# 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)<br>48,150 (GSHP) | 67,500 (conventional)<br>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.

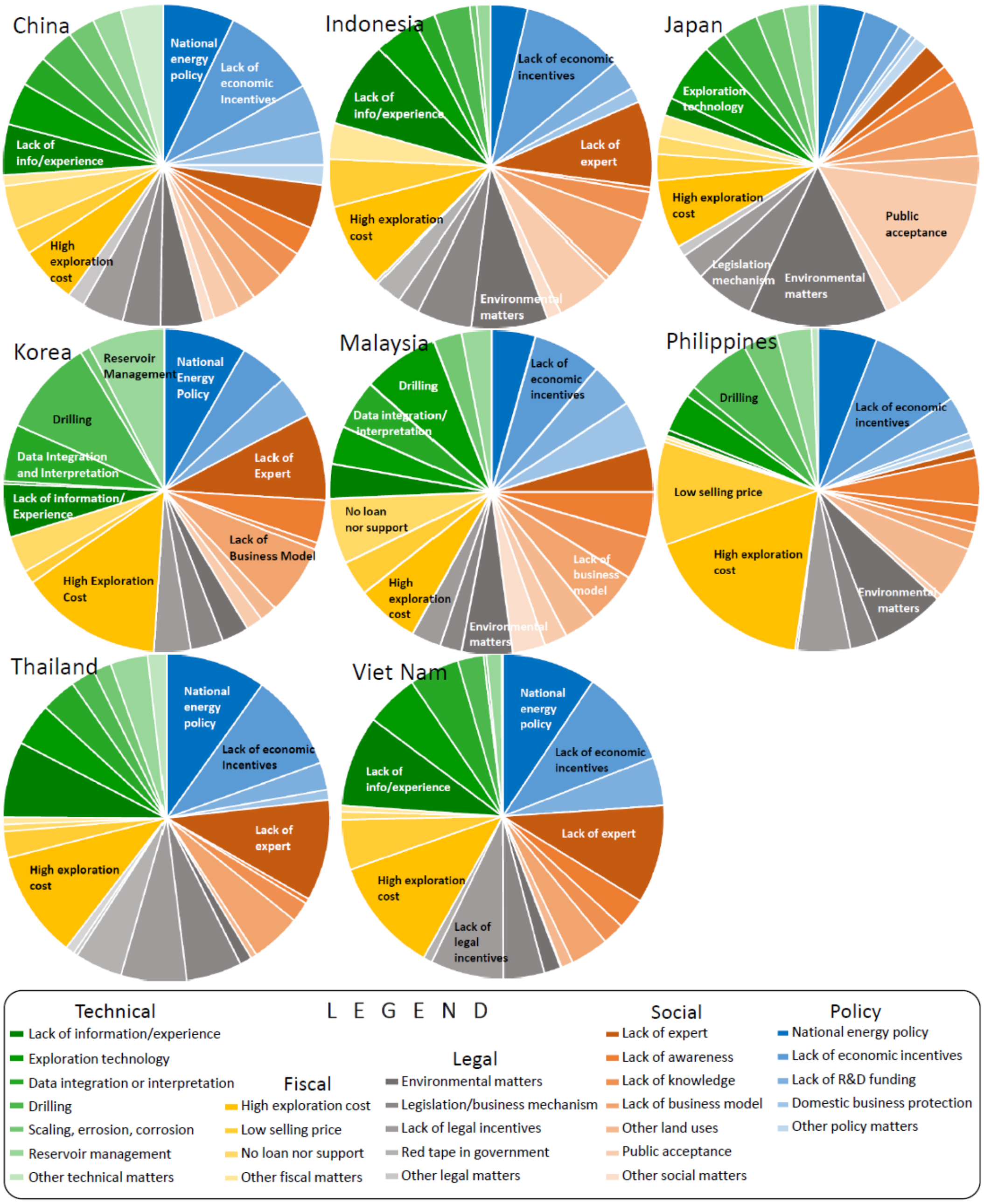
## 2.2 Barrier evaluation

### *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.

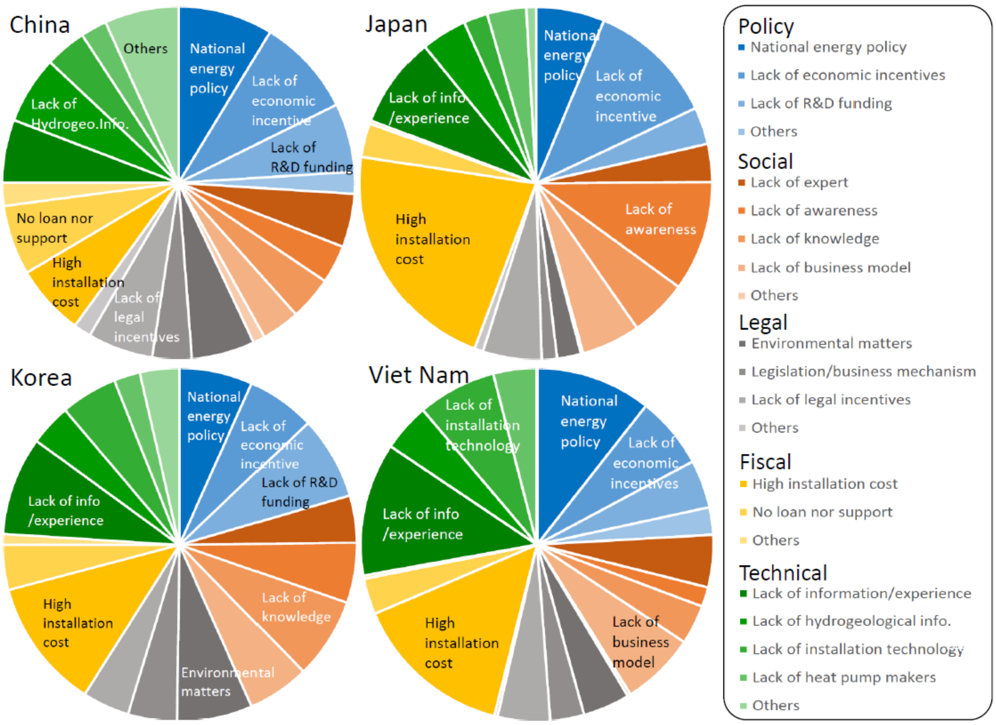
Figure 2.2-1 and Figure 2.2-2 show the evaluation results on barriers to geothermal power generation and