Trends in Geothermal Applications 2015

Survey Report on Geothermal Utilisation and Development in IEA Geothermal Member Countries in 2015

with trends in geothermal power generation and heat use 2000 - 2015

IEA Geothermal

GEOTHERMAL TREND REPORT 2015

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1 INTRODUCTION

1.1 About IEA Geothermal

The International Energy Agency (IEA) is an inter-governmental organization which acts as an energy policy advisor to 29 member countries in their efforts to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to coordinate measures in times of oil supply emergencies. While this continues to be a key aspect of its work, the IEA has evolved and expanded. Today, the IEA's four main areas of focus are: energy security, economic development, environmental awareness, and engagement worldwide.

To promote international scientific collaboration and to foster research, development and deployment of particular technologies, the IEA created a legal contract, the Implementing Agreement, and a system of standard rules and regulations. The Geothermal Implementing Agreement (GIA), or IEA Geothermal, provides an important framework for wide-ranging international cooperation in geothermal R&D. The GIA went into effect for an initial period of five years in 1997 and is now in its fourth term of operation, which will take its mandate to February 2018. Efforts concentrate on encouraging, supporting and advancing the sustainable development and use of geothermal energy worldwide, both for power generation and direct use applications (Fig. 1).

The management of the organisation is conducted by an Executive Committee with one representative from each country and each sponsor member, while the management of the various major activities (Working Groups, WG) is the responsibility of the Operating Agents and their WG Leaders. In 2015, the IEA Geothermal has 17 members: 13 country members - Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Norway, Korea, Switzerland, the United Kingdom, and the United States; the European Union, and three sponsors: the Canadian Geothermal Energy Association, the Geothermal Group of the Spanish Renewable Energy Association, and ORMAT Technologies Inc.

The GIA's activities cover a diverse range of research areas, or Tasks, which are organised in five Working Groups (as at 2016): WG 1 - Environmental Impacts of Geothermal Development, WG 8 - Direct Use of Geothermal Energy, WG 12 - Deep Roots of Volcanic Geothermal Systems, and WG 13 - Emerging Geothermal Technolgies. A geothermal data and information activity is organised in WG 10 - Data Collection and Information, which all country members are required to participate in.

The main objective of WG 10 is to collect essential data on geothermal energy uses, trends and developments in GIA member countries and to publish these data in an annual report, the Geothermal Trend Report. This report provides a brief overview of data such as installed/running capacities and electricity generation and heat use. Individual reports from each country, which are based on a standardised questionnaire, provide the basis for the data collection presented here. To illustrate trends and a comparison with geothermal uses worldwide, additional data sources, such as the publications associated with the World Geothermal Congress, are also evaluated.

This report "Trends in Geothermal Applications" presents the sixth annual collection of standardised data from 15 GIA countries (country members & two sponsors) and extends the information provided in the more general GIA Annual Reports. Future trend reports will supply substantial information on geothermal applications and help to illustrate trends in geothermal energy use on an international scale.

For further information please visit the website of the IEA Geothermal: http://iea-gia.org.

Figure 1: Wairakei geothermal power station and aquaculture

1.2 Units and abbreviations

Units of Energy and Capacity

Energy produced (electricity, heat): **watt-hour** [Wh]; **joule** [J]

Capacity (electric, thermal): **watt** [W_e], [W_t]

Table 1: Energy units, conversion factors and prefixes

1 megawatt-hour [MWh]	1,000 kilowatt-hours [kWh]
1 gigawatt-hour [GWh]	1 million kilowatt-hours [kWh]
1 terawatt-hour [TWh]	1 billion kilowatt-hours [kWh]
1 gigawatt-hour [GWh]	3.6 terajoule [TJ]
1 terawatt-hour [TWh]	3.6 petajoule [PJ]
1 terajoule [TJ]	0.2778 gigawatt-hours [GWh]
1 petajoule [PJ]	0.2778 terawatt-hours [TWh]

Kilo- (k)	10^3
Mega- (M)	10^6
Giga- (G)	10^9
Tera- (T)	10^{12}
Peta- (P)	10^{15}
Exa- (E)	10^{18}

Country codes

Table 2: Participating countries (ISO 3166 country codes)

Country	**Country code**
Australia	AUS
Canada	CAN
France	FRA
Germany	DEU
Iceland	ISL
Italy	ITA
Japan	JPN
Mexico	MEX
Republic of Korea	KOR
New Zealand	NZL
Norway	NOR
Spain	ESP
Switzerland	CHE
United Kingdom	GBR
United States of America	USA

Abbreviations

BHE	Borehole Heat Exchanger
CAGR	Compound Annual Growth Rate
COP	Coefficient of Performance
GIA	Geothermal Implementing Agreement
GSHP/GHP	Ground Source Heat Pump/Geothermal Heat Pump
IEA	International Energy Agency
na	(data) not available
R&D	Research and Development
SPF	Seasonal Performance Factor
WG	Working Group

1.3 Glossary

Autoproducers generate electricity and/or heat wholly or partly for their own use as an activity which supports their primary activity. An example is a thermal spa using geothermal water from their own well, while also selling a smaller amount to a neighbour (Ketilsson et al., 2015).

Capacity factor: Indication of the amount of use over a given period of time, usually a year. For power generation, the capacity factor is the ratio of the actual output of a power plant to its output if operated at full nameplate capacity over a given time. A capacity factor of 1 would indicate a year-round use, and 0.5 would indicate a use of 4,380 full-load hours per year (Lund et al., 2005).

Coefficient of Performance (COP)/Seasonal Performance Factor (SPF): The COP describes the efficiency of ground source heat pumps. It is the ratio of the output energy divided by the input energy (electricity) and usually varies from 3 to 6 (Curtis et al., 2005). In Europe, this is frequently referred to as the SPF, which is the average COP over the heating and cooling season and takes into account system properties.

Geothermal energy: Heat energy which is contained within the Earth. Geothermal energy derives from residual heat from the original formation of the Earth and from decay of naturally occurring radioactive isotopes. Heat from radioactive decay is estimated to contribute about half of Earth's total heat flux in newer studies (KamLAND Collaboration, 2011).

Geothermal power plants:

Dry steam plants use hot steam piped directly from a geothermal reservoir to drive turbines which spin a generator to produce electric power.

Flash steam plants are the most common form of geothermal plants. High-pressure hot water is converted to steam to drive turbines. The cooled steam condenses to water which is injected back into the ground to avoid a depletion of the reservoir.

Binary cycle power plants transfer heat from geothermal hot water to a working fluid with a lower boiling point in a second cycle. The working fluid is vaporized by passing the geothermal fluid through a heat exchanger. The vapour is used to drive a turbine to produce power and then condensed and reused in a closed cycle. Organic Rankine Cycle (ORC) plants use organic working fluids, Kalina Cycle plants a mixture of water and ammonia.

High/Medium/Low enthalpy geothermal reservoir: The enthalpy of a reservoir is used to express the thermal energy content of a system and is the most common criterion to classify geothermal resources (Dickson & Fanelli, 2004). A standard terminology to define low, intermediate or high enthalpy geothermal systems does not exist. The IPCC geothermal report 2008 (Fridleifsson et al., 2008) specifies a reservoir fluid temperature of 180 °C as the boundary between medium and high enthalpy and may serve as a guide value. The threshold for low/medium enthalpy is frequently given at 100 °C.

Installed capacity: Nameplate energy output of a power or heating plant.

Main activity producers generate electricity and/or heat for sale to third parties as their primary activity. This includes both public and private utilities as well as power plants (Ketilsson et al., 2015).

Operating/Running capacity: Actual capacity of a power or heating plant.

Thermal waters/Brines: Naturally occurring waters with temperatures above 20 °C.

Figure 2: The Champagne Pool at Wai-O-Tapu, New Zealand.

1.4 Geothermal applications data: an overview

Geothermal energy can be used for a wide range of applications from standard 12 kW_t heat pump systems in residential buildings up to geothermal power plants with electric capacities of 100 MW_e and more. The application depends mainly on the system's heat content (enthalpy) and on the designated use of the geothermal source. For geothermal power generation usually a minimum fluid temperature of 100 °C is required.

With signing of the IEA Geothermal Implementing Agreement, the current 17 GIA members (13 countries, the European Commission, and three industry organisations/companies) have declared their intention to promote the sustainable utilisation of geothermal energy worldwide. Accounting for 58% of the world's geothermal power generation and 36% of the geothermal heat produced worldwide, GIA member countries contribute a considerable share of the global energy use. Figure 3 gives an overview of the geothermal capacities and energy produced in GIA member countries in 2015.

