Geothermics 89 (2021) 101970

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Reinjection in geothermal fields: An updated worldwide review 2020

Zahratul Kamila, Eylem Kaya *, Sadiq J. Zarrouk

Department of Engineering Science, University of Auckland, Private Bag 92019, New Zealand

ARTICLE INFO

Keywords:
Reinjection
Geothermal field
Recharge
Thermal breakthrough
Chemical breakthrough
Induced subsidence
Seismic activity

ABSTRACT

Reinjection is key to maintaining and managing geothermal resources during utilization. This study presents an updated review of the worldwide reinjection experience in geothermal fields. Data from 152 geothermal fields from around the world were used to investigate the impact of reinjection location, reinjection depth, distance from production wells, reinjection fluid temperature, and the amount of reinjection fluid. Positive and detrimental effects on the relevant reservoirs were assessed. Changes in reinjection strategies in response to production and the lessons learned from reinjection experiences in various fields are also discussed. This updated review demonstrates the importance of understanding the type of geothermal system before starting reinjection. Main challenges to successful reinjection are also reviewed along with possible solutions with particular emphasis on pressure support, cooling mitigation, injectivity, scaling and solid deposition, microearthquake and tracer testing.

1. Introduction

During early geothermal developments, large-scale discharge of reject waters from liquid dominated geothermal systems was disposed into water bodies (e.g. Waikato River (New Zealand), Büyük Menderes river (Turkey), Pacific Ocean (El Salvador) and the Philippine Sea (The Philipines). Environmental considerations and sustainable energy recovery became imperative in the early 1980s, which is when the injection of wastewaters back into the geothermal reservoirs was first tested and implemented.

Reinjection in geothermal fields plays an indispensable role not only as a method to dispose of used wastewater that adversely affects the environment, but also to provide the necessary recharge (replenish) for the geothermal system that eventually will sustain the geothermal exploitation. To develop optimum and effective management of geothermal resources, it is crucial to have a good understanding of the current industry experience in reinjection practices. Nevertheless, finding the 'optimum' reinjection strategy is somewhat complicated because every geothermal field has its unique geological setting and reservoir characteristics (Diaz et al., 2016; Kaya et al., 2011).

In a few fields, excessive geothermal fluid production has resulted in water invasion when there is a large water body nearby. For example, due to large reservoir pressure drawdown during the early stages of production at Tiwi/Albay (Hoagland and Bodell, 1990) and Momotombo (Bjornsson, 2008) geothermal reservoirs, inflows from sea waters from the Philippine Sea and lake waters from Lake Momotombo, respectively, have highlighted the need for an integrated injection strategy and reservoir management.

Detrimental environmental problems in several geothermal fields were caused by a lack of knowledge and experience in the earlier phase of large-scale geothermal resource development. Poorly managed reinjection was often followed by negative consequences such as cooling of nearby production wells and other challenges to sustainable reservoir exploitation. However, the lessons learned from these early implementations have brought about significant learning and experience that helped change the reinjection practices worldwide. The research into the impact and benefit of reinjection in geothermal systems was pioneered by Stefánsson (1997).

In this work, we have conducted an extensive survey of open literature on power development around the world to capture the latest global reinjection experiences. This research is an updated review that complements earlier work by Diaz et al. (2016) and Kaya et al. (2011). We include the most recent information on electric-power producing geothermal fields worldwide, e.g. power plants' installed capacity, production and injection conditions, current reinjection strategies, and the response of the reservoir to these strategies. Moreover, we also investigated additional parameters such as reservoir temperature, production enthalpy, the vertical and horizontal distance between reinjection and production zones to capture the holistic understanding of reinjection strategies and their consequences. The objective of this study

* Corresponding author.
E-mail address: e.kaya@auckland.ac.nz (E. Kaya).

https://doi.org/10.1016/j.geothermics.2020.101970
Received 2 June 2020; Received in revised form 21 September 2020; Accepted 23 September 2020
Available online 23 October 2020

is to bring a qualitative review of reinjection strategies around the world. The results of this work provide useful guidelines on reinjection to all geothermal field operators.

We like to point out that the term "reinjection" has been widely used and admittedly loosely accepted by the geothermal industry to describe the injection strategies applied in sustaining geothermal utilization.

1.1. Categories of geothermal systems

Diaz et al. (2016) and Kaya et al. (2011) demonstrated that; while there are general characteristics or similarities between all geothermal fields the impact of reinjection strongly depends on the type of the individual geothermal system; therefore, reinjection should be evaluated accordingly. The types of geothermal systems can be summarised as follows:

a. Hot Water Systems (HWS) contain only liquid (water/brine) in their natural state, boiling does not occur before or during production. The risk of reservoir pressure drop due to fluid withdrawal is higher, when production is commenced without pressure maintenance by reinjection, which can lead to a rapid decline in output. Reinjection wells should provide pressure support to the system, but should also be placed far enough to avert thermal breakthrough.

b. Two-phase Liquid-Dominated Systems (LDS) where boiling takes place during utilization. Pressure decline usually is fast before boiling occurs, then slows down when boiling is induced by the pressure drop. There are three sub-classifications: low enthalpy, medium enthalpy, and high enthalpy, based on the field production enthalpy.

i. Low enthalpy systems (LE-LDS) are characterised by considerably high in situ (natural) reservoir permeability. These systems often have strong recharge from the boundaries as pressure declines during fluid production. They are hence less likely to run out of water and outfield reinjection is recommended.
ii. Medium enthalpy systems (ME-LDS) commonly have a lower reservoir permeability than LE-LDS. Only a few significant fractures exist in the systems. The exploitation results in local boiling near production wells due to pressure drop, hence the fluid enthalpies are higher. A combination of infield and outfield reinjection is recommended.
iii. High enthalpy systems (HE-LDS). The difference between HE-LDS and ME-LDS lies in the smaller number of major fractures. HE-LDS are sometimes also characterised by close proximity to hot rock/intrusions, even magma. They have tighter rock formations, hence lower permeability. These systems also undergoe local boiling near production wells, and infield reinjection is required.

c. Vapour-dominated systems (VDS) produce steam and contain voluminous immobile water. They have limited water recharge due to the low permeability nature of the reservoirs and even tighter boundaries. As the production continues, the pressure drop will allow the immobile liquid to boil and become steam. However, eventually, the fluid inside the reservoir will run out while the heat remains in the rock matrix. Therefore, reinjection inside the system is often necessary to sustain production.

The geothermal system classification used for this study is based on the previous study by (Kaya et al. (2011). Table 1 from that study is used in here to assist with the evaluation of reinjection effects.

1.2. Location

Spatial distance between reinjection wells and producing wells and hydraulic connection between the wells is a crucial parameter in the design of a reinjection system. Poor reinjection location selection often leads to detrimental effects on the reservoir (e.g. thermal breakthrough). However, there is no universally accepted rule when setting the spatial distance. Some authors (e.g. SKM (2006)) have defined infield reinjection and outfield reinjection in terms of how well the injection and production wells are connected, established by pressure communication; others (e.g. Axelsson (2012)) have classified them based on how reinjection wells are located relative to production wells (infield: in-between production wells, or outfield: outside of the main production zone).

Table 1
Categories of geothermal systems (modified after Kaya et al. (2011)).

System Category		Temperature	Production Enthalpy
Hot water		T < 220 °C	h < 943 kJ/kg
Two-phase, liquid-dominated:	Low enthalpy	220 °C < T < 250 °C	943 kJ/kg < h < 1100 kJ/kg
	Medium enthalpy	250 °C < T < 300 °C	1100 kJ/kg < h < 1500 kJ/kg
	High enthalpy	250 °C < T < 350 °C	1500 kJ/kg < h < 2600 kJ/kg
Two-phase, vapour-dominated		250 °C < T < 350 °C	2600 kJ/kg < h < 2800 kJ/kg

In this study, we have followed the classification of Diaz et al. (2016) and Axelsson (2012): Infield reinjection refers to injection well locations that are close to the producing wells and within the hot part of the system (resistivity/MT boundary). Outfield reinjection is located outside the boundary of the system and might not directly connect hydrologically to the hydrothermal system. Edgefield or peripheral injection refers to the injection that is located at the edge/boundary or in the outflow of the system but still in hydrological connection with the hot part of the system. The distance is not universal from one geothermal field to another since each system has a distinct geological structure. Moreover, this criterion can only be confirmed once reinjection wells have been drilled and more information about the reservoir has been obtained.

2. Available information

The present study is based on the publications available in the open literature from 152 power-generating geothermal fields found around the world (Appendix A–F). The data is summarised in Appendix A–F, covers aspects such as the natural condition of the reservoirs (e.g. initial reservoir temperature and average enthalpy); the name of field and power plant, its installed capacity/current generation; production and injection mass flow rates; summary of strategies and technology used in reinjection; the effect of reinjection on production; and other issues or problems associated with reinjection, such as mineral silica scaling, thermal and chemical front progression, microearthquakes, and ground deformation. It should be noted that these tables provide detailed information as far as it is available that may not be complete in all cases.

