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

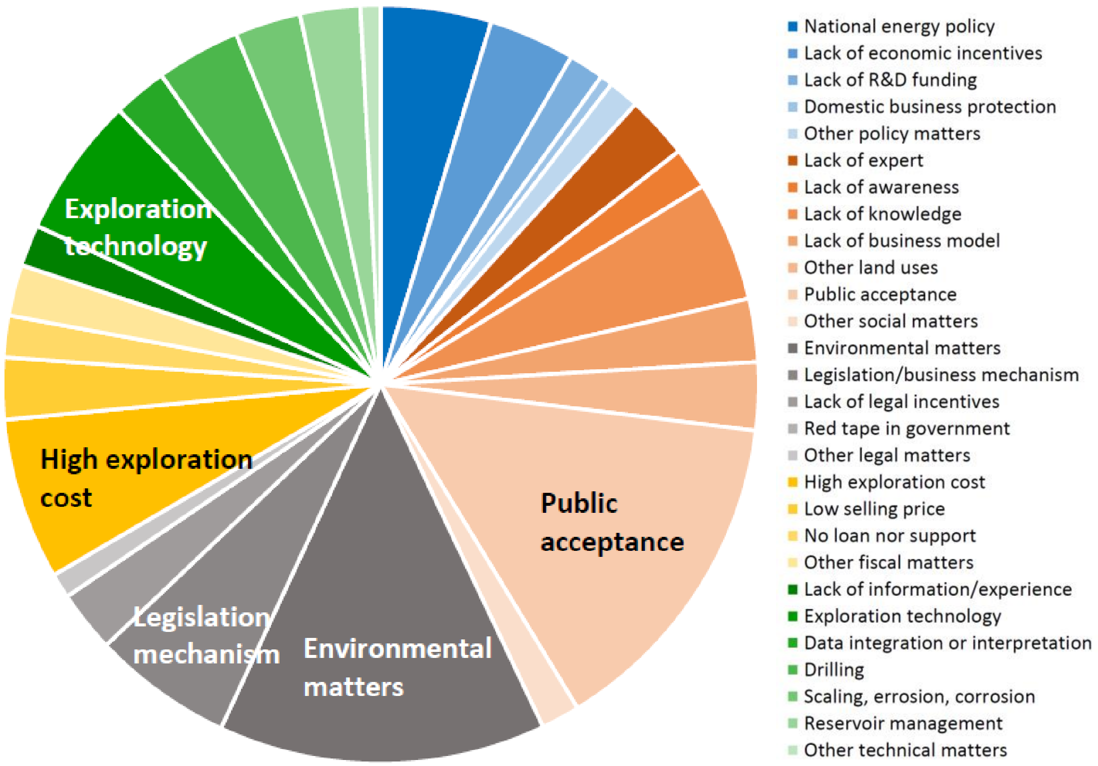
In addition, there is a long-term target towards 2050 by implementing 'supercritical geothermal power generation'. The Cabinet Office of the government of Japan, in the National Energy and Environment Strategy for Technological Innovation Towards 2050, places supercritical geothermal power generation 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:

$$588 \times 1{,}083 \times 24 \times 365.25 \times 0.7 = 3{,}907{,}616{,}514 \text{ kg-}CO_2\text{/year}$$

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

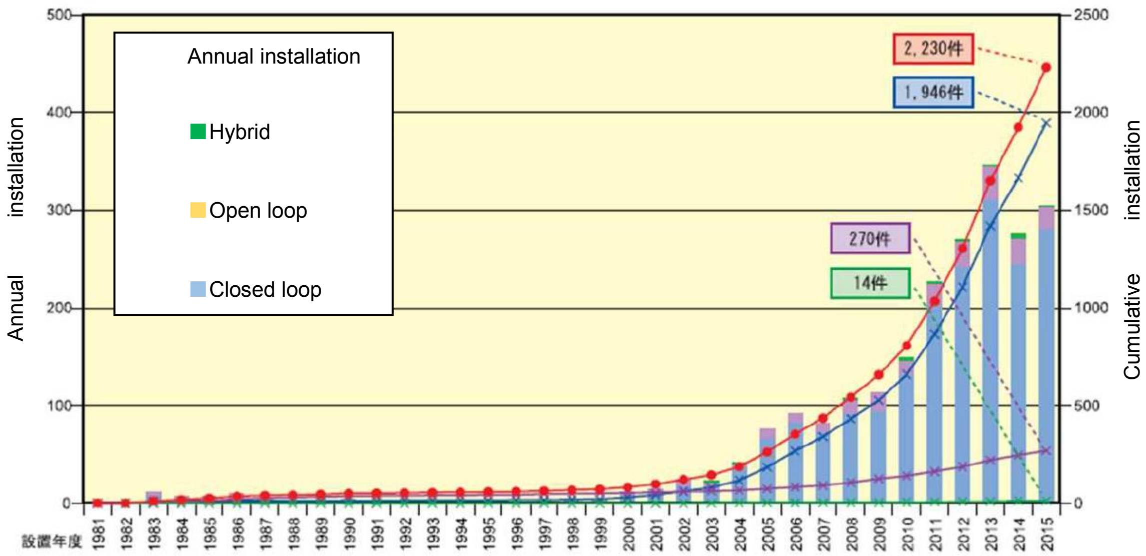
3.6.1 Brief history of GSHP use, target installation, and barriers in Japan

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.