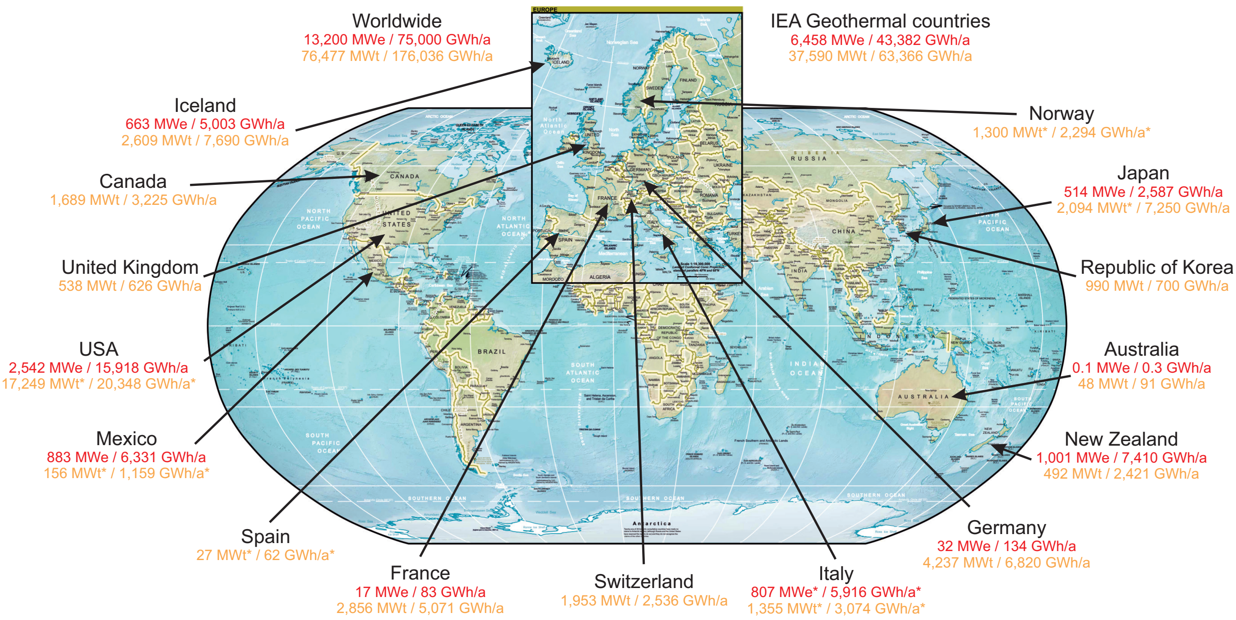

Figure 3: Overview of geothermal power (red) and heat (orange) utilisation in member countries and worldwide 2015. *Heat related data includes direct uses as well as geothermal heat pump use. Country data: GIA WG 10 country reports 2015, electric capacities are running capacities; world data for power: REN21 Global Status Report 2016, electric capacities are installed capacities; world data for heat: estimated assuming a compound annual growth rate of 7.9% for capacity and 6.9% for heat use. *includes data from previous year. Maps: The World Factbook 2013, CIA (www.cia.gov).*

Figure 4: 140 MW_e Nga Awa Purua triple flash power station near Taupo, New Zealand.

2 GEOTHERMAL POWER GENERATION

2.1 Introduction

The designed output of a power plant is indicated by its **installed** capacity which is usually denoted in megawatts [MW] and sometimes in kilowatts [kW]. Sometimes however, these installed capacity values do not represent the capacity that is available for energy production. For example, this may be due to a temporary shutdown of part of the facilities for longer term refurbishment or because of declining temperatures or flow rates in the geothermal fluid supply at which point the operator will usually advise the grid of the operational capacity that the grid can rely on.

Therefore, the IEA Geothermal has decided to collect and publish data on the **operating/running** capacity rather than on installed capacity in order to reflect the actual situation. This has the advantage that the average capacity factor for a country is not distorted by facilities that are out of service and not running. The capacity factor is the ratio of the actual output of a power plant to its potential output if operated at full nameplate capacity over a given period of time.

In 2015, nine of the member countries produced geothermal electricity. With an existing net summer capacity of 2,541.5 MW_e (EIA, 2016) used as **running** capacity for the USA, the USA contributed the largest share in the member countries, followed by New Zealand, Mexico, Italy, Iceland, and Japan (Table 3, Fig. 5).

New plants and changes in 2015 were reported from Mexico. Two 5 MW_e each back-pressure units started to operate in the Domo San Pedro geothermal field in February/March 2015. These are the first power plants owned and operated by a private company (Grupo Dragón) in Mexico. These plants were already used, and were refurbished by the field operator. In the Los Azufres geothermal field a new power unit of flash type and 53.4 MW_e gross capacity (50 MW_e net) started to operate commercially in February 2015, as programmed, and four of the seven 5 MW_e back-pressure units were decommissioned.

The total **running** capacity in the reporting countries reached 6,458.1 MW_e in 2015.

Geothermal power generation amounted to 43,382.2 GWh, with the USA being the biggest producer. Geothermal power worldwide reached an **installed** capacity of 13,200 MW_e and an electricity production of 75,000 GWh in 2015 (REN21 Global Status Report 2016; Tables 3, 6 & 7, Fig. 6 & 7). About 58% of the geothermal power generation in the world is thus attributed to GIA countries.

Based on the **installed** capacity and electricity production reported in the REN21 Global Status Report 2016 an average worldwide **capacity factor** of 0.65 was calculated for 2015 (Table 3). An average capacity factor of 0.77 for all member countries was calculated on the basis of **running** capacities which explains the higher value compared to the worldwide capacity factor (Table 3).

Table 3: Geothermal power generation in member countries and worldwide in 2015. *Country data: WG 10 country reports 2015; #existing net summer capacity (EIA, 2016); world data: installed capacity from REN21 Global Status Report 2016; *data from previous year*

Country	Running capacity (2015) [MW_e]	Energy produced (2015) [GWh/a]	Capacity factor
AUS	0.1	0.3	0.34
DEU	31.9	133.6	0.48
FRA	16.5	83.0	0.57
ISL	663.0	5,003.0	0.86
ITA	807.0*	5,916.0*	0.84
JPN	513.7	2,587.3	0.57
MEX	883.4	6,331.0	0.82
NZL	1,001.0	7,410.0	0.85
USA	2,541.5#	15,918.0	0.71
Total GIA	**6,458.1**	**43,382.2**	**0.77**
World	**13,200**	**75,000**	**0.65**

A capacity factor of 1 indicates year-round use, or 8,760 full load hours. Among the member countries, capacity factors ranged from 0.34 in Australia (2,978 full load hours on average) to 0.86 in Iceland (7,534 full load hours).

Reasons for low capacity factors are short-term downtimes due to maintenance, repair work, or legal reasons.

Statistics of the International Energy Agency (IEA) include a breakdown of geothermal capacity and gross energy production according to **main activity producers** and **autoproducers** (see Chapter 1.3 for details) subdivided into pure power plants and combined heat and power plants (CHP).

This report provides a breakdown of running capacity and gross energy production in order to make statistics more comparable and comprehensible between different organisations (Table 4 & 5).

Table 4: Breakdown of running capacity in member countries in 2015 by main activity producers and autoproducers. *Data: WG 10 country reports 2015. *data from previous year*

	Running capacity [MW_e]			
	Main activity producers		Autoproducers	
Country	**Power**	**CHP**	**Power**	**CHP**
AUS	0.1			
DEU	18.8	13.1		
FRA	16.5			
ISL	60.0	603.0		
ITA	807.0*			
JPN	501.2		12.5	
MEX	883.4			
NZL	1,001.0			
USA	2,541.5			
Total	**5,829.5**	**616.1**	**12.5**	

The majority of running capacity and gross power production is provided by geothermal power plants operated by main activity producers which sell electricity to third parties. Iceland and Germany reported power supply by combined heat and power plants. Only in Japan geothermal power is produced for own use by autoproducers.

Table 5: Breakdown of gross power production in member countries in 2015 by main activity producers and autoproducers. *Data: WG 10 country reports 2015. *data from previous year*

	Gross power production [GWh]			
	Main activity producers		Autoproducers	
Country	**Power**	**CHP**	**Power**	**CHP**
AUS	0.3			
DEU	87.6	46.0		
FRA	83.0			
ISL	487.4	4,515.6		
ITA	5,916.0*			
JPN	2,529.9		57.4	
MEX	6,331.0			
NZL	7,410.0			
USA	15,918.0			
Total	**38,763.2**	**4,561.6**	**57.4**	

2.2 Trends 2000 - 2015: installed (2000 - 2009) and running (2010 - 2015) capacity

As already mentioned, the IEA Geothermal has decided to report on running capacity for which data is only available since the reporting year 2010. Therefore, table 6 is divided into columns for installed capacity for the years 2000 to 2009 and for running capacity from 2010 on.

From 2000 to 2015, the installed capacity for geothermal power generation worldwide grew from 7,974 MW_e to 13,200 MW_e (Huttrer, 2001; Bertani, 2005, 2007, 2012, 2016; REN21 Global Status Report 2016).

In the same period, the capacity in IEA Geothermal member countries increased from 4,926 MW_e in 2000 (installed capacity) to 6,458 MW_e in 2015 (running capacity), contributing nearly 50% to the geothermal electric capacity worldwide (Table 6, Fig. 6).

The United States accounted for the largest proportion of electric capacity in member countries with a running capacity of 2,541.5 MW_e in 2015. Significant growth from installed capacity in 2000 to running capacity in 2015 was reported from New Zealand with 564 MW_e and Iceland with 493 MW_e newly installed capacity (Table 6, Fig. 5).