The reinjection strategy and its impacts are reported and analysed according to the classification of geothermal systems presented in Table 1. Most of the fields covered in this survey have utilised one reinjection strategy. However, in some cases, one field can have different production sectors which have different reservoir conditions (temperature, enthalpy, or chemical composition). For example, the Wairakei-Tauhara field has Te Mihi, Wairakei, Poihipi, and Tauhara power plants. The Wairakei power plant utilises low enthalpy fluid, while the Poihipi power plant generates from dry steam from the shallow vapour zone (Contact Energy Ltd, 2019). Therefore, in this study, different reinjection strategies will be discussed forapplied at different sectors of the same field.

Previous analysis by Diaz et al. (2016) has been updated as new information has become available. For example, the classification of some fields in Japan (e.g. Yamagawa, Onuma) have changed from HE-LDS to ME-LDS or LE-LDS based on an exergy assessment (Jalilinasrabady and Itoi, 2015). Fig. 1 demonstrates the present field classification based on the updated reported enthalpies.

Based on the available data, the world's total geothermal energy

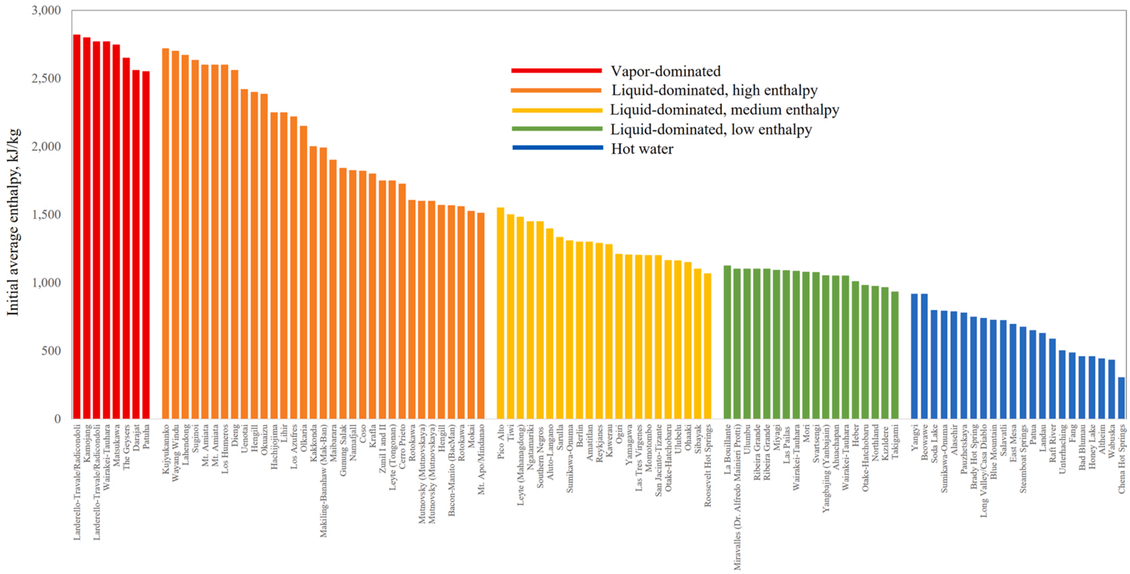

Fig. 1. Reservoir enthalpy of the geothermal systems studied here classified on basis of system type for each field and the types of systems, based on available information (Appendix A–F).

active installed capacity up to date is approximately 14,800 MWe (Fig. 2). It should be noted that this number is based on available published data at the point of preparing this work (early 2020). The most recent geothermal power generation data is given as 15,950 by Huttrer (2020).

Fig. 3 expresses the installed power capacity in megawatts (MWe) per type of system. Some fields are not included in the pie chart as they could not be classified due to the lack of information on their reservoir temperature or enthalpy (Appendix F). Therefore, this figure represents 97.3 % of the world's energy production for electric power production. LDS (75 geothermal fields) provide most of the power generation, representing 66 % of total installed capacity. This survey also shows that despite only eight VDS being developed, these systems have a high installed capacity (20 % of the world's total capacity). On the contrary, HWS produce only 12 % of the total installed capacity from 62 fields.

The percentage of power generation from the installed capacity or the capacity factor of each type of geothermal system is presented in Fig. 4. It should be noted that the availability of generation data is limited to 124 fields, representing 83 % of the world's installed capacity. On average, geothermal power plants operate within a range of 73–83% capacity factor, with higher average capacity factors in the LDS (82 %). Some fields have recent addtional power plants' installation, but the published data of generating capacity may not include the new plant (e.g. in Las Pailas (Nietzen and Solis, 2019)), thus contributing to a lower capacity factor. Some fields run at lower ratings than the installed capacity of the plants, due to a shortage in steam availability (e.g. Kamojang (Sofyan et al., 2019)).

The capacity factors of HWS have risen from 66 % to 73 %, while for VDS they have risen from 71 % to 78.1 %, compared to 2015 data presented by Diaz et al., (Diaz et al., 2016). In some cases, changes in

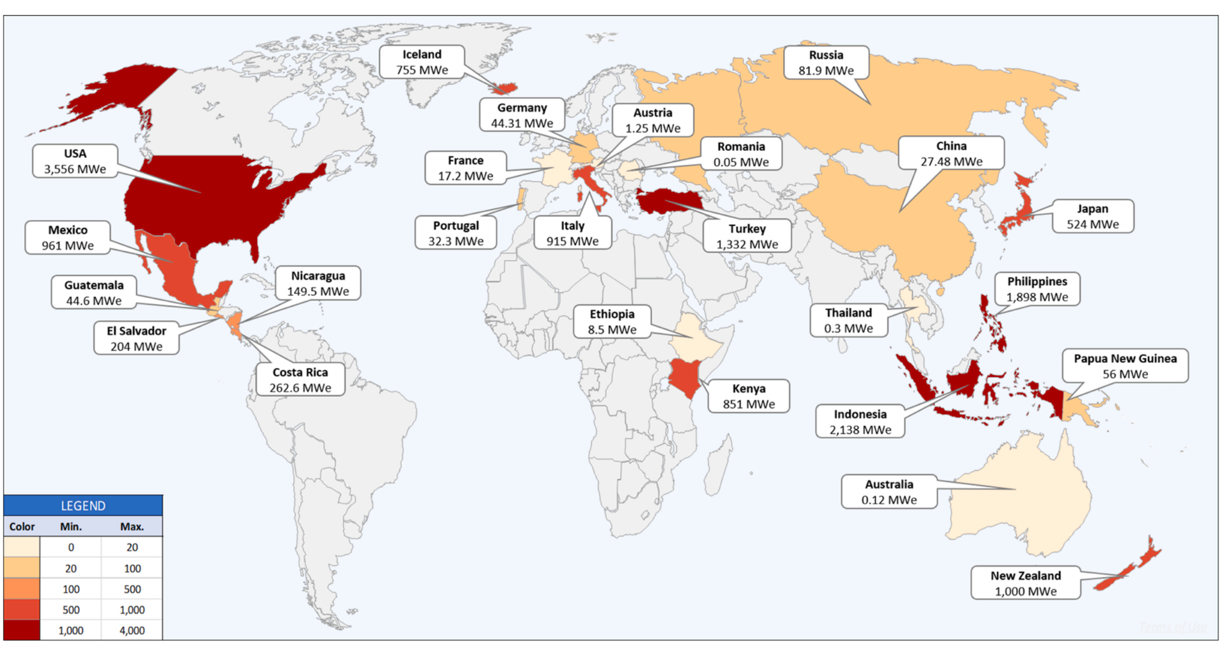

Fig. 2. Global geothermal installed capacity map, based on published data (Appendix A–F) at the point of preparing this work (early 2020) (created by using Someka Excel Generator (2019)).

