer, ☐consultant/technical service, ☐banker/insurance)
Others (specify:)

Background: Period of involvement in geothermal power-related businesses or researches (_____ years/_____ months)

2. Please evaluate the contribution of barriers in your country and fill the value in numbers (%).

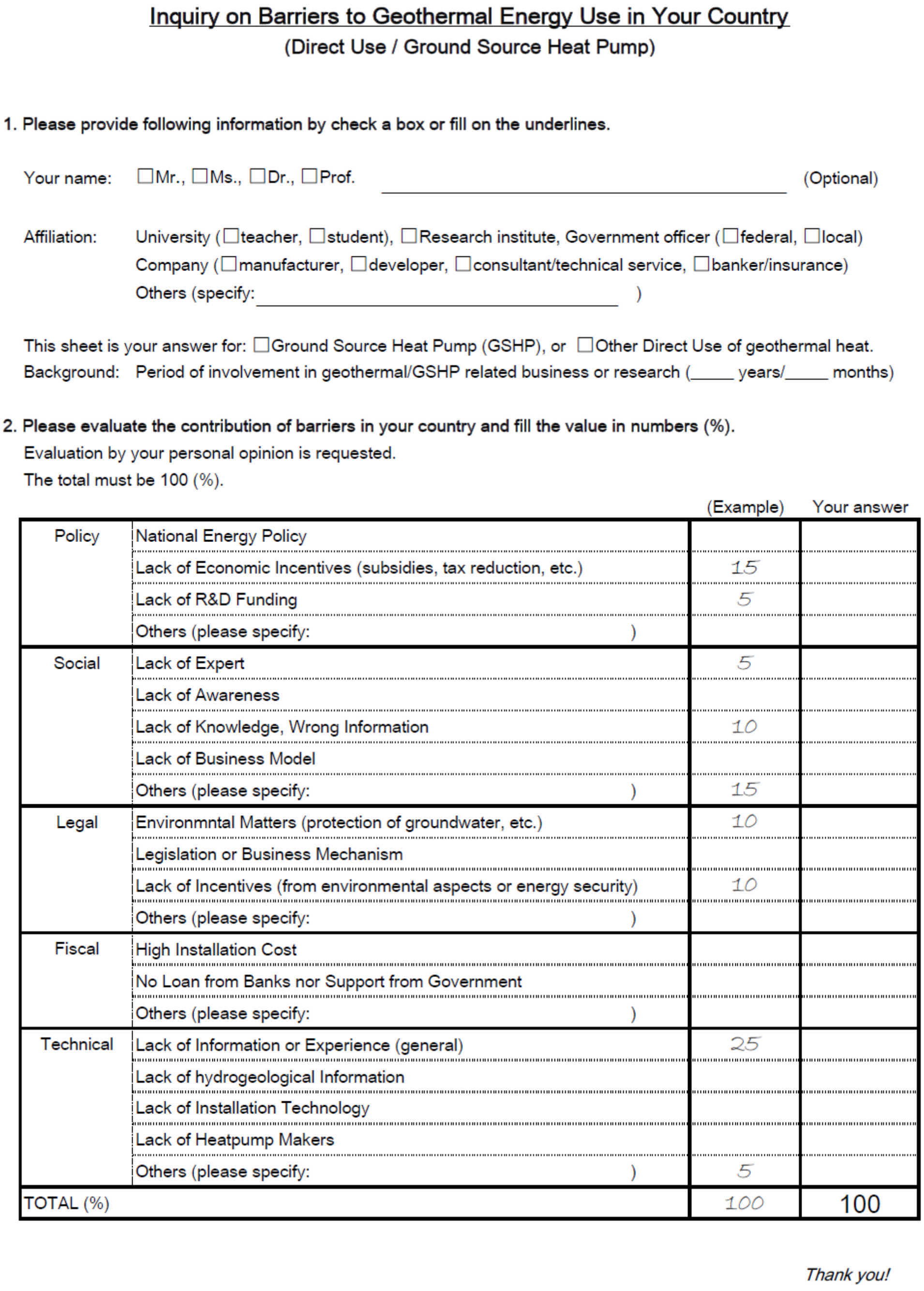
Evaluation by your personal opinion is requested.

The total must be 100 (%).

		(Example)	Your answer
Policy	National Energy Policy		
	Lack of Economic Incentives (subsidies, FiT, tax reduction, etc.)		
	Lack of R&D Funding		
	Refusal of Foreign Technology or Expert for Domestic Business/Info. Protection		
	Others (please specify:)		
Social	Lack of Expert	25	
	Lack of Awareness		
	Lack of Knowledge, Wrong Information		
	Lack of Business Model	15	
	Other Land Uses		
	Public Acceptance (PA)		
	Others (please specify:)		
Legal	Environmntal Matters (national parks, forestry, etc.)		
	Legislation or Business Mechanism	10	
	Lack of Incentives (from environmental or energy security aspects)		
	Others (please specify:)	5	
Fiscal	High Exploration Cost	10	
	Low Selling Price		
	No Loan from Banks nor Support from Government		
	Others (please specify:)		
Technical	Lack of Information or Experience (general)		
	Exploration Technology		
	Data Integration or Interpretation	30	
	Drilling		
	Scaling, Errosion	5	
	Reservoir Engineering and Management		
	Others (please specify:)		
TOTAL (%)		100	100

Thank you!

Appendix 2 (Form of the inquiry surveys for direct use and GSHP)



Inquiry on Barriers to Geothermal Energy Use in Your Country

(Direct Use / Ground Source Heat Pump)

1. Please provide following information by check a box or fill on the underlines.

Your name: ☐Mr., ☐Ms., ☐Dr., ☐Prof. ________________________________ (Optional)

Affiliation: University (☐teacher, ☐student), ☐Research institute, Government officer (☐federal, ☐local)
Company (☐manufacturer, ☐developer, ☐consultant/technical service, ☐banker/insurance)
Others (specify: ____________________________)

This sheet is your answer for: ☐Ground Source Heat Pump (GSHP), or ☐Other Direct Use of geothermal heat.
Background: Period of involvement in geothermal/GSHP related business or research (_____ years/_____ months)

2. Please evaluate the contribution of barriers in your country and fill the value in numbers (%).
Evaluation by your personal opinion is requested.
The total must be 100 (%).

		(Example)	Your answer
Policy	National Energy Policy		
	Lack of Economic Incentives (subsidies, tax reduction, etc.)	15	
	Lack of R&D Funding	5	
	Others (please specify:)		
Social	Lack of Expert	5	
	Lack of Awareness		
	Lack of Knowledge, Wrong Information	10	
	Lack of Business Model		
	Others (please specify:)	15	
Legal	Environmntal Matters (protection of groundwater, etc.)	10	
	Legislation or Business Mechanism		
	Lack of Incentives (from environmental aspects or energy security)	10	
	Others (please specify:)		
Fiscal	High Installation Cost		
	No Loan from Banks nor Support from Government		
	Others (please specify:)		
Technical	Lack of Information or Experience (general)	25	
	Lack of hydrogeological Information		
	Lack of Installation Technology		
	Lack of Heatpump Makers		
	Others (please specify:)	5	
TOTAL (%)		100	100

Thank you!