direct use, respectively. Surveys on direct use were conducted only in China, Japan, Korea, and Viet Nam, where increase of direct use was expected. For Figure 2.2-2, note that the result of China 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.

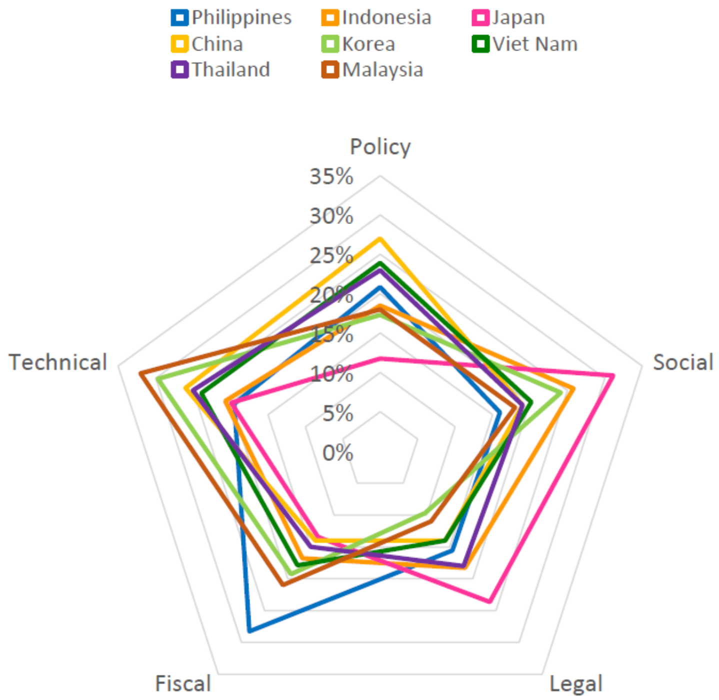
**Figure 2.2-2. Barriers to Direct Use and Ground Source Heat Pump in Four Countries as Evaluated by Domestic Experts**



Source: Authors.