In 2015, the total running capacity of member countries showed an increase of 473.9 MW_e compared to 2010. Significant growth in the same period was reported by New Zealand (+243.0 MW_e), the United States (+136.9 MW_e), Iceland (+88.0 MW_e), Italy (+78.9 MW_e), and Germany (+25.5 MW_e). However, from 2010 to 2015 running capacity decreased by 74.6 MW_e in Mexico and by 24.0 MW_e in Japan.

Table 6: Installed (2000-2009) and running (2010-2015) electric capacities in member countries and worldwide. *Years 2001, 2002 and 2003 have been hidden for lack of space. For details see previous Trend Reports. Country data: WG 10 country reports (for 2010-2015), GIA Annual Reports (for 2003-2009) and Huttrer (2000). World data: Huttrer (2000), Bertani (2005, 2007, 2012, and 2016), REN21 Global Status Report 2016. * data from previous year; ** installed capacity (no data on running capacity available)*

	Installed capacity [MW_e]							Running capacity [MW_e]					
Country	**2000**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
AUS	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DEU	0.0	0.2	0.2	0.2	3.2	3.2	7.1	6.4	6.4	11.1	30.1	32.2	31.9
FRA	4.2	na	15.0	15.0	15.0	17.2	17.2	16.3	15.4	15.4	10.3	16.1	16.5
ISL	170.0	202.0	202.0	422.0	485.0	575.0	575.0	575.0	665.0	665.0	663.0	661.0	663.0
ITA	785.0	862.0	791.0	810.0	810.0	810.5	842.5	728.1	728.0	766.0	767.0	807.0	807.0*
JPN	547.0	535.0	535.3	535.3	535.3	535.3	535.3	537.7	540.1	540.1	515.1	515.2	513.7
MEX	755.0	953.0	953.0	953.0	958.0	958.0	958.0	958.0	883.0	805.0	839.0	840.2	883.4
NZL	437.0	452.0	435.0	450.0	452.0	632.0	632.0	758.0	758.0	758.0	1,008.0	1,009.8	1,001.0
USA	2,228.0	2,400.0	2,534.0	2,831.0	2,936.5	3,040.0	3,168.0	2,404.6	2,409.2	2,592.1	2,607.0	2,514.3	2,541.5
Total GIA	**4,926.4**	**5,404.4**	**5,465.7**	**6,016.6**	**6,195.1**	**6,571.3**	**6,735.2**	**5,984.2**	**6,005.2**	**6,152.8**	**6,439.6**	**6,395.9**	**6,458.1**
World	**7,974.0**	na	**8,903.0**	na	**9,732.0**	na	na	**10,895****	na	na	na	**12,729****	**13,200****

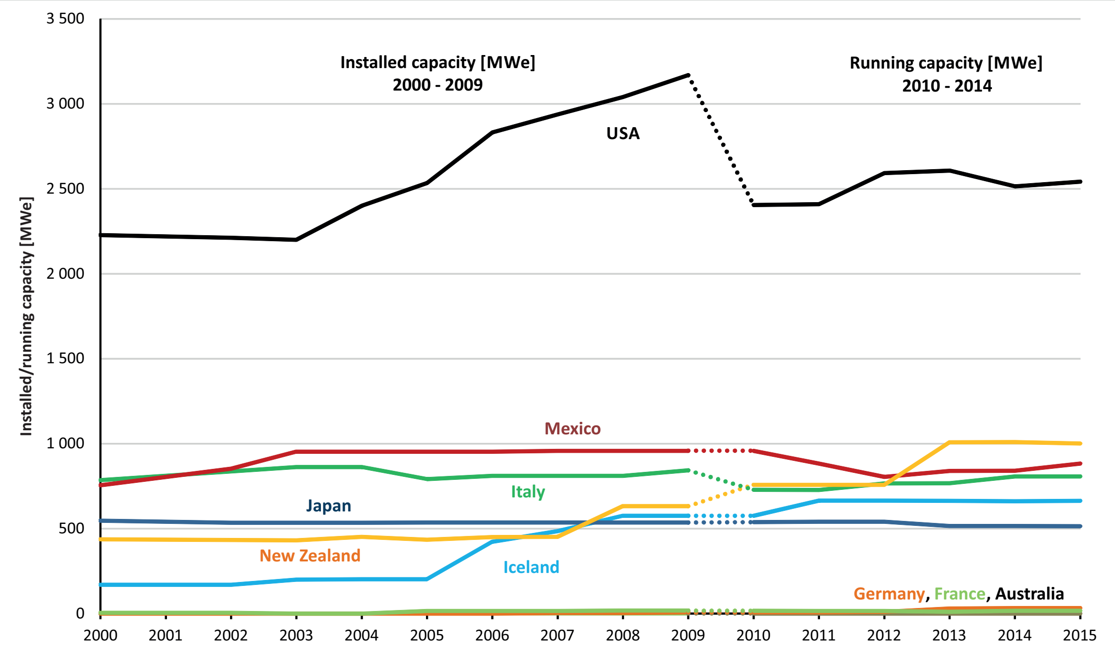

Figure 5: Installed and running capacities [MW_e] in member countries 2000 - 2015. *Data: WG 10 country reports (for 2010-2015), GIA Annual Reports (for 2003-2009) and Huttrer (2000).*

In 2015, the Philippines with an installed capacity of 1,906 MW_e and Indonesia (1,340 MW_e) were the main players in the geothermal market among the non-member countries, but also Turkey, Kenya, Costa Rica and El Salvador contributed a considerable amount to the worldwide installed capacity (624 MW_e, 607 MW_e, 217 MW_e, and 204 MW_e, respectively; IRENA, 2017). These six countries together with the GIA member countries provided about 98% of the worldwide **installed** electric capacity.

This shows that a rather small number of countries contribute significantly to the world's geothermal power market.

A forecast of the development of running capacity in the member countries until 2020 was made on the basis of information made available in the WG 10 country reports and is shown in figure 6. According to this, running capacity is estimated to increase by about 750 MW_e and reach more than 7,200 MW_e in 2020.

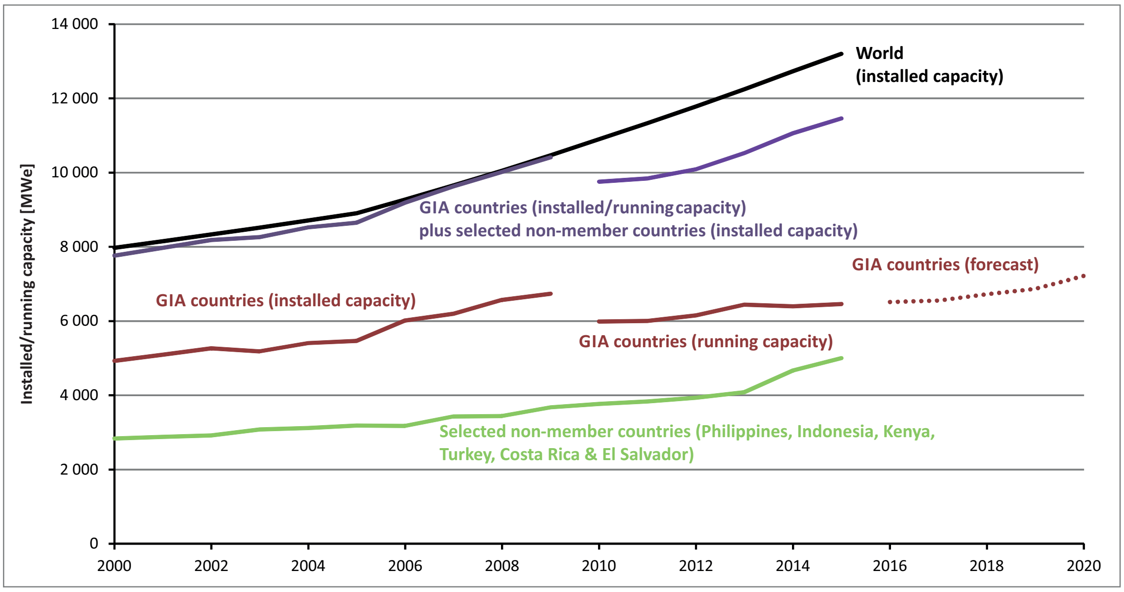

Figure 6: Installed and running capacities [MW$_e$] in GIA countries, selected non-member countries and worldwide 2000 - 2015, and forecast of the development of running capacities in GIA countries until 2020. *GIA country data: WG 10 country reports (for 2010-2020), GIA Annual Reports (for 2003-2009) and Huttrer (2000). World and selected non-member countries data: Huttrer (2000), Bertani (2005, 2007, 2012, and 2016), REN21 Global Status Report 2016, IRENA (2017).*

2.3 Trends 2000 - 2015: electricity production

From 2000 to 2015, the electricity produced by geothermal power plants worldwide increased from 49,261 GWh in 2000 to 75,000 GWh in 2015 (Huttrer, 2001; Bertani, 2005, 2007, 2012, REN21 Global Status Report 2016). Geothermal power generation in the GIA member countries grew from 31,635.5 GWh in 2000 to 43,382.2 GWh in 2015 with a net increase of 3,203.8 GWh since 2010 (Table 7, Fig. 7).