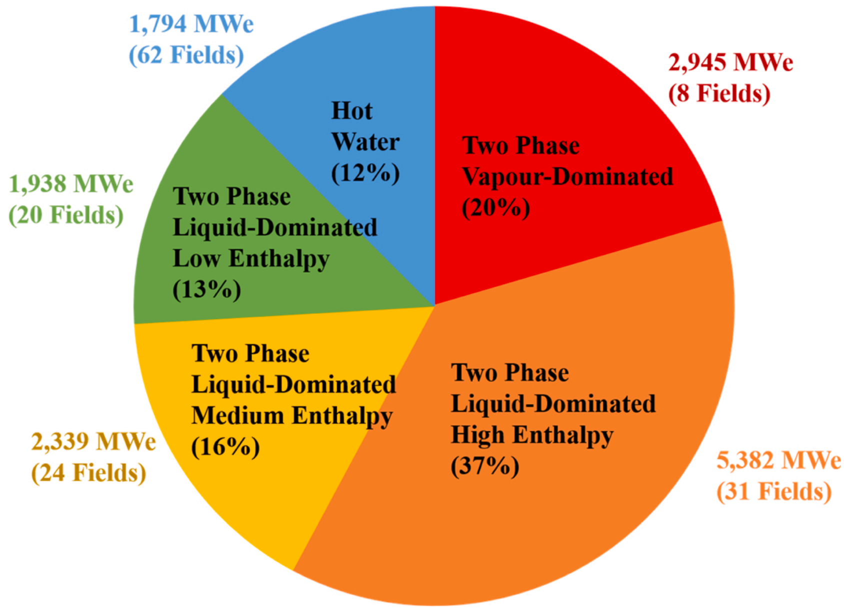

Fig. 3. Total installed capacity in MWe for the different types of geothermal systems based on published data (Appendix A–F).

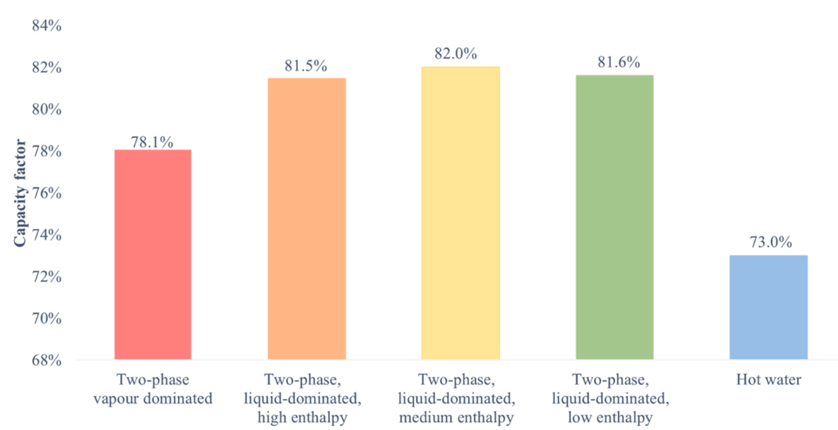

Fig. 4. Capacity factors for the different types of geothermal systems based on published data (Appendix A-F).

reservoir management, particularly reinjection strategies, have brought about a rise of power generation that results in higher capacity factors. On the other hand, both HE-LDS and LE-LDS decrease from 90 % and 88 % to 81.5 % and 81.6 % capacity factor, respectively. Some of this change can also be related to more information being publicly available.

The overall results agree with IRENA's reported data (IRENA, 2017), which states that geothermal plants using direct steam have capacity factors higher than 80 %, while projects utilising lower temperature resources (normally requiring downhole pumps) using binary plants have capacity factors of 60–80 %.

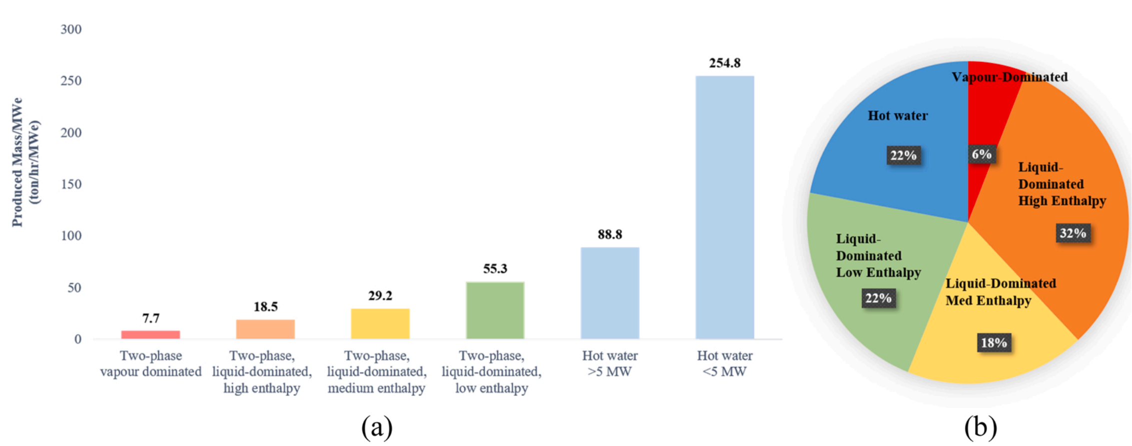

Fig. 5. (a) Produced mass (t/h) per MWe for each type of geothermal system (b) total produced mass per type of system based on published data (Appendix A-F).

The mass flow rate (t/h) needed to produce 1.0 MWe varies from one type of system to the other. Due to the limited published data, the information used in Fig. 5a represents the data from 113 fields (accounting for 90 % of the total installed capacity). Fig. 5a shows that the higher the enthalpy, the less mass is needed for every 1.0 MWe produced. For HWS with less than 5 MWe installed capacity, more mass flow is needed for every 1.0 MWe produced, because of the high parasitic load. In contrast, VDS require much less fluid per MWe of power produced than any other system type. HWS with 5 MWe or higher installed capacity require 11 times more mass flow rate than VDS to generate 1 MWe and about 33 times more mass/MWe with less than 5 MWe installed capacity (Fig. 5a).

Fig. 5b shows the contribution of each type of geothermal system to the total geothermal fluid (~260,000 t/h) produced worldwide based on data from 115 fields, which represent 90 % of the total installed capacity. The study showes that 72 % of the total extracted geothermal fluid is from LDS. Higher flow rates in HWS presented in Fig. 5b are balanced with a lower power generation from these systems compared to the other systems (of Table 1). Nevertheless, this review shows that HWS account for about 22 % of global geothermal fluid produced.

Fig. 6a shows the reinjection rate (t/h) per unit power (MWe) generated for each type of geothermal system. The reinjected mass also includes some of the additional (supplementary) water, not only geothermal brine and steam condensates. Available information from 91 fields (81 % of the worldwide installed capacity) was used in Fig. 6. This injected mass is also divided by the corresponding actual power generation. Fig. 6a shows that the injected flow rate per MWe and the produced flow rate per MWe follow similar trends to those in Fig. 5.

The contribution of each type of geothermal system to the total reinjected mass (163,225 t/h) using information from 90 fields (81 % of the worldwide installed capacity) is presented in Fig. 6b. The predominant injection fluid is from LDS (66 %), while HWS account for 29 % of the total injected mass. Predictably, low-enthalpy systems (i.e., HWS and LE-LDS) have a higher total injected mass, compared to the total produced mass, since they have more wastewater available to reinject. Comparison between Figs. 5a and 6a show that in all systems, the mass injected/MWe is less than the mass-produced/MWe as some of the condensed steam is lost in the cooling towers. This is with the exception of most < 5 MWe HWS power plants; this is likely because 100 % reinjection is implemented when using binary plants and the reinjection of supplementary (additional) water to maintain reservoir pressure.

Fig. 7 presents the ratio of the total produced mass flow rate to the total injected mass flow rate per system type, based on data from 78 fields (71 % of the total worldwide installed capacity at the time of the analysis.). For this analysis, only geothermal projects with known production and injection rates, and power generation were used. Fig. 7 shows that VDS have 58 % of their produced mass injected; this also includes the external water added to cover the low amount of residual liquid water after losing 70–90 % of the produced steam in the cooling towers. For HE-LDS, the ratio of produced mass reinjected back to the reservoir is around 57 %, while in ME-LDS and LE-LDS, the ratio is 68 % and 82 % respectively. Note that there is limited information available on production and reinjection rates for the ME-LDS, hence data shows lower fluid production and reinjection mass. Most (96 %) of the produced fluid from HWS tends to be reinjected since many plants utilise closed-loop binary systems. However, few HWS with less than 5 MWe installed capacity systems employ full surface discharge.

The ratio of injected fluid given in Fig. 7 varies slightly from the data presented by Diaz et al. (2016). The changes correspond to increasing reinjection rates reported in some fields; the total produced and injected fluid is greater than previously reported. This can be related to the increase in power production and the introduction of new plants the past five years. Some of this change can also be related to more information being publically available now.

Fig. 8 and Fig. 9 present the production and reinjection flow rates per unit MWe generated by different types of systems. Published data shows that there is a direct correlation between produced and injected mass, also the fact that higher enthalpy systems require less fluid mass flow per MWe which requires less fluid to be reinjected per MWe than in lower enthalpy systems. At the same time, the unique setting of each geothermal field results in a variable ratio between produced and injected mass per unit of power generation, for systems of the same type.