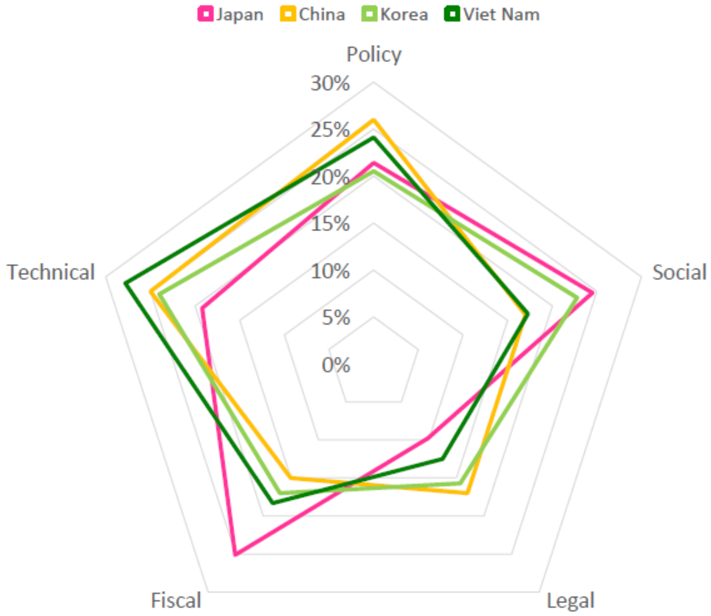
Figure 2.2-3 and Figure 2.2-4 show barriers to geothermal power generation and direct use, including GSHP, respectively. Note that Figure 2.2-4 shows countries that set target for direct use only. In the categories such as policy and legal shown in the figures, the tendency of each county can be identified 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<br>➢ 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<br>➢ 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<br>➢ 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<br>➢ Higher performance of business by saving energy cost | |
| **Local Development and Welfare** | | ➢ Melting of snow on roads and parking lots<br>➢ New public services and facilities by saving cost for heating and cooling. |
| **Environmental Advantages** | ➢ $CO_2$ mitigation by energy saving<br>➢ 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<br>➢ 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:

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

That of an LNG plant is:

$43.5 \times 0.55$ (MJ/kg) / 3600 (sec) = $6.65 \times 10^{-3}$ (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)/ $4.89 \times 10^{-3}$ (MWh/kg) = $1.235 \times 10^6\ W$ (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)/ $6.65 \times 10^{-3}$ (MWh/kg) = $9.22 \times 10^5\ W$ (kg/year) (3b)

= $4.54 \times 10^4\ W$ (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) = $4.66 \times 10^5\ W$ (US$/year). (4a)

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

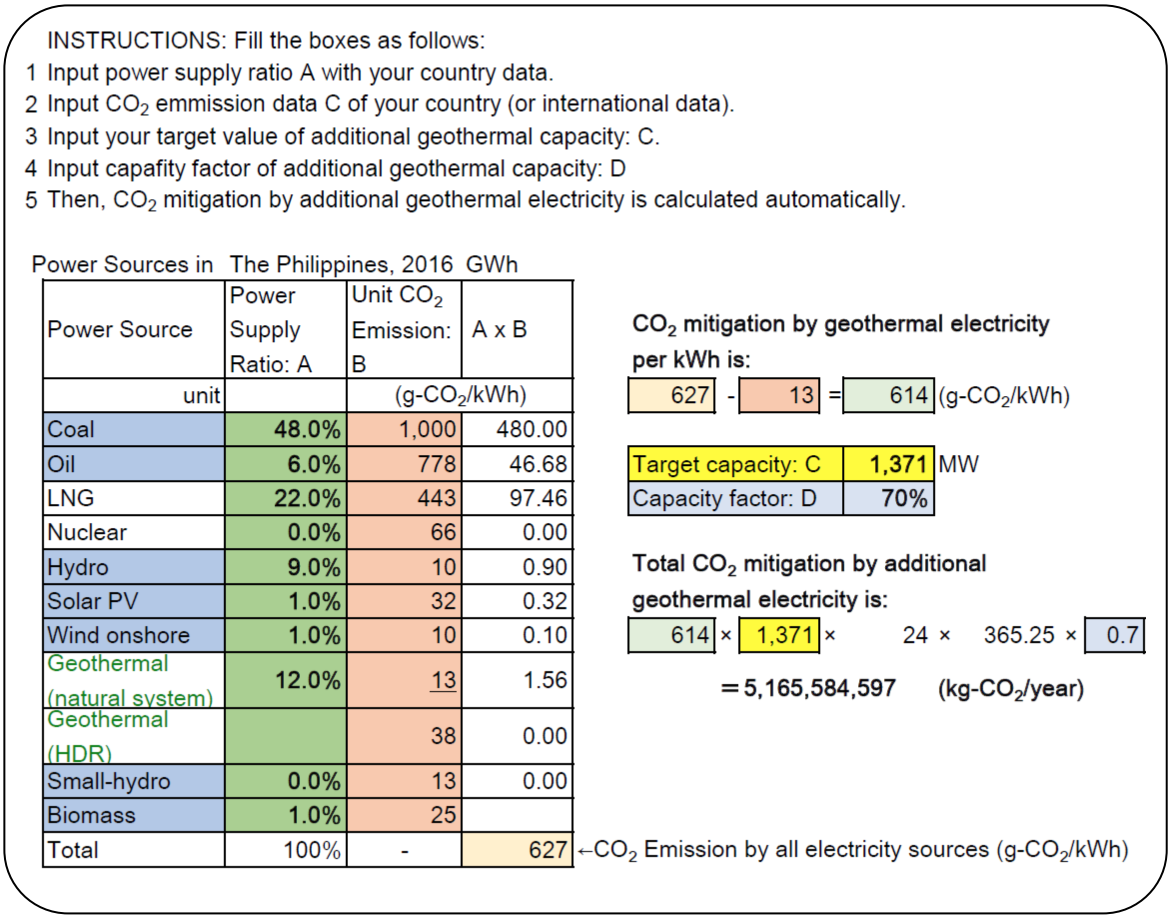
$4.54 \times 10^4 W$ (MBtu/year) x 5 (US$/MBtu) = $2.27 \times 10^5\ W$ (US$/year). (4b)