In 2015, geothermal electricity produced in nine member countries made up about 58% of the world's total geothermal power generation (Fig. 7). Significant growth compared to 2010 was reported from New Zealand(+1,860 GWh), the United States (+602 GWh), Iceland (+538 GWh), and Italy (+540 GWh). In contrast, geothermal electricity production decreased in Japan (-321 GWh) and Mexico (-287 GWh) in the same period (Fig. 8).

Table 7: Geothermal electricity [GWh/a] produced in member countries and worldwide 2000 - 2015. *Years 2001, 2002 and 2003 have been hidden for lack of space. For details see previous Trend Reports. Country data: Annex X country reports (for 2010-2014), GIA Annual Reports (for 2003-2009) and Huttrer (2000). World data: Huttrer (2000), Bertani (2005, 2012, and 2016), REN21 Global Status Report 2016. * data from previous year*

	Geothermal electricity produced [GWh/a]												
Country	**2000**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
AUS	0.9	1.0	0.5	0.7	0.5	0.8	0.6	0.0	0.6	0.5	0.5	0.6	0.3
DEU	0.0	0.4	0.2	0.4	0.4	18.0	19.0	27.5	18.7	25.4	54.3	80.0	133.6
FRA	24.6	na	102.0	102.0	95.0	90.0	89.0	14.9	56.6	50.6	80.6	79.0	83.0
ISL	1,138.0	1,433.0	1,483.0	2,631.0	3,600.0	4,000.0	4,553.0	4,465.0	4,701.0	5,210.0	5,245.0	5,238.0	5,003.0
ITA	4,403.0	5,127.0	5,340.0	5,200.0	5,233.0	5,181.0	5,200.0	5,376.0	5,315.0	5,235.0	5,659.0	5,916.0	5,916.0*
JPN	3,532.0	3,486.0	3,467.0	3,228.0	3,102.0	3,064.0	2,765.0	2,908.0	2,652.2	2,688.8	2,620.4	2,604.7	2,587.3
MEX	5,681.0	6,360.0	6,282.0	6,685.0	7,393.0	7,056.0	6,740.0	6,618.0	6,524.0	5,817.0	6,070.0	6,000.0	6,331.0
NZL	2,756.0	2,631.0	2,981.0	3,177.0	3,354.0	3,966.0	4,589.0	5,550.0	5,774.0	5,843.0	6,053.0	6,847.0	7,410.0
USA	14,100.0	14,811.0	14,692.0	14,568.0	14,637.0	14,840.0	15,009.0	15,219.0	15,316.0	15,562.0	15,775.0	15,877.0	15,918.0
Total GIA	**31,635.5**	**33,849.4**	**34,347.7**	**35,592.1**	**37,414.9**	**38,215.8**	**38,964.6**	**40,178.4**	**40,358.1**	**40,432.3**	**41,557.8**	**42,624.3**	**43,382.2**
World	**49,261.0**	na	**55,709.0**	na	na	na	na	**67,202.0**	na	na	na	**73,689.0**	**75,000.0**

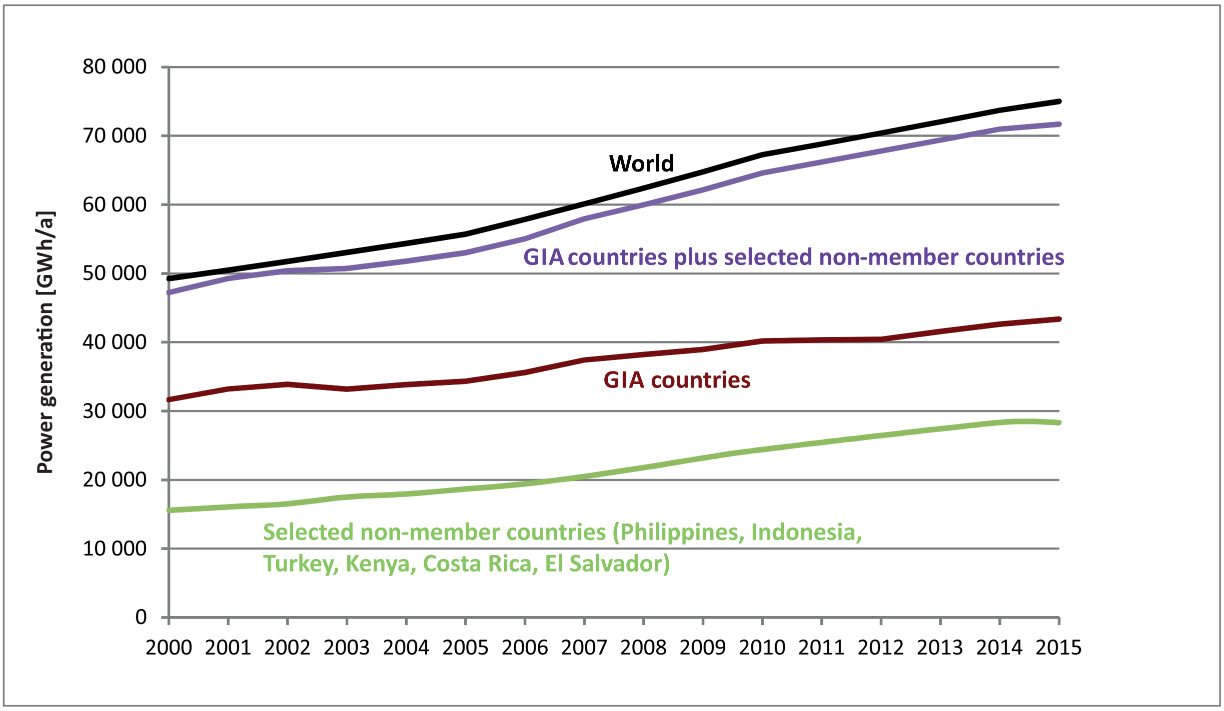

Figure 7: Geothermal power generation [GWh/a] in GIA countries, selected non-member countries and worldwide 2000 - 2015. *GIA country data: WG 10 country reports (for 2010-2020), GIA Annual Reports (for 2003-2009) and Huttrer (2000). World and selected non-member countries data: Huttrer (2000), Bertani (2005, 2007, 2012, and 2016).*

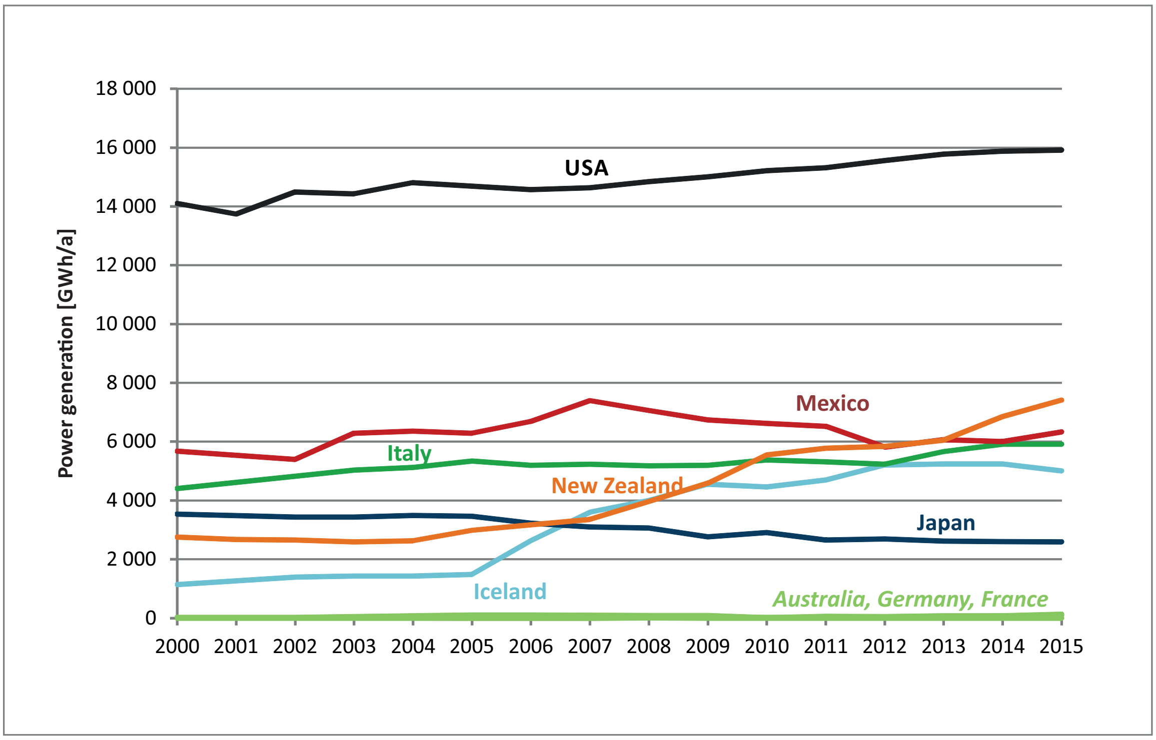

Figure 8: Geothermal power generation [GWh/a] in member countries 2000 - 2015. *Data: WG 10 country reports (for 2010-2015), GIA Annual Reports (for 2003-2009) as well as Huttrer (2000) and EIA (2016) .*

3 DIRECT USE OF GEOTHERMAL HEAT

3.1 Introduction

Direct use of geothermal energy is not only one of the oldest but also the most common form of utilisation. Thermal waters suitable for direct use applications usually originate from deep geothermal aquifers. Required water temperature may be reached near the Earth's surface due to a high geothermal gradient in high enthalpy fields. Separated waste water from geothermal power plants can also be used for heating or other purposes.