Fig. 10 presents the flow rates of wastewater discharged to the surface, for the geothermal fields where partial or full surface discharge is reported and information is available. Some of the information presented in Fig. 10 represents the actual data reported in the literature. For the remaining fields, this information was estimated. For the relevant HWS, the surface discharge rate was taken to equal the total mass produced. For LDS the discharge rate was calculated as the sum of the separated brine plus 20 % of the produced steam rate (assuming that between 70 % and 80 % of the steam is lost in power plant's cooling towers due to evaporation).

Comparison of Fig. 10 with the results presented by Diaz et al. (2016), shows that fields that previously applied surface disposal scheme, still dispose of wastewater to the surface, especially in small, scale power plant of HWS (less than 5 MWe), such as Birdsville (ErgonEnergy, 2014), Fang (Wood et al., 2016), Husavik Diaz et al. (2016), Tsuchiyu (Renewable Energy World, 2015), Honey Lake Diaz et al. (2016) and Wabuska (Diaz et al. (2016))). Other geothermal fields use wastewater for direct use applications (e.g. Svartsengi for pool recreation (blue lagoon) (Flóvenz et al., 2015), Yangbajain for greenhouse and swimming pool (Zheng and Wang, 2012), Reykjanes for district heating (Björnsson et al., 2010), Suginoi for hotel bathing and heating (Kudo, 1996), Namajfall for district heating and bathing Diaz et al. (2016), Husavik for district heating, industry use, and fish farming Diaz et al. (2016)). In many small geothermal fields, surface discharge is common at the very early period of field development (e.g. when there is only one

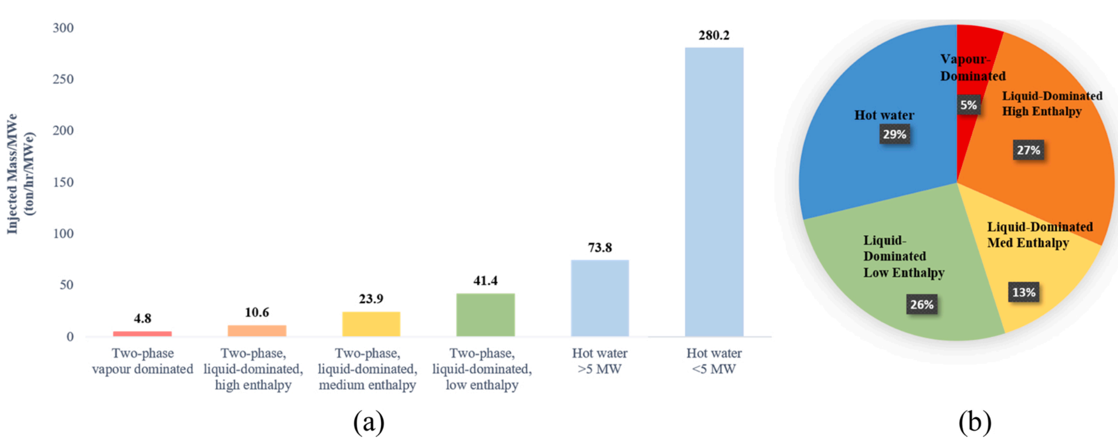

Fig. 6. (a) Injected mass (t/h) per MWe for each type of geothermal system (b) total injected mass per type of system, based on published data (Appendix A-F).

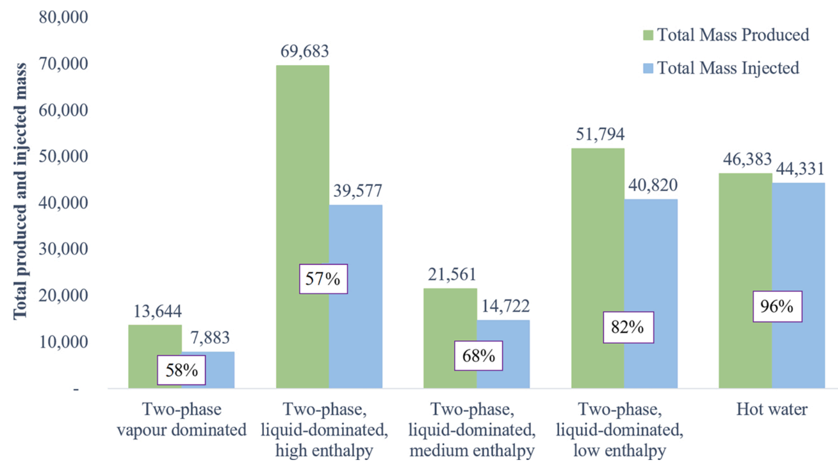

Fig. 7. Produced flow rate mass (green) and reinjected flow rate mass (blue) in t/h for each type of geothermal system, and the percentage of injected mass to produced fluid (shown in purple squares), based on published data (Appendix A–F). (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

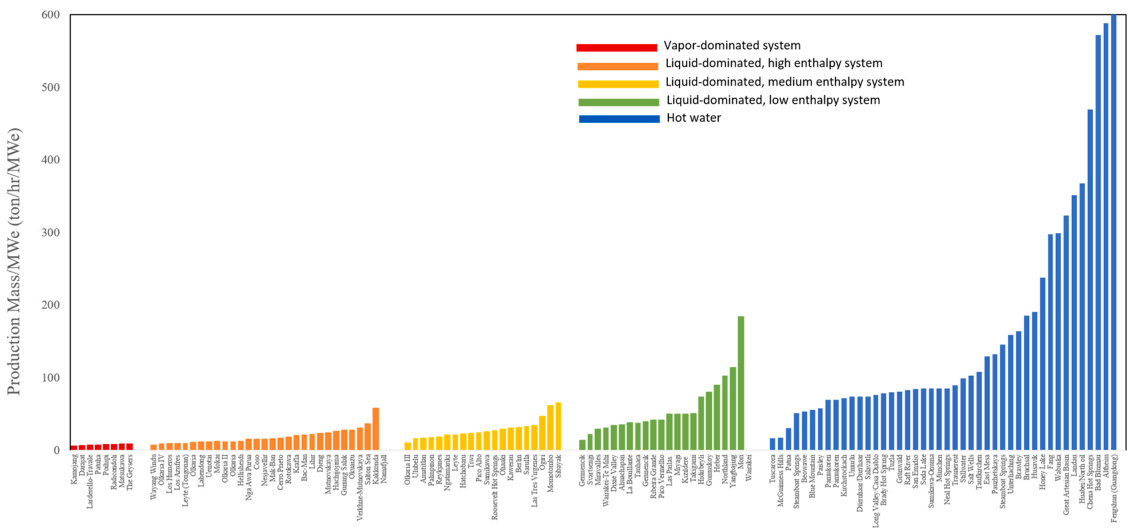

Fig. 8. Produced mass in t/h per MWe generated for each type of geothermal system based on published data (Appendix A-F).

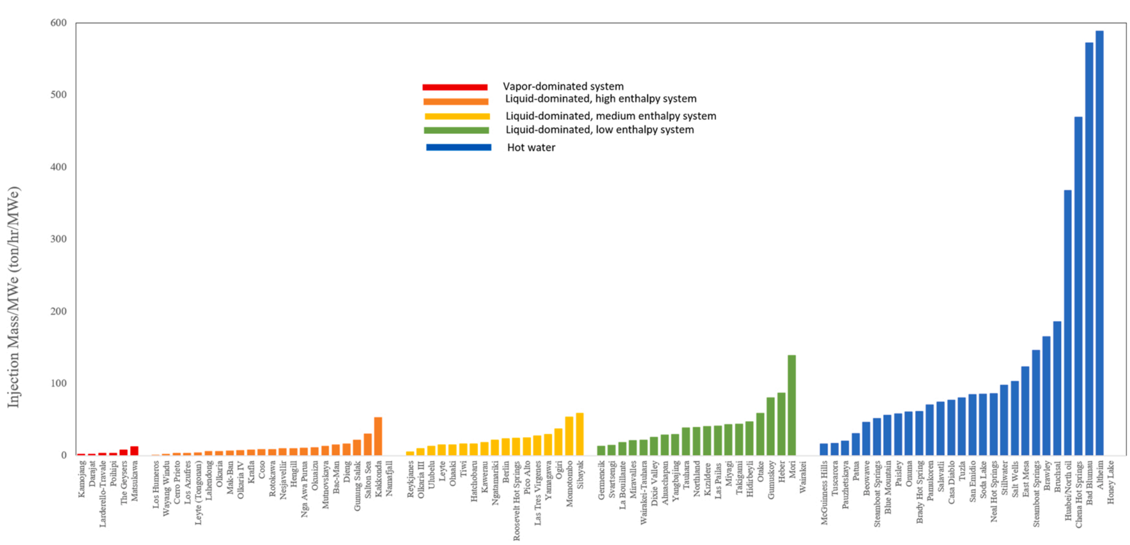

Fig. 9. Injected mass in t/h per MWe generated for each type of geothermal system, based on published data (Appendix A-F).