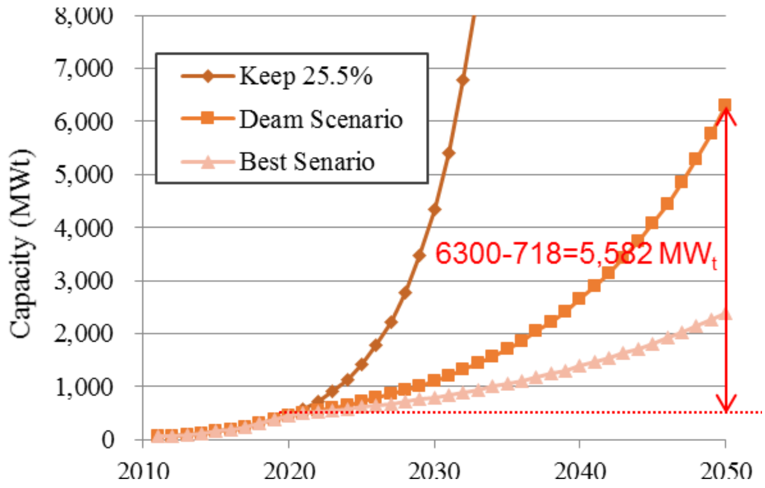
2) Target in 2025 and 2050

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,

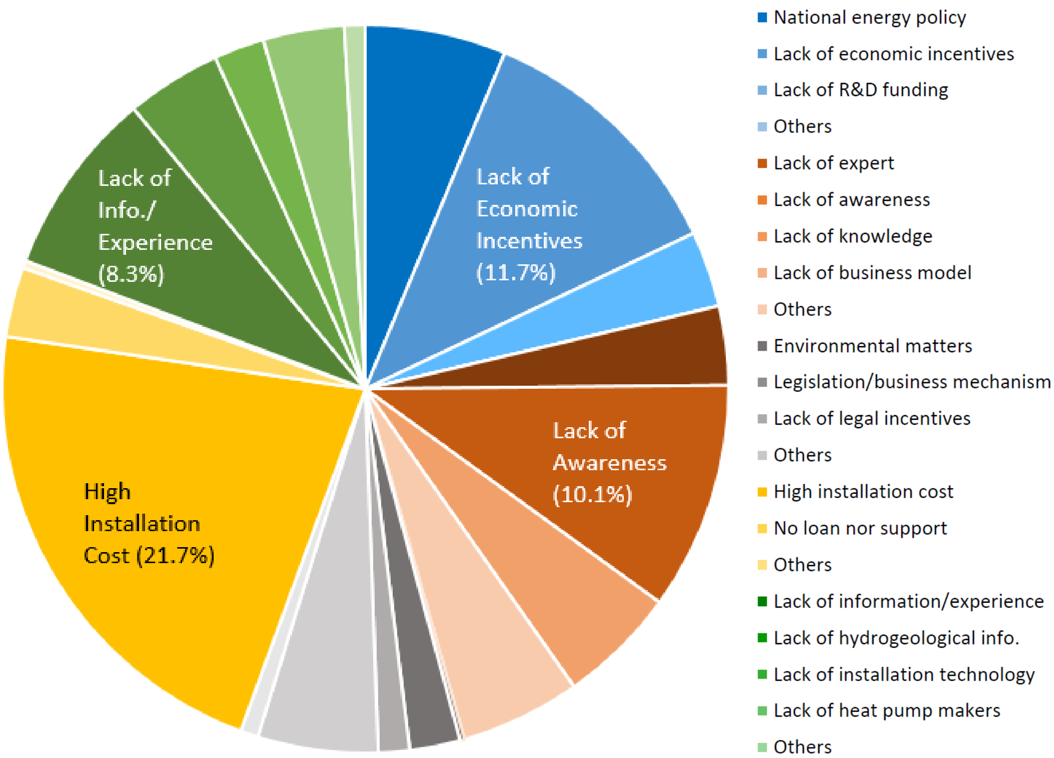
- Ehara et al. (2008) estimated installation in 2050 for three scenarios: base scenario, best scenario, and dream scenario.
- With the current increment rate of 25.5%, capacity in 2020 satisfies the installation in the best scenario (465 MW_t).
- Since the current increment already satisfies the best 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.

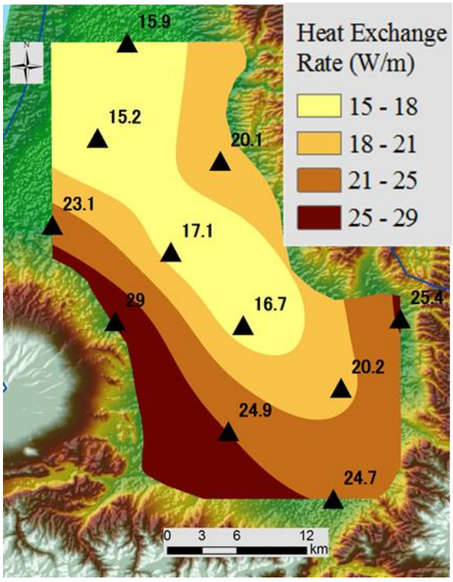
3.6.2 Innovative ideas to remove barriers

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.

<u>Electricity saving by GSHP system for space cooling compared to ACs</u>

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;

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

…………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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