Common direct use applications are district or space heating, bathing, and the heating of greenhouses. In some regions, geothermal heat is used for snow melting, aquaculture/fish farming or industrial applications. In the Larderello geothermal field in Italy, waste heat from the San Martino power plant is used as cheap and eco-friendly process heat in a nearby dairy for cheese production.

The most widespread application of geothermal heat are geothermal heat pumps. They contribute the major part of geothermal heat use in the world (Lund & Boyd, 2016). As they use auxiliary energy to raise the fluid's energy level, they do not actually use geothermal heat in a "direct" way, though they are often summarised with other direct use applications.

In this report, we distinguish between centralised installations which directly use geothermal heat in a more exact sense, such as greenhouses, district heating and thermal spas, and geothermal heat pumps.

3.2 Centralized installations for direct heat uses

In 2015, direct use of geothermal heat by centralised installations in GIA countries accounted for an installed capacity of 7,483.2 MW_t, a net increase of 474.6 MW_t compared to 2015 (Table 8).

Table 8: Direct use capacity [MW_t] of geothermal heat in member countries in different IEA categories and IEA Geothermal subcategories (other than heat pumps) 2010 - 2015. *Data: WG 10 country reports 2010 - 2015 (#row sum; *data from previous year).*

		Installed capacity of direct use categories 2015 and country total 2010 - 14 (other than heat pumps) [MW_t]															
Category (IEA)	**Sub-category (IEA Geothermal)**	**AUS**	**CAN**	**CHE**	**DEU**	**ESP**	**FRA**	**GBR**	**ISL**	**ITA**	**JPN**	**KOR**	**MEX**	**NOR**	**NZL**	**USA**	**Total/ category**
Residential				**1.5**	**3.3**	**3.5***				**78.0***		**2.2**			**2.0**	**130.2**	**220.7**
	Space heating			1.5	3.3	3.5*				78.0*		2.2			2.0	130.2	220.7
Commercial and public		**12.0**	**8.8**	**25.2**	**333.3**	**2.6***		**3.0**		**500.0***	**1,906.8**	**41.3**	**155.8***		**120.0**	**154.6**	**3,263.4**
	Space heating				285.0			2.0		79.0*	71.1	8.7	0.5*		62.0	65.1	573.4
	Bathing/ Swimming	12.0	8.8	25.2	48.3	2.6*		1.0		421.0*	1,685.5	32.6	155.3*		58.0	87.7	2,538.0
	Snow melting										150.2					1.8	152.0
Agriculture/ Forestry						**14.9***				**69.0***	**41.4**	**0.2**			**24.0**	**72.5**	**222.0**
	Green-houses					14.9*				69.0*	35.4	0.2			24.0	66.0	209.5
	Crop drying										6.0					6.5	12.5
	Other														na		na
Industry	Industry									**18.0***	**1.4**				**284.0**	**6.7**	**310.1**
Fisheries		**1.1**		**0.4**						**122.0***	**7.6**				**17.0**	**84.4**	**232.5**
	Aqua-culture	1.1		0.4						122.0*	7.6				17.0	84.4	232.5
Other	Other										**136.3**				**33.0**	**0.2**	**169.5**
	Total/country 2015	**13.1**	**8.8**	**27.1**	**336.6**	**21.0***	**456.0**	**3.0**	**2,609.0**	**787.0***	**2,093.5**	**43.7**	**155.8***	**0.0**	**480.0**	**448.6**	**7,483.2#**
	Total/country 2014	12.0	8.8	31.0	288.9	21.0	385.0	3.0	2,083.0	787.0	2,093.5	43.7	155.8	0.0	480.0	615.9	7,008.6#
	Total/country 2013	11.0	8.8	27.5	258.4	21.0	336.9	2.6	2,083.0	767.0	2,093.5	43.7	156.0	0.0	401.0	563.9	6,774.3#
	Total/country 2012	10.3	8.8	34.5	217.0	20.6	345.0	2.6	na	500.0	2,093.5	43.7	156.0	0.0	383.6	563.9	4,379.5#
	Total/country 2010	106.0	na	39.0	163.2	22.3	345.0	na	na	500.0	2,086.2	43.6	156.0	0.0	371.6	563.8	4,396.7#

In 2015, three countries reported a significant growth in installed capacity for direct heat uses: Iceland (+526.0 MW_t), France (+71.0 MW_t), and Germany (+47.7 MW_t). Most of the other reported values were similar to year 2014. This is mainly due to poor data bases on direct use in the reporting countries. Only a few countries like Germany and Switzerland have annual statistics on heat utilisation, most other member countries provided annual estimates.

In 2015, geothermal direct heat uses (other than heat pumps) in the member countries amounted to 25,485.3 GWh, a net decrease of 1,210.8 GWh compared to 2014 (Table 9).

If values for installed capacity were stated but values for the produced heat were not provided, annual heat use was calculated using capacity factors for the various categories of use given in Lund & Boyd (2016) by the following equation (Pester et al., 2007):

$$E = \frac{P \cdot 8760 \cdot capacity\ factor}{1000}$$

where E = annual production in GWh, P = installed capacity in MW_t, and 8760 hours = 1 year

In addition to IEA Geothermal subcategories, tables 8 & 9 include IEA categories to enhance the comparability of geothermal energy statistics between different organisations.

In 2015, the application of thermal waters for spas and for swimming was the most common geothermal utilisation with 10,435.2 GWh. The main share was attributed to the widespread use of thermal springs in Japan which amounted to 5,758.7 GWh.

Iceland (7,689.9 GWh) and Japan (7,249.6 GWh) were the largest producers of geothermal direct heat among GIA countries in 2015, followed by New Zealand (2,396.4 GWh), Italy (2,151.9 GWh), and the USA (1,828.6 GWh; Table 9).

Table 9: Direct use [GWh] of geothermal heat in member countries in different IEA categories and IEA Geothermal subcategories (other than heat pumps) 2010 - 2015. *Data: WG 10 country reports 2010 - 2015 (#row sum, *data from previous year).*

		Direct use in different categories 2015 and country total 2010 - 14 (other than heat pumps) [GWh/a]															
Category (IEA)	**Sub-category (IEA-GIA)**	**AUS**	**CAN**	**CHE**	**DEU**	**ESP**	**FRA**	**GBR**	**ISL**	**ITA**	**JPN**	**KOR**	**MEX**	**NOR**	**NZL**	**USA**	**Total/ category**
Residential				**4.2**	**9.5**	**21.2***			**2,784.3**	**168.3***		**8.7**			**2.0**	**288.7**	**3,286.9**
	Space heating			4.2	9.5	21.2*			2,784.3	168.3*		8.7			2.0	288.7	3,286.9
Commercial and public		**54.7**	**76.9**	**209.7**	**1,106.1**	**14.6***		**14.8**	**3,998.0**	**1,216.9***	**6,184.1**	**155.8**	**1,158.7***		**541.9**	**721.5**	**15,453.7**
	Space heating				706.1			9.3	2,784.3	189.7*	305.4	14.8	1.2*		160.0	144.4	4,315.2
	Bathing/ Swimming	54.7	76.9	209.7	400.0	14.6*		5.5	635.0	1,027.2*	5,758.7	141.0	1,157.5*		381.9	572.5	10,435.2
	Snow melting								578.7		120.0					4.6	703.3
Agriculture/ Forestry						**26.2***			**150.8**	**201.4***	**125.0**	**0.4**			**121.6**	**184.2**	**809.6**
	Green-houses					26.2*			150.8	201.4*	103.7	0.4			101.0	157.1	740.6
	Crop drying										21.3					27.1	48.4
	Other														20.6		20.6
Industry	Industry								**272.5**	**30.0***	**8.5**				**1,401.0**	**72.8**	**1,784.8**
Fisheries		**5.4**		**2.0**					**484.4**	**535.3***	**34.2**				**54.4**	**560.9**	**1,676.6**
	Aqua-culture	5.4		2.0					484.4	535.3*	34.2				54.4	560.9	1,676.6
Other	Other										**898.0**				**275.5**	**0.5**	**1,174.0**
	Total/country 2015	**60.1**	**76.9**	**215.9**	**1,115.6**	**62.0***	**1,300.0**	**14.8**	**7,689.9**	**2,151.9***	**7,249.6**	**164.9**	**1,158.7***	**0.0**	**2,396.4**	**1,828.6**	**25,485.3#**
	Total/country 2014	55.0	76.9	247.2	1,026.3	62.0	1,574.7	14.8	7,964.1	2,151.9	7,249.6	164.9	1,158.7	0.0	2,396.4	2,553.4	26,696.1#
	Total/country 2013	50.5	77.1	233.1	989.4	62.0	1,379.7	12.3	7,113.0	2,141.0	7,249.6	164.9	710.6	0.0	2,375.0	2,287.0	24,845.4#
	Total/country 2012	47.7	77.1	233.1	841.0	67.4	1,094.5	12.3	7,021.0	3,027.7	7,249.6	164.9	710.6	0.0	2,624.0	2,287.0	25,458.1#
	Total/country 2010	354.0	na	272.3	716.2	51.0	1,508.4	na	6,833.0	3,027.7	7,120.0	164.9	710.6	0.0	2,810.0	2,287.0	25,855.1#

As already mentioned in the chapter on geothermal power, statistics of the International Energy Agency (IEA) include a breakdown of geothermal capacity and gross energy production according to **main activity producers** and **autoproducers** (see Chapter 1.3 for details) subdivided into pure heat plants and combined heat and power plants (CHP).