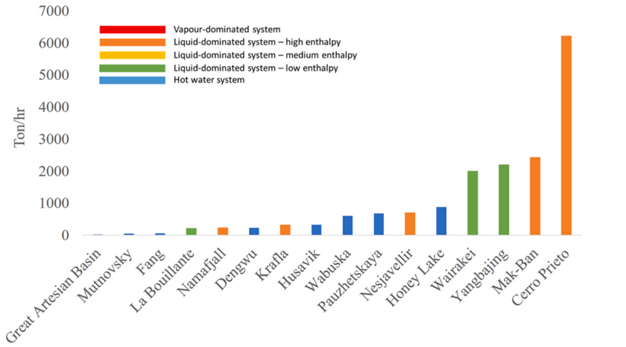

Fig. 10. Wastewater surface discharge in t/hr for geothermal fields, based on available information (Appendix A-F), where full or partial surface disposal is applied.

well in the field) and during well tests (e.g. due to absence of adequate infrastructure in rural areas, such as lack of electrical transformers to operate injection pumps) (GT'2019, 2019).

Reinjection strategies have changed from partial reinjection to full reinjection (100 % of wastewater reinjection) in some geothermal fields (e.g. Momotombo (Diaz et al., 2016)), or at least they reduced the amount of wastewater discharged at the surface by increasing injected fluid. This is an indication that geothermal field operators appreciate the contribution of reinjection to the long term sustainability of their operation.

The relative location/position of the reinjection targets is a key aspect during the design and management of geothermal systems during utilization. Table 2 shows the distance between reinjection and production wells for each type of geothermal system based on the data from 81 fields presented in the appendices. The average distances are the arithmetic averages of available data for each type of system.

The data in Table 2 gives a wide range of distances between reinjection and production wells for each system type. In VDS, wastewater is injected mostly infield, with only a few fields relocating their injection to the edgefield and outfield. In HWS, reinjection is applied infield and outfield with wells up to 6 km apart. The average distance between production and injection targets for the LDS indicates that the distance between production and injection targets decreases with the increase in production enthalpy. This is to balance the natural recharge, which depends on reservoir permeability, and the level of rock fracturing for different geothermal systems (e.g. the HE-LDS typically has a few major fractures which limit natural recharge, whereas the LE-LDS have more general fracturing and widely spread permeability, which allow more recharge).

The temperature of injected fluid is another important parameter in any reinjection strategy. The reinjected fluid temperature greatly depends on the mineral (silica) scaling potential of reinjected geothermal fluid. Therefore, the selection of the injected fluid temperature is essential as the fluid temperature can impact the thermo-mechanical properties of the rock fractures, thus changing the injectivity of the target formation. Table 3 provides the reinjected fluids temperature ranges for different types of geothermal systems, at the same time the arithmetic averages of the injectate temperatures and temperature differences between the reinjected fluids and the reservoir (from 63 fields). Table 3 clearly shows that the average temperature difference between the reservoir fluid and injectate increases with enthalpy. Although the risk of thermal breakthrough does not only depend on the temperature difference as the hydraulic conductivity play a significant role (Diaz et al., 2016), the high temperature difference between injection and reservoir fluid temperatures can cause a greater temperature decline when there is a thermal breakthrough.

Table 2
Average distance and distance ranges between production and injection zones per system type based on published data (Appendix A–F).

Category		Range of distance between production and reinjection zones (km)	Average distance between production and injection zones (km)
Hot water		0.2 – 6.0	1.37
Two-phase, liquid-dominated	Low Enthalpy	0.2 – 4.0	1.37
	Medium Enthalpy	0.1 – 4.0	1.33
	High Enthalpy	0.5 – 3.0	1.26
Two-phase, vapour-dominated		Infield	

3. Reinjection strategies for different types of geothermal systems

3.1. Vapour-dominated systems (VDS)

Summary of reinjection experience for VDS is presented in Appendix A. In VDS, the condensed steam is fully reinjected. Moreover, additional surface (make-up) water is added in some fields due to the lack of natural recharge, such as in Kamojang (Sofyan et al., 2019), Darajat (Diaz et al., 2016), Matsukawa (Diaz et al., 2016), Larderello (Diaz et al., 2016), and The Geysers (Enedy and Ca, 2016). The source of the additional surface water can be from wastewater (The Geysers (Enedy and Ca, 2016)), rain and stream water (e.g. The Geysers (Enedy and Ca, 2016)), river water (e.g. Matsukawa (Diaz et al., 2016)), lake water (e.g. Kamojang (Diaz et al., 2016)), and groundwater (e.g. Kamojang (Sofyan et al., 2019)). In general, supplementary water has proven to benefit VDS, such as maintaining reservoir pressure, controlling steam-flow decline rate, and reducing NCG content in the produced steam due to lack of NCG's in the additional surface water.

Fig. 11 shows the total mass flow rate of produced and injected fluid, as well as their reinjection percentage per field. Some of the additional water data is estimated by assuming that reinjected condensate accounts for 20 % mass extracted as the net mass loss accounts for 70–80% in cooling towers due to evaporation (Enedy and Ca, 2016). In Kamojang, the small reinjected mass ratio is due to limited available surface water, which has led to a rapid steam flow decline (Sofyan et al., 2019). On the other hand, The Geysers reinject about 86 % of the total mass-produced because large scale wastewater augmented projects have been successfully implemented (Enedy and Ca, 2016). From Fig. 11, we can also predict, that the fields with limited reinjection/production ratio (%) are more likely to struggle in sustaining current levels of production in the

Table 3
Reinjected fluid temperatures for the different types of geothermal systems, based on published data (Appendix A-F).

Category		Temperature ranges of injectates (C)	Average temperature of injectates (C)	Average temperature difference between reservoir and injectates (C)
Hot water		45 - 148	75	82.6
Two-phase, liquid-dominated	Low Enthalpy	30 - 163	100	128
	Medium Enthalpy	25 - 180	134	179
	High Enthalpy	30 - 226	110	187
Two-phase, vapour-dominated		condensate	30	210

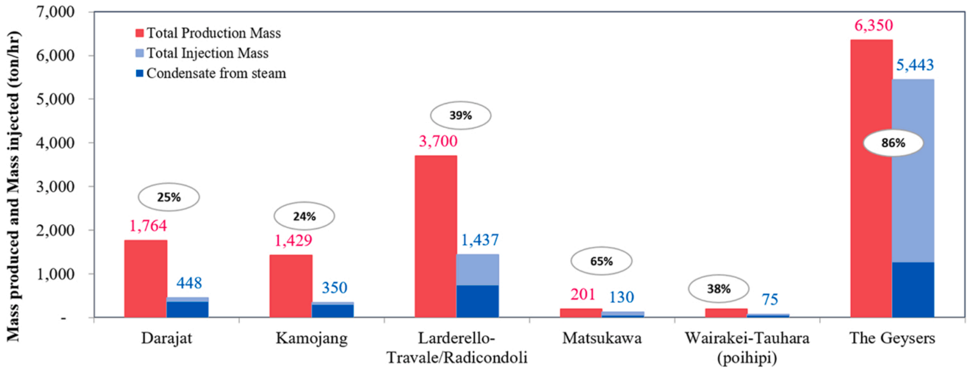

Fig. 11. Produced flow rate mass (red), reinjected flow rate mass from condensate (dark blue), and total reinjected flow rate mass from condensate and additional water (light blue) in t/h for VDS with available information (Appendix A). The percentage of injected mass to the mass-produced is also shown. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

future.

Injection within the boundary of the system is mainly chosen to provide induced recharge and maintain steam productivity of the VDS. However, some adverse effect has been observed in the production wells that are very close to injection wells. One of the reasons for cooling in VDS is the placement of reinjection wells in largely fractured, yet low-temperature parts of the system. The distribution of temperature in the reservoir is a prime factor for the heat recovery, so the steam condensation is likely to occur in the parts where the heat flow is lower (e.g. Matsukawa (Fukuda et al., 2018)). Temperature decrease also has been recorded when high volume injection was performed in highly fractured rock (e.g. The Geysers (Diaz et al., 2016)). Therefore, changes in injection rate are often made to reduce the impact of the thermal breakthrough (e.g. The Geysers (Diaz et al., 2016), Kamojang (Diaz et al., 2016)). Another cooling mechanism is the reinjection location overlap with the marginal natural recharge in some injection zones (e.g. Darajat (Simatupang et al., 2015)). Thus, repositioning injection wells to a more peripheral area in Darajat has helped to minimise harmful effects (Paramitasari et al., 2018).