**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

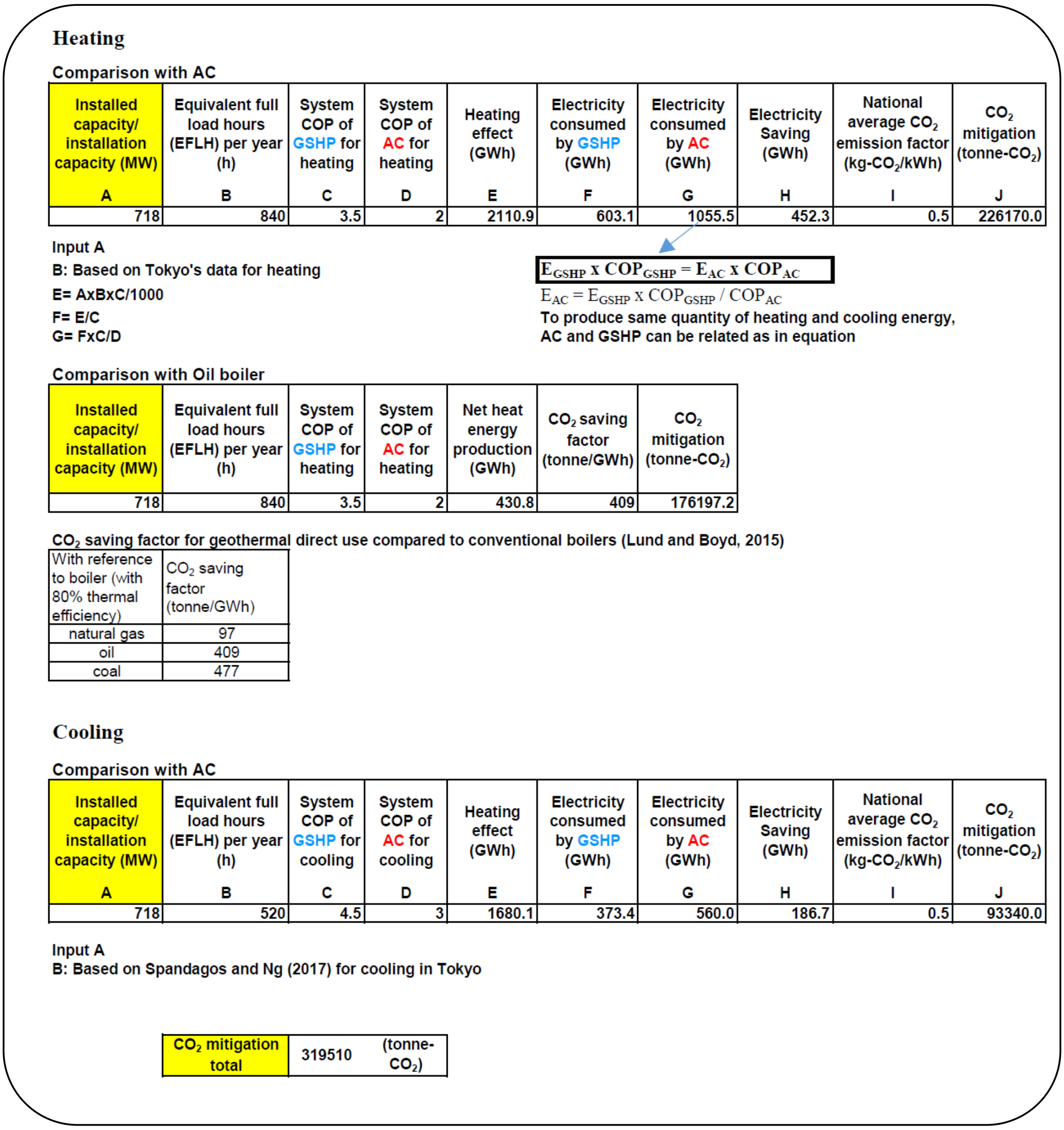
**= 5,165,584,597 (kg-$CO_2$/year)**

$CO_2$ = 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)<br>A | Equivalent full load hours (EFLH) per year (h)<br>B | System COP of GSHP for heating<br>C | System COP of AC for heating<br>D | Heating effect (GWh)<br>E | Electricity consumed by GSHP (GWh)<br>F | Electricity consumed by AC (GWh)<br>G | Electricity Saving (GWh)<br>H | National average $CO_2$ emission factor (kg-$CO_2$/kWh)<br>I | $CO_2$ mitigation (tonne-$CO_2$)<br>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

$E_{GSHP}\ \mathrm{x}\ COP_{GSHP} = E_{AC}\ \mathrm{x}\ COP_{AC}$

$E_{AC} = E_{GSHP}\ \mathrm{x}\ COP_{GSHP} / COP_{AC}$

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)<br>A | Equivalent full load hours (EFLH) per year (h)<br>B | System COP of GSHP for cooling<br>C | System COP of AC for cooling<br>D | Heating effect (GWh)<br>E | Electricity consumed by GSHP (GWh)<br>F | Electricity consumed by AC (GWh)<br>G | Electricity Saving (GWh)<br>H | National average $CO_2$ emission factor (kg-$CO_2$/kWh)<br>I | $CO_2$ mitigation (tonne-$CO_2$)<br>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**