The breakdown of installed thermal capacity and gross energy production for GIA countries is shown in tables 10 & 11.

Autoproducers which produce heat mainly for their own use play a more important role in the heat market than in the electricity market (cf. Chap. 2.1).

About 41% of installed capacity and 50% of gross heat production is attributed to the autoproducers. The largest proportion of this is contributed by thermal spas in Japan.

The largest share of gross heat production by main activity producers can be found in Iceland, where space and district heating is a widespread form of direct heat use.

About 10% of installed thermal capacity and 8% of gross heat production is supplied by combined heat and power plants which are operated in Iceland and Germany.

Table 10: Breakdown of installed thermal capacity [MW_t] in member countries in 2015 by main activity producers and autoproducers. *Data: WG 10 country reports 2015.*

	Installed capacity [MW_t]			
	Main activity producers		Autoproducers	
Country	**Heat**	**CHP**	**Heat**	**CHP**
AUS	na	na	na	na
CAN			8.8	
CHE	1.5		25.6	
DEU	206.3	82.0	48.3	
ESP	na	na	na	na
FRA	456.0			
GBR	2.0		1.0	
ISL	2,000.0	609.0	na	
ITA	na	na	na	na
JPN			2,093.5	
KOR			43.7	
MEX	155.3		0.5	
NOR				
NZL	301.0		179.0	
USA	114.8		333.8	
Total	**3,236.9**	**691.0**	**2,734.2**	**0.0**

Table 11: Breakdown of gross heat production [GWh] in member countries in 2015 by main activity producers and autoproducers. *Data: WG 10 country reports 2015.*

	Gross heat production [GWh]			
	Main activity producers		Autoproducers	
Country	**Heat**	**CHP**	**Heat**	**CHP**
AUS	na	na	na	na
CAN			76.9	
CHE	4.2		211.7	
DEU	548.8	166.8	400.0	
ESP	na	na	na	na
FRA	1,300.0			
GBR	9.3		5.5	
ISL	4,948.4	1,784.1	957.3	
ITA	na	na	na	na
JPN			7,249.6	
KOR			164.9	
MEX	1,157.5		1.2	
NOR				
NZL	1,455.4		941.0	
USA	204.4		1,624.2	
Total	**9,628.0**	**1,950.9**	**11,632.3**	**0.0**

3.3 Geothermal heat pumps (GHP)

Residental space heating using ground source heat pumps (GSHP) or geothermal heat pumps (GHP) is the most common application of geothermal energy. According to Lund & Boyd (2016), geothermal heat pumps accounted for 70.9% of the total installed capacity and 55.2% of total geothermal energy use in 2014.

Geothermal heat pumps use near-surface heat as a renewable heat source. Common systems are horizontal heat collectors, borehole heat exchangers (brine/water systems, Fig. 9), and groundwater systems with extraction and injection well(s) (water/water systems). Typical capacities of geothermal heat pumps for residential requirements range from about 10 to 14 kW_t (GZB, 2010). For heating and cooling of larger buildings, such as offices, commercial buildings and schools, ground source heat pump systems using borehole heat exchangers (BHE), ground water wells, or energy piles are becoming increasingly popular. Systems for heating and cooling of larger buildings often have installed capacities of several 100 kW_t.

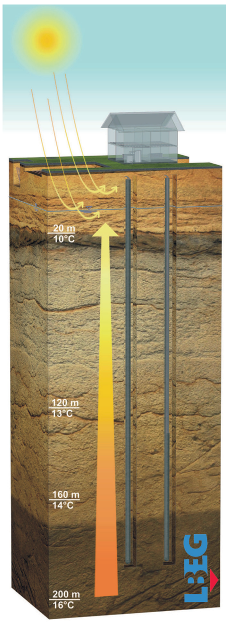

Figure 9: Principle of GSHP systems using borehole heat exchangers. *The yellow arrow shows the average geothermal gradient. The enthalpy of near-surface systems, indicated by the shallow cavities on the left side, derives mainly from solar radiation. Image: Courtesy of State Authority for Mining, Energy and Geology, Lower Saxony, Germany (LBEG).*

For the GIA Trend Report, we aimed to distinguish between individual use of small heat pumps in private houses and utilisation in commercial and public buildings. Furthermore, we also tried to collect data on geothermal cooling with GHPs. However, in most countries statistics on heat pumps are poor and reliable data were often not available. Therefore, data on small residential systems and larger systems are combined in this report.

GHP numbers

As not all member countries reported current numbers of total and newly installed units for 2015, the 2.19 million units given in table 12 are only a rough approximation of the total number of geothermal heat pumps in operation. In 2015, the majority of heat pumps were operating in the United States with about 1.4 million units, followed by Germany (325,000), France (200,000), Canada (120,000), and Switzerland (97,325). Numbers on newly installed heat pumps have only been reported by 7 member countries and added up to a total of 26,362. Therefore, the real number should be much higher.

Calculation

1. Annual heat use: The annual heat use can be calculated using the installed capacity and the annual full load hours of geothermal heat pumps, which differ due to regional aspects and modes of use. If data for annual heat use were not provided, values were calculated for a given number of heat pumps assuming an average installed capacity of 12 kW_t and a mean runtime of 2,200 full load hours per year; stated average values for common heat pump systems worldwide according to Lund & Boyd (2016).

2. Geothermal contribution: Heat pumps need auxiliary power - usually electricity - to operate. For this report, we outline the geothermal heating contribution of GHP installations (the renewable share of the produced heat). The renewable (geothermal) contribution can be calculated according to Annex VII of the EU Directive 2009/28/EC "Renewable Energy" by the equation:

$$E_{geothermal} = Q_{usable} \cdot (1 - \frac{1}{SPF})$$

where $E_{geothermal}$ = geothermal energy in GWh, Q_{usable} = the estimated total usable heat delivered by heat pumps in GWh, and SPF = seasonal performance factor

For the calculation, a mean SPF of 3.5 was used, following various authors (GZB, 2010; Sonnenfroh et al., 2010). The SPF equates to the average coefficient of performance (COP) of the heating and cooling season and takes into account system properties (Curtis et al., 2005).

Heat pump utilisation 2015

In 2015, the total installed capacity (including auxiliary power) of geothermal heat pumps in GIA countries amounted to 30,125 MW_t, more than four times the capacity of all other thermal uses (Tables 8 & 12). The geothermal contribution of the annual heat use was 37,909 GWh or 136,474 TJ. In 2015, the worldwide total capacity of GHPs was estimated at 54,625 MW_t with an estimated annual heat use of 100,148 GWh or 360,532 TJ (Table 12). Thus, GIA member countries contribute a large share to the worldwide installed capacity (60%) and heat use (38%).

Geothermal cooling with heat pumps is a low-emission form of air conditioning and a very common use of geothermal heat pumps, which can be used for both heating and cooling. Most countries lack reliable statistics on geothermal cooling, however. Only two countries, Australia and Korea, provided data on geothermal cooling for this report. The supply of 11 GWh of geothermal cooling in Australia indicates that in warm climate zones, cooling is an important option of GHP use. In Korea, geothermal cooling (413 GWh in 2015) nearly reaches the value of annual heat use (536 GWh).