Nonetheless, for few VDS, outfield injection is still performed, such as at the Larderello Radicondoli (Diaz et al., 2016) area (due to high-pressure reservoir nature), and Poihipi area (Diaz et al., 2016) (a steam-dominated area in Wairakei). This strategy has been chosen to prevent cold condensate from inflowing the steam cap in the Poihipi area that could result in cooling the steam zone (Yeh, 2019).

The optimum depth for infield reinjection in VDS varies and highly depends on their reservoir structure. Kamojang targets the deeper and lower permeability zone (Suryadarma and Dwikorianto, 2010). Darajat condensate also moves to a deeper depth based on the observed micro-earthquakes (Paramitasari et al., 2018). On the other hand, Larderello injects into the shallower level, taking advantage of the superheated condition and good vertical permeability in the systems (Diaz et al., 2016). Finally, The Geysers (Diaz et al., 2016) and Matsukawa (Fukuda et al., 2018) have almost the same injection level as producing depth, using natural and induced (fractured rocks) permeability.

3.2. High enthalpy, liquid-dominated systems (HE-LDS)

Appendix B summarise the information available for HE-LDS. In these types of systems, the separated geothermal water is fully reinjected into the reservoir in most cases (e.g. Zunil (Diaz et al., 2016), Hellisheidi (Gunnarsson et al., 2016), Gunung Salak (Yoshioka et al., 2015), Lahendong (Prabowo et al., 2015), Wayang Windu (Utami et al., 2018), Mt Amiata (Diaz et al., 2016), Olkaria NE and Domes (Ouma et al., 2016), Los Azufres (Gutiérrez Negrín and Lippmann, 2016), Mokai (Diaz et al., 2016), Rotokawa (Hernandez et al., 2015), and Maibarara (Maturgo et al., 2015)). Moreover, in some cases, additional supplementary water is also incorporated to impede steam decline (e.g. Coso (Eneva et al., 2018)) and to improve the recharge due to the development of dry superheated zone (e.g. Okuaizu (Okabe et al., 2016)).

The partial injection (e.g. Nesjavellir (Diaz et al., 2016), Krafla (Mortensen et al., 2015), Olkaria East (Ouma et al., 2016), Cerro Prieto (Sarychikhina et al., 2016), Los Humeros (Arellano et al., 2015a), Leyte (Diaz et al., 2016), Mak-Ban (Diaz et al., 2016), and Motnovsky (Diaz et al., 2016)), and surface discharge is still performed in several HE-LDS. For instance, Namafjall waste fluid is pumped to groundwater (Diaz et al., 2016), and Suginoi effluent water is used for heating the local hotel (Diaz et al., 2016). Nonetheless, it should be noted that in HE-LDS, the characteristics of the reservoir may involve limited recharge due to limited permeability and the number of connected fractures. Consequently, the withdrawal of geothermal fluid without the adequate addition of fluid from reinjection would result in depressurisation, which eventually leads to steam decline, as reported in Cerro Prieto (Miranda-Herrera, 2015). Fig. 12 shows produced mass and injected mass for several HE-LDS, along with the mass percentage of reinjection to production.

Infield location is the dominant chosen location for reinjection in HE-LDS. This strategy has been beneficial to increase energy recovery by providing additional recharge (e.g. Gunung Salak (Libert, 2017), Los Humeros (Arellano et al., 2015a), Bacman (Espartinez and See, 2015), Los Humeros (Iglesias et al., 2015)), and minimise the rate of pressure decline (Olkaria (Ouma et al., 2016), Dieng (Sirait et al., 2015)). Nevertheless, many studies have reported chemical and thermal breakthrough issues due to infield injection (e.g. Hellisheidi (Kristjansson et al., 2016), Gunung Salak (Libert, 2017), Uenotai (Diaz et al., 2016), Bacman (Espartinez and See, 2015), Tongonan (Uribe et al., 2015), Los Azufres (Arellano et al., 2015b)). For these circumstances, cooling mitigation is achieved by relocating reinjection further away from production or combining infield reinjection with edge/outside boundary reinjection, as reported in Gunung Salak (Libert, 2017), Bac-Man (Espartinez and See, 2015), Tongonan (Uribe et al., 2015), Uenotai (Diaz et al., 2016), Coso (Eneva et al., 2018), and Mindanao (Diaz et al., 2016). Also, controlling the reinjection rate or temporarily stopping the injection (especially cold injectate) has reduced the impact of thermal breakthrough in infield reinjection (e.g. Tongonan (Uribe et al., 2015), Loz Azufres (Diaz et al., 2016), Olkaria (Ouma et al., 2016)). Other fields have peripheral reinjection to avoid cooling (e.g. Lahendong (Prabowo et al., 2015), Wayang Windu (Diaz et al., 2016), Mokai (Bromley et al., 2015), Rotokawa (Hernandez et al., 2015)). Infield reinjection usually accompanies edgefield to provide recharge (Okuaizu (Okabe et al., 2016)), due to reinjection capacity limitation (e.g. Hellisheidi (Gunnarsson et al., 2016)).

The chosen depth is also critical and should be considered. Based on this survey, injecting into the same or deeper levels than the production zone is common in HE-LDS (e.g. Gunung Salak (Diaz et al., 2016), Hellisheidi (Gunnarsson et al., 2016), Okuaizu (Okabe et al., 2016), Los

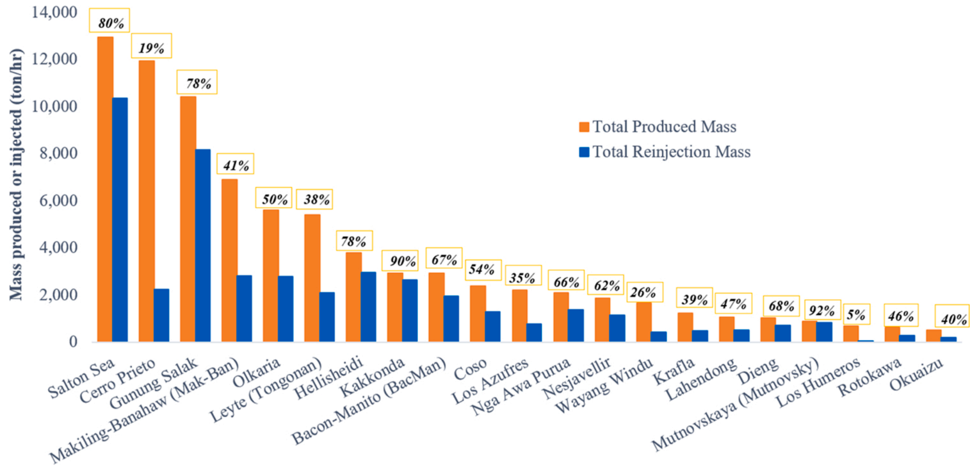

Fig. 12. Produced flow rate (orange), reinjected flow rate (blue), in t/h for HE-LDS with available information (Appendix B). The percentage of injected mass to produced fluid is also shown. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

Azufres (Diaz et al., 2016), Los Humeros (Iglesias et al., 2015), Mokai (Bromley et al., 2015), Rotokawa (Addison et al., 2017), Tongonan (Diaz et al., 2016), Kakkonda (Diaz et al., 2016), Lihir (Diaz et al., 2016), Maibarara (Maturgo et al., 2015), Mak-Ban (Diaz et al., 2016), Coso (Kaven et al., 2014), Salton Sea (Diaz et al., 2016)). The deep reinjection in Tongonan (Diaz et al., 2016) and Los Azufres (Diaz et al., 2016) provided good results since deep reinjection allows improved heat transfer.

Shallow injection often complements deep reinjection, mostly for condensate injection as observed in Rotokawa (Hernandez et al., 2015), and Hellisheidi (Gunnarsson et al., 2016), or as a decision early-on in the operation because of great natural recharge (e.g. Nesjavellir (Diaz et al., 2016)). However, shallow reinjection poses a higher risk of overpressure at shallow levels (e.g. Kakkonda (Diaz et al., 2016), Mokai (Bromley et al., 2015), Rotokawa (McNamara et al., 2016)). The shallow reinjection at high pressure could lead to chemical or thermal interference due to the gravity-driven flow of shallow water to the two-phase reservoir (e.g. occurred in Kakkonda (Diaz et al., 2016), Okuaizu (Okabe et al., 2016), Rotokawa (Diaz et al., 2016), Mokai (Bromley et al., 2015)).

3.3. Medium enthalpy, liquid-dominated systems, (ME-LDS)

Appendix C summarise the information obtained for these types of systems. Full reinjection strategy is common in most ME-LDS (e.g. Berlin (Diaz et al., 2016), Amatitlan (Diaz et al., 2016), Sarulla (Wolf and Gabbay, 2015), Sibayak (Diaz et al., 2016), Ulubelu (Yuniar et al., 2015), Ogiri (Diaz et al., 2016), Otake-Hatchobaru (Diaz et al., 2016), Olkaria West (Diaz et al., 2016), Las Tres Virgenes (Lopez and Torres-Rodriguez, 2015), Ngatamariki (Buscarlet et al., 2016), Momotombo (Diaz et al., 2016), Leyte (Mahanagdong) (Diaz et al., 2016), Tiwi (Sicad, 2015), Pico Alto (Franco et al., 2017), and Roosevelt Hot Springs (Diaz et al., 2016)) as a way of disposing of wastewater and to support the reservoir pressure.