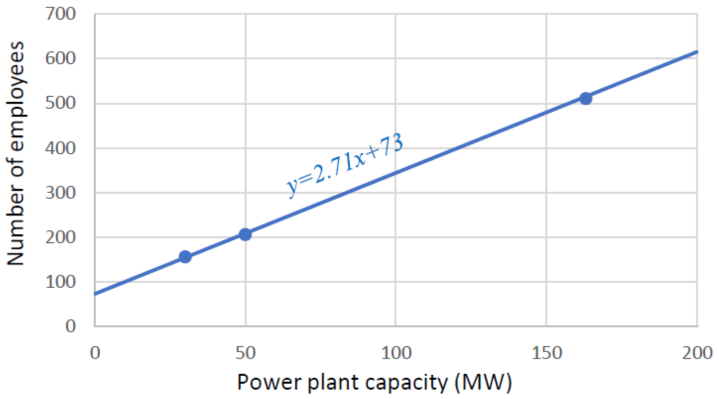
Hienuki et al. (2015) calculated life-cycle employment of geothermal power generation using an extended input–output model. The model shows that the embodied employment of geothermal power generation by life cycle stages is 0.89 [person/GWh] and employment for operation and maintenance is 66% of total 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.

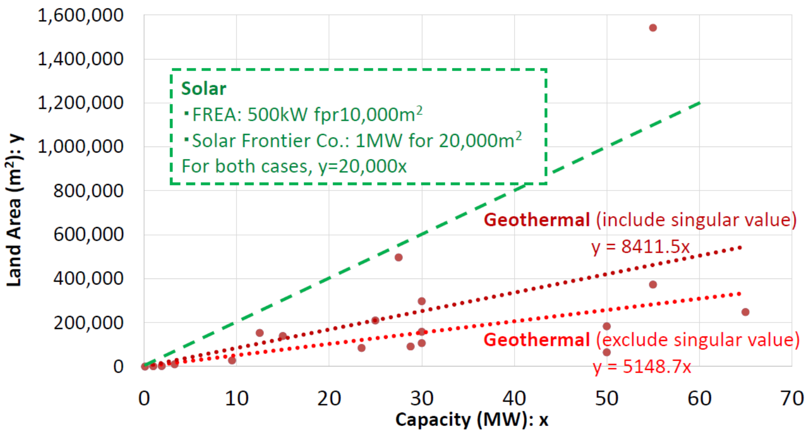
Although three plots are not sufficient to discuss general tendency and smaller power plants may have different curves, we will use in the following sections the linear relationship shown in Figure 2.4-2 ($y = 2.71x + 73$) to roughly estimate the number of possible new local employment generated by geothermal 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 $MW_e$ (+ 150$MW_t$), 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)<br>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.)<br>Profit is NZ$500,000/yr.<br>(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.<br>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.