Table 12: Geothermal heat pumps in member countries: installed capacity and annual heat use (geothermal contribution) 2010, 2014 and 2015. *Country data: WG 10 country reports 2010, 2014 and 2015; world data 2010 & 2014: Lund & Boyd (2016); 2015: estimated assuming a compound annual growth rate of 8.7% for capacity and 10.3% for annual heat use. This table only contains data for the heating mode. (*data from previous year)*

	Total number of GHP 2015	Number of new GHP in 2015	Installed capacity (total) [MWt]			Annual heat use (geothermal contribution) [GWh/a]			Annual heat use (geothermal contribution) [TJ/a]		
Country			**2010**	**2014**	**2015**	**2010**	**2014**	**2015**	**2010**	**2014**	**2015**
AUS	580	100	26	32	35	11	27	31	40	97	111
CAN	120,000	na	na	1,449	1,680	na	3,086	3,148	na	11,110	11,333
CHE	97,325	3,532	1,327	1,747	1,926	1,714	2,030	2,320	6,171	7,309	8,353
DEU	325,000	17,000	2,880	3,564	3,900	2,500	4,609	5,704	9,000	16,592	20,534
ESP	na	142	70	7	6	140	na	na	504	na	na
FRA	200,000	3,700	1,671	1,999	2,400	2,535	3,142	3,771	9,127	11,311	13,577
GBR	20,995	1,868	na	478	535	na	548	611	na	1,972	2,199
ISL	na	na	na	na	na	na	na	na	na	na	na
ITA	na	na	500	568	568*	472	922	922*	1,700	3,318	3,318*
JPN	1,513*	na	13	18	18*	19	29	29*	68	103	103*
KOR	na	na	234	774	946	171	567	536	617	2,041	1,928
MEX	na	na	na	na	na	na	na	na	na	na	na
NOR	26,000*	na	1,000	1,300	1,300*	3,000	2,294*	2,294*	10,800	8,260*	8,260*
NZL	137	20	4	9	12	6	19*	25	22	69*	89
USA	1,400,000*	na	12,000	16,800	16,800*	18,857	18,519	18,519*	67,886	66,670	66,670*
Total GIA	**2,191,550**	**26,362**	**19,725**	**28,745**	**30,125**	**29,425**	**35,792**	**37,909**	**105,934**	**128,852**	**136,474**
World	**4,190,000***	na	**33,134**	**50,258**	**54,625**	**55,597**	**90,791**	**100,148**	**200,149**	**326,848**	**360,532**

3.4 Trends in geothermal heat use 2000 - 2015

In 2000, geothermal heat use in the world amounted to 52,972 GWh with an installed capacity of 15,145 MW_t. In 2010, 78 countries reported geothermal heating utilisations with a total installed capacity of 48,493 MW_t and an annual use of 117,731 GWh, and in 2014, 82 countries had 70,885 MW_t in operation with a geothermal heat use of 164,635 GWh (Lund & Boyd, 2016). Estimates for 2015 indicate a heat use of 176,036 GWh with a capacity of 76,477 MW_t (Table 13).

In the GIA member countries, the installed thermal capacity for all uses (direct use and GHP use) amounted to 8,927 MW_t in 2000 and 37,590 MW_t in 2015 (Table 13). Geothermal heat use increased from 25,894 GWh in 2000 to 63,366 GWh (228,117 TJ) in 2015. Altogether, the 15 member countries accounted for about 49% of the worldwide thermal capacity and 36% of heat use in 2015.

Figures 10 & 11 show installed capacities and heat use of geothermal energy worldwide (based on data from Lund & Freeston, 2001; Lund et al., 2005 and 2011; Lund & Boyd, 2016; and estimates for 2015) and in GIA countries from 2000 to 2015.

Overall, efforts to show trends for geothermal heat use in member countries are based on miscellaneous data sources. Attempts to collect standardised data within the IEA Geothermal from 2010 on, show that reliable and up-to-date statistical data on geothermal heat use is often not available in the reporting countries. It is the aim of WG 10 and WG 8 (Direct Use of Geothermal Energy) to further improve the data base. This is done in cooperation with other data collecting organisations, like IEA, IGA, EGEC and Eurostat within the GeoStat Joint Activity proposed under the framework of the Geothermal ERA-NET (Ketilsson et al., 2015).

Table 13: Geothermal heat use (direct and GSHP) in member countries in 2010, 2014 & 2015. *Country data: WG 10 country reports (2010, 2014 and 2015); world data 2010 & 2014: Lund & Boyd (2016); 2015: estimated assuming a compound annual growth rate of 7.9% for capacity and 6.9% for heat use. *includes data from previous year*

	Installed capacity (Direct use and GHP) [MW_t]			Heat use (geothermal contribution) [GWh/a]			Heat use (geothermal contribution) [TJ/a]		
Country	**2010**	**2014**	**2015**	**2010**	**2014**	**2015**	**2010**	**2014**	**2015**
AUS	132	44	48	365	82	91	1,314	295	328
CAN	na	1,458	1,689	na	3,163	3,225	na	11,386	11,610
CHE	1,366	1,778	1,953	1,987	2,278	2,536	7,152	8,199	9,130
DEU	3,063	3,853	4,237	3,180	5,635	6,820	11,449	20,287	24,551
ESP	92	28	27*	191	62	62*	688	223	223*
FRA	2,016	2,384	2,856	4,044	4,717	5,071	14,557	16,980	18,257
GBR	na	481	538	na	563	626	na	2,025	2,252
ISL	na	2,083	2,609	6,833	7,964	7,690	24,599	28,671	27,684
ITA	1,000	1,355	1,355*	3,500	3,074	3,074*	12,600	11,065	11,065*
JPN	2,100	2,112	2,094*	7,138	7,278	7,250	25,698	26,202	26,099
KOR	277	818	990	336	732	700	1,210	2,635	2,521
MEX	156	156	156*	711	1,159	1,159*	2,558	4,171	4,171*
NOR	1,000	1,300	1,300*	3,000	2,294	2,294*	10,800	8,260	8,260*
NZL	375	489	492	2,816	2,416	2,421	10,138	8,696	8,716
USA	12,564	17,416	17,249*	21,144	21,073	20,348*	76,119	75,862	73,251*
Total GIA	**24,142**	**35,755**	**37,590**	**55,245**	**62,490**	**63,366**	**198,882**	**224,957**	**228,117**
World	**48,493**	**70,885**	**76,477**	**117,740**	**164,635**	**176,036**	**423,864**	**592,638**	**633,730**

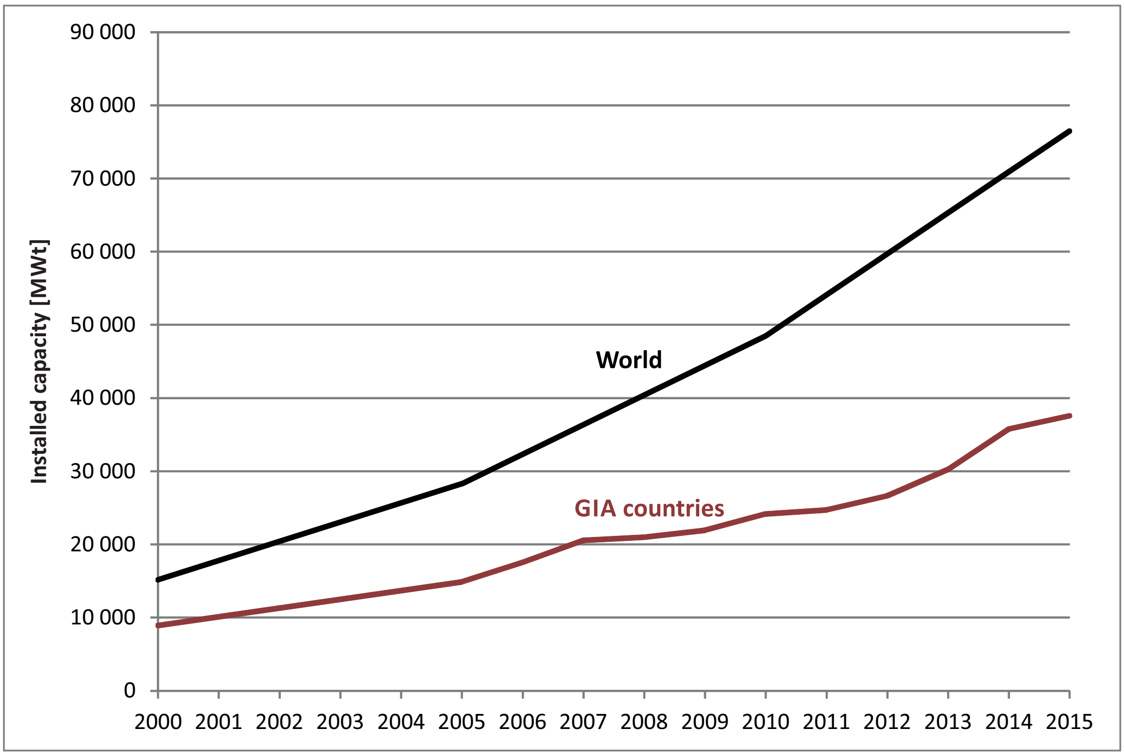

Figure 10: Installed capacity [MW$_t$] of all geothermal heat uses (direct use and GHP use) in GIA countries and worldwide 2000 - 2015. *GIA country data: GIA Annual Reports 2007, 2008 and 2009, and WG 10 country reports 2010 to 2015; world data: Lund & Freeston, 2001; Lund et al., 2005 and 2011; and Lund & Boyd, 2016; 2015: estimated assuming a compound annual growth rate of 7.9%.*