Nevertheless, partial reinjection is still practiced in several fields (e.g. Reykjanes (Axelsson et al., 2015), Kawerau (Li et al., 2016), Ohaaki (Sherburn et al., 2015)). However, the limited fluid recharge during large-scale utilisation identifies the need for increasing reinjection (e.g. Reykjanes (Axelsson et al., 2015)). Overall, there is a trend of increasing the amount of wastewater reinjection in an attempt to increase energy recovery (e.g. Reykjanes) (Axelsson et al., 2015)), or due to the installation of a new power plant (e.g. Kawerau (Milicich et al., 2016)). The amount of produced/injected mass and the percentage of reinjection to production in ME-LDS are given in Fig. 13.

The exploitation of ME-LDS mostly incorporate an infield reinjection strategy as a way to increase energy recovery and maintain reservoir pressure (e.g. Berlin (Diaz et al., 2016), Aluto Langano (Gherardi et al., 2014), Reykjanes (Matthiasdottir et al., 2015), Ulubelu (Yuniar et al., 2015), and Roosevelt Hot Springs (Simmons et al., 2018)). Yet, adverse effects such as chemical and thermal breakthrough have been reported when the distance between injection and production is relatively short (e.g. Berlin (Diaz et al., 2016), Sumikawa (Kaya et al., 2015), Reykjanes (Axelsson et al., 2015), Ulubelu (Giriarso et al., 2015), Momotombo (Diaz et al., 2016), Roosevelt Hot Springs (Simmons et al., 2018), Tiwi

Fig. 13. Produced flow rate (yellow), reinjected flow rate (blue), in t/h for each ME-LDS with available information (Appendix C). The percentage of injected mass to produced fluid is shown in the boxes. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

(Sicad, 2015)). For that reason, the operators have in some cases opted to move the injection further away from production wells within the field boundary (e.g. Hatchobaru (Diaz et al., 2016), Ulubelu (Siahaan et al., 2015)) or having to ultimately move the reinjection site to an edgefield/outfield location (e.g. Palinpinon (Solis and Taboco, 2015), Tiwi (Sicad, 2015), Sumikawa (Diaz et al., 2016)) to distribute the injection flow.

In order to combat cooling, peripheral or edgefield reinjection can be chosen to give an adequate distance between production and reinjection wells. Hence, cooling hasn't been experienced yet in such cases (e.g. Ngatamariki (Buscarlet et al., 2016)). However, when the injector is hydraulically connected to the production well, injecting near the boundary or at a great distance may not be sufficient, and the thermal breakthrough might still occur (e.g. Leyte (Diaz et al., 2016)).

In ME-LDS, shallow reinjection is common for brine (e.g. Ulubelu (Siahaan et al., 2015), Yamagawa (Diaz et al., 2016)) or condensate (e.g. Kawerau (Milicich et al., 2016)). However, the impact of shallow reinjection should be monitored as it can result in enthalpy decline (e.g. Yamagawa (Diaz et al., 2016), Momotombo (Diaz et al., 2016)). The deep injection can successfully maintain field enthalpy and provide pressure support (e.g. Kawerau (Milicich et al., 2016), Ngatamariki (Buscarlet et al., 2016)). Furthermore, experiences and numerical models have shown that the cooling effects are smaller when the injection is performed at a deeper zone rather than in the shallower zone (e.g. Hatchobaru (Diaz et al., 2016), Momotombo (Kaspereit et al., 2016)).

3.4. *Low enthalpy, liquid-dominated systems (LE-LDS)*

Appendix D summarise the information obtained for these types of systems. Fig. 14 shows the amount of produced and injected fluid in LE-LDS and the fraction of reinjection mass compared to the produced fluid. Full reinjection is common in most LE-LDS (Las Pailas (Nietzen and Solis, 2019), Miravalles (Nietzen and Solis, 2019), Ahuachapan (Diaz et al., 2016), Mori (Diaz et al., 2016), Takigami (Asada and Yamada, 2017), Te Mihi (Diaz et al., 2016), Pico Vermelho (Rangel et al., 2017), Ribeira Grande (Rangel et al., 2017), Gumuskoy (Diaz et al., 2016), Hidirbeyli (Diaz et al., 2016), Heber (Diaz et al., 2016), Kizildere (Satman et al., 2017)). This is expected since, in LE-LDS, a high amount of fluid is extracted per MWe (Fig. 5a). Consequently, it is necessary to replenish the reservoir fluid so that the pressure drop can be minimised. Augmented water is also added in fields for different purposes, such as maintaining the pressure to sustain a culturally significant surface feature (e.g. Ngawha (Sherburn et al., 2015)). Moreover, in Dixie Valley, the augmented water has been advantageous to prevent additional makeup well drilling as this strategy has been stabilising geothermal fluid withdrawal and productivity (Benoit, 2015).

In some LE-LDS, partial reinjection is implemented (e.g. Yangbajing (Diaz et al., 2016), La Bouillante (Traineau et al., 2015), Svartsengi (Sigrún Brá Sverrisdóttir, 2016), Wairakei (Diaz et al., 2016)). However, the limited fluid recharge due to partial reinjection may lead to the pressure drop, which results in subsidence (e.g. Yangbajing (Li et al., 2016), Wairakei (White et al., 2005)). Increasing the injection rate has successfully reduced the subsidence rate (e.g. Svartsengi (De Freitas, 2018)).

As LE-LDS are often characterised by widespread fractures, high permeability, and strong lateral natural recharge, the large amount of injected water can interfere with the hot reservoir. As a result, infield reinjection in LE-LDS should be monitored as they pose a higher risk of thermal breakthrough, as has been reported for Las Pailas (Torres-Mora and Axelsson, 2015), Ahuachapan (Diaz et al., 2016), Mori (Diaz et al., 2016), Otake (Diaz et al., 2016), and Kizildere (Senturk, 2019). To combat this issue, relocation of reinjection to a more distant site is often chosen (e.g. Mori (Diaz et al., 2016), Otake (Diaz et al., 2016), Pico Vermelho (Rangel et al., 2017)). Moving further has helped production and enthalpy to recover (e.g. Mori (Diaz et al., 2016), Ahuachapan (Diaz et al., 2016)). Edgefield and outfield locations are often chosen or combined with inside boundary sites to reverse the negative effect of the thermal front (e.g. Yangbajin (Diaz et al., 2016), Ngawha (Diaz et al., 2016), Gumuskoy (Diaz et al., 2016), Kizildere (Garg et al., 2015a), Svartsengi (Sigrún Brá Sverrisdóttir, 2016)).

The reinjection depth in LE-LDS is usually at the same or a deeper level than production (e.g. Svartsengi (Sigrún Brá Sverrisdóttir, 2016), Yangbajain (Zhu et al., 2015)), resulting in better pressure recovery, whereas shallower reinjection is also common to avoid subsidence (e.g. Wairakei (Diaz et al., 2016)) and sustain natural surface features (e.g. Tauhara (Diaz et al., 2016)). Often a combination of these two strategies is applied to achieve both purposes (e.g. Wairakei (Dean et al., 2014), Kizildere (Senturk, 2019), Svartsengi (Diaz et al., 2016)).