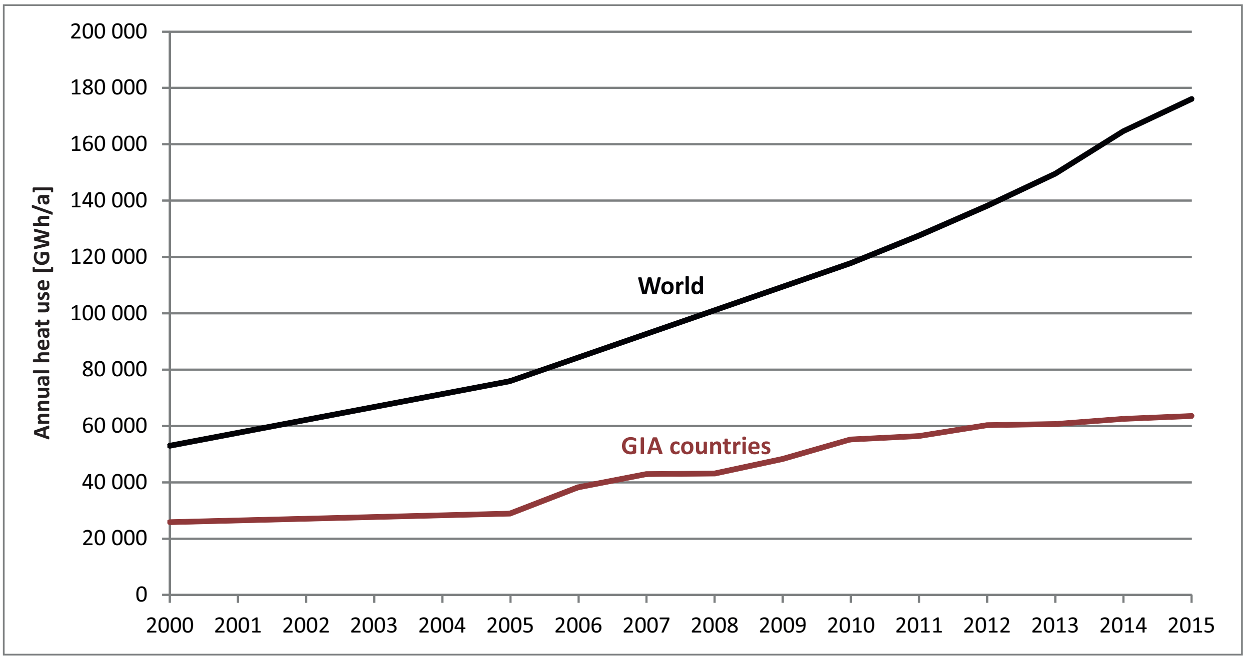

Figure 11: Annual heat use [GWh/a] of all geothermal heat uses (direct use and GHP use) in GIA countries and worldwide 2000 - 2015. *GIA country data: GIA Annual Reports 2007, 2008 and 2009, and GIA WG 10 country reports 2010 to 2015; world data: Lund & Freeston, 2001; Lund et al., 2005 and 2011; and Lund & Boyd, 2016; 2015: estimated assuming a compound annual growth rate of 6.9%.*

4 CO_2 AND FOSSIL FUEL SAVINGS

4.1 Fossil fuel savings by geothermal applications

The fuel oil savings factors used to calculate the savings in table 14 are based on the GIA conversion (Mongillo, 2005) assuming an efficiency factor of 35% if the competing energy is used to replace electricity, and an efficiency factor of 70% for direct burning to produce heat according to Lund & Boyd (2016). Fossil fuel savings (Table 14) were estimated using the figures for produced geothermal electricity and heat given in the previous chapters.

Geothermal cooling with heat pumps also helps to reduce the use of fossil fuels for applications like air conditioning. For instance, in Korea and Australia fossil fuel savings amounted to 52,327 and 1,394 tonnes of oil equivalent, respectively.

Table 14: Fossil fuel savings by geothermal energy uses in member countries in 2015. *Calculation based on values for produced electricity and geothermal heat (all uses) given in the WG 10 country reports 2015. (toe = tonnes of oil equivalent)*

Country	Fossil fuel savings for geothermal power generation [toe]	Fossil fuel savings for geothermal heat utilizations [toe]	Fossil fuel savings for geothermal heat & power utilizations [toe]
AUS	76	11,530	11,606
CAN	0	408,608	408,608
CHE	0	321,311	321,311
DEU	33,854	864,094	897,948
ESP	0	7,855	7,855
FRA	21,032	642,496	663,528
GBR	0	79,314	79,314
ISL	1,267,760	974,323	2,242,083
ITA	1,499,114	389,425	1,888,539
JPN	655,622	918,575	1,574,197
KOR	0	88,690	88,690
MEX	1,604,275	146,845	1,751,120
NOR	0	290,700	290,700
NZL	1,877,694	306,741	2,184,435
USA	4,033,621	2,578,092	6,611,713
Total 2015	**10,993,048**	**8,028,599**	**19,021,647**
Total 2014	10,805,533	7,917,267	18,722,800
Total 2013	10,718,835	7,538,284	18,257,119
Total 2012	10,556,960	7,515,069	18,072,028
Total 2011	10,576,449	7,144,985	17,721,434
Total 2010	10,128,251	6,999,436	17,127,687

4.2 CO_2 emission savings

CO_2 savings for geothermal power generation

CO_2 savings in table 15 were calculated using savings factors given by Lund et al. (2005) assuming an efficiency factor of 35% for production of electricity. The savings were calculated by the equation:

$$CO_2 \ savings = energy \ produced \cdot savings \ factor$$

By way of comparison, based on CO_2 emissions of different conventional plant types as stated by the German Federal Environment Agency (Klaus et al., 2009), a rather small coal-fired plant with 200 MW_e installed capacity and operating at 6,000 full load hours per year would produce over 1 million tonnes CO_2 per year, and a gas plant of the same size about 400,000 tonnes of CO_2 per year.

In 2015, total CO_2 savings by geothermal power generation in GIA countries accounted for 41.3 million tonnes of CO_2 for the replacement of coal, 35.4 million tonnes of CO_2 for oil, and 8.4 million tonnes for the replacement of gas, an increase of about 1.7% compared to savings in 2014.

Table 15: CO_2 savings for geothermal electricity in GIA countries. *Calculation based on figures for produced electricity from WG 10 country reports 2015.*

	CO_2 emission savings for geothermal power generation [tonnes of CO_2]		
Country	Gas	Oil	Coal
AUS	58	245	286
CAN	0	0	0
CHE	0	0	0
DEU	25,785	109,151	127,321
ESP	0	0	0
FRA	16,019	67,811	79,099
GBR	0	0	0
ISL	965,579	4,087,451	4,767,859
ITA	1,141,788	4,833,372	5,637,948
JPN	499,349	2,113,824	2,465,697
KOR	0	0	0
MEX	1,221,883	5,172,427	6,033,443
NOR	0	0	0
NZL	1,430,130	6,053,970	7,061,730
USA	3,072,174	13,005,006	15,169,854
Total 2015	**8,372,765**	**35,443,257**	**41,343,237**
Total 2014	8,229,945	34,838,677	40,638,017
Total 2013	8,163,911	34,559,146	40,311,954
Total 2012	8,040,620	34,037,238	39,703,167
Total 2010	7,714,098	32,655,018	38,090,859

It has to be noted that these numbers do not take into account the natural emissions of CO_2 through geothermal power plants which operate without a closed circuit and produce steam from high-temperature geothermal fields. On a global average these contribute about 122 g CO_2/kWh (Fridleifsson et al., 2008). For example, geothermal power plant natural CO_2 (equivalent) emissions in New Zealand amounted to 874,000 tonnes (average: 118 g CO_2/kWh) in 2015.

CO2 savings for geothermal heat

CO_2 savings calculations in table 16 are based on savings factors according to Lund et al. (2005), assuming an efficiency factor of 70% for direct burning to produce heat. The savings were calculated using the figures for geothermal heat production (all uses) presented in the previous chapter by the equation:

$$CO_2 \ savings = energy \ produced \cdot savings \ factor$$

In 2015, total CO_2 emission savings by geothermal heat uses in GIA countries amounted to 30.2 million tonnes of CO_2 for coal replacement, 25.9 million tonnes CO_2 for oil, and 6.2 million tonnes for gas replacement, an increase of 1.4% compared to savings in 2014.

Additional savings of 40,061 and 1,067 tonnes of CO_2 (in the case of natural gas replacement) could be achieved in Korea and Australia, respectively, by geothermal cooling with heat pumps.

Table 16: CO_2 savings by geothermal heat uses in member countries 2015. *Calculation based on figures for geothermal heat (all uses) from WG 10 country reports 2015.*

	CO_2 emission savings for geothermal heat [tonnes of CO_2]		
Country	**Gas**	**Oil**	**Coal**
AUS	8,827	37,219	43,407
CAN	312,825	1,319,025	1,538,325
CHE	245,992	1,037,224	1,209,672
DEU	661,540	2,789,380	3,253,140
ESP	6,014	25,358	29,574
FRA	491,887	2,074,039	2,418,867
GBR	60,722	256,034	298,602
ISL	745,930	3,145,210	3,668,130
ITA	298,139	1,257,102	1,466,107
JPN	703,250	2,965,250	3,458,250
KOR	67,900	286,300	333,900
MEX	112,423	474,031	552,843
NOR	222,557	938,410	1,094,429
NZL	234,837	990,189	1,154,817
USA	1,973,756	8,322,332	9,705,996
Total 2015	**6,146,599**	**25,917,103**	**30,226,059**
Total 2014	6,061,367	25,557,716	29,806,921
Total 2013	5,771,222	24,334,319	28,380,124
Total 2012	5,753,446	24,259,375	28,292,718
Total 2011	5,470,114	23,064,705	26,899,424
Total 2010	5,358,682	22,594,858	26,351,460

Figure 12: Los Azufres geothermal power plant, Mexico.

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