3.5. *Hot water systems (HWS)*

Fig. 15 presents the available data (summarised in Appendix E) of reinjection and production mass in HWS. Numerous HWS have a 100 % reinjection strategy (e.g. Altheim (Tanase, 2016), Huabei (Wang et al., 2016), Bruchsal (Evans et al., 2012), Onuma (Diaz et al., 2016), Pamukoren (Karahan et al., 2015), Salavatli (Serpen et al., 2015), Umurlu (Yucetas et al., 2018), Tuzla (Diaz et al., 2016), Alasehir (Akin, 2019), Brady Hot Springs (Diaz et al., 2016), Brawley (Llenos and Michael, 2016), Chena hot springs (Leland et al., 2015), Cove Fort (Diaz et al., 2016), East Mesa (Diaz et al., 2016), Lightning Dock (Diaz et al., 2016), Casa Diablo (Report, 2017), Neal hot springs (Warren, 2016),

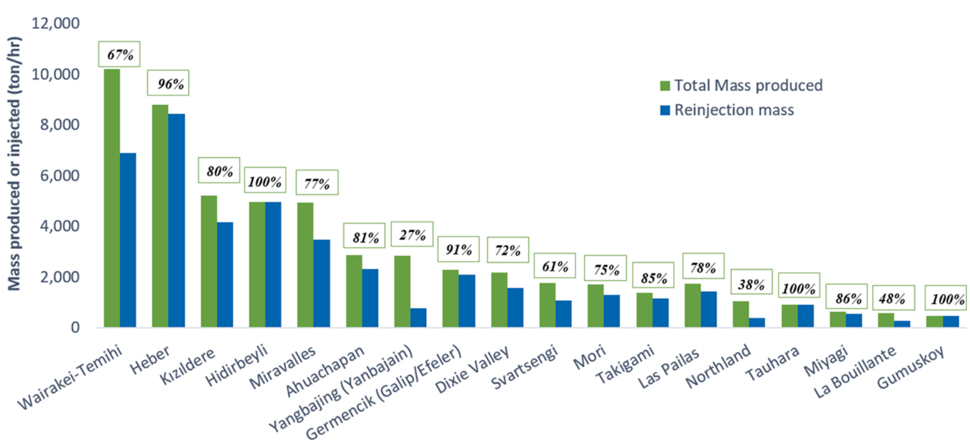

Fig. 14. Produced flow rate mass (green), reinjected flow rate mass (blue), in t/h for LE-LDS fields with available information (Appendix D). The ratio of injected mass to produced fluid is also given. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

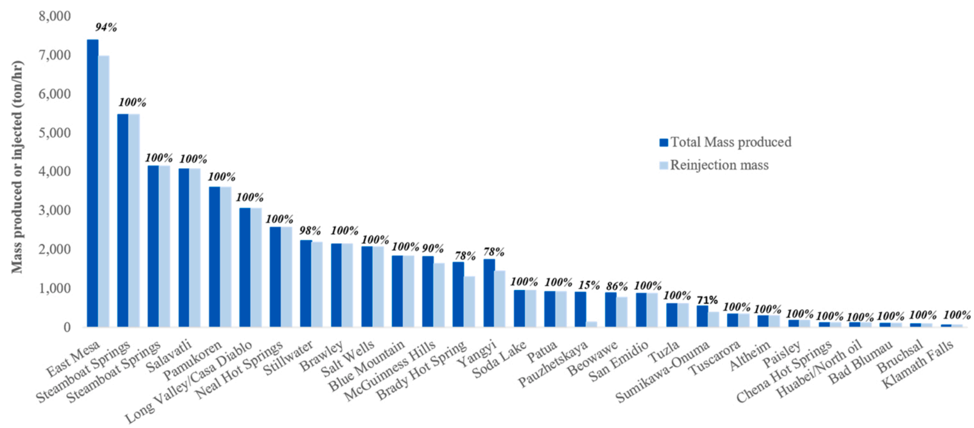

Fig. 15. Produced flow rate (dark blue), reinjected flow rate (light blue), in t/h for HWS with available data (Appendix E). The ratio of injected mass to produced fluid is also shown. (For interpretation of the references to colour in the Figure, the reader is referred to the web version of this article).

OIT (Diaz et al., 2016), Paisley (Mink et al., 2015), Patua (Cladouhos et al., 2017), Raft River (DiPippo and Kitz, 2015), Salt Wells (Diaz et al., 2016), Soda Lake (Diaz et al., 2016), Steamboat Springs (Sorey and Spielman, 2017), Thermo Hot Springs (Diaz et al., 2016), Tuscarora (Chabora et al., 2015), Wild Rose (Orenstein et al., 2015)). In HWS, full reinjection is critical to compensate for the large pressure drop due to the large fluid take per MWe produced. In addition, binary plants are utilised in most HWS, which involve a closed-loop system, so 100 % of wastewater reinjection is fully attainable.

The reinjection strategy in most HWS is to reinject the produced fluid in wells adjacent to the production zone, i.e., infield (e.g. Bruchsal (Evans et al., 2012), Onuma (Diaz et al., 2016), Umurlu (Yucetas et al., 2018), Brawley (Llenos and Michael, 2016), Steamboat Springs (Bjornsson et al., 2014)). This strategy positively stabilises the reservoir pressure (e.g. Patua (Murphy et al., 2017), McGinness Hills (Lovekin et al., 2016), Bruchsal (Diaz et al., 2016)), maintains production (Landau (Evans et al., 2012)), and water level/pressure (e.g. Altheim (Diaz et al., 2016)). It has been recorded that HWS operations have moved from an outfield reinjection to infield to reduce pressure drawdown (e.g. Beowawe (Diaz et al., 2016)). This can also prevent cold groundwater from infiltrating into the reservoir (e.g. Beowawe (Kirby et al., 2015)) or reduces production losses (e.g. Brady Hot Springs (Diaz et al., 2016)). Nonetheless, the chemical and thermal breakthrough commonly occurs in HWS, like reported in Onuma (Diaz et al., 2016), Pauzhetskaya (Diaz et al., 2016), Beowawe (Kirby et al., 2015), Blue Mountain (Swyer et al., 2016), Lightning Dock (Reimus et al., 2018), Casa Diablo (Diaz et al., 2016), Soda Lake (Diaz et al., 2016), and Tuscarora (Chabora et al., 2015). In few cases, the reinjection was originally located too close to production zone. A more distant location for reinjection has been pursued to reduce these adverse effects (e.g. Onuma (Diaz et al., 2016), Soda Lake (Benoit and Lake, 2016)).

Cooling is likely to happen when implementing shallow reinjection (e.g. Casa Diablo (Diaz et al., 2016), Brady Hot Springs (Diaz et al., 2016), Neal Hot Springs (Warren, 2016), Steamboat Springs (Sorey and Spielman, 2017)) due to gravity-driven (advection) downward flow of reinjected water. Furthermore, reinjecting deeper than the production level can allow the injectate to remain in the reservoir and reheat (e.g. Salavatli (Diaz et al., 2016)).

4. REINJECTION: BENEFITS, PROBLEMS and solutionS

4.1. Pressure support

The decline in production as a result of pressure drawdown is common in geothermal exploitation (Stefánsson, 1997). Thus, reinjection helps to lessen this consequence. In general, reinjection within boundary has successfully provided pressure support to many geothermal fields (e.g. Larderello (Diaz et al., 2016), Olkaria (Ouma et al., 2016), Dieng (Sirait et al., 2015), Rotokawa (Addison et al., 2017), Kawerau (Milicich et al., 2016), Palinpinon (Solis and Taboco, 2015), Ribeira Grande (Diaz et al., 2016), Kizildelre (Senturk, 2019), Miravalles (Diaz et al., 2016), Oradea (Bendea et al., 2015), Dixie Valley (Benoit, 2015), Patua (Murphy et al., 2017), McGinness Hills (Lovekin et al., 2016), Pamukoren (Karahan et al., 2015), Alasehir (Aydin et al., 2018)). The pressure support from infield reinjection is especially helpful to impede steam decline or maintain production, as reported in The Geysers (Enedy and Ca, 2016), Larderello (Diaz et al., 2016), Matsukawa (Diaz et al., 2016), Coso (Buck, 2016), Bacman (Espartinez and See, 2015), Tiwi (Calibugan et al., 2015a), Kawerau (Askari et al., 2015), Germencik (Tureyen et al., 2016), and Beowawe (Kirby et al., 2015). Moreover, pressure support can help to control water level decline, especially in HWS (e.g. Huabei (Diaz et al., 2016), Altheim (Diaz et al., 2016)).

In many fields, more pressure support is needed to prevent steam loss (e.g. Coso (Eneva et al., 2018), Dixie Valley (Benoit, 2015)) or protect surface features (e.g. Ngawha (Sherburn et al., 2015)). Hence, the injection of additional cold surface water has been undertaken. However, this will require a thorough assessment of the water resource and its sustainability. Not many geothermal sites are close to abundant water resources. Even if there is a water resource in the proximity of the geothermal field, sometimes the utilisation should be limited as it also supplies the local people or agriculture activity (e.g. Kamojang (Sofyan et al., 2019)).

Experiences have also shown that pressure support can lead to the change of the fluid thermodynamic state by suppressing boiling or promoting condensation in reservoirs. This causes enthalpy and temperature decline, which decreases steam production as the water phase becomes more mobile than steam (e.g. Hellisheidi (Gunnarsson et al., 2016), Tiwi (Sicad, 2015), Los Azufres (Arellano et al., 2015b), Mahanagdong (Diaz et al., 2016)). Similarly, the cooling effect associated with pressure support can also occur when shallow reinjection is carried out. In that case, the high shallow pressure will lead to gravity-driven coldwater inflow to the hot reservoir (e.g. Mokai (Bromley et al., 2015), Okuaizu (Okabe et al., 2016)). Several field cases reveale that deep injection is chosen as it provides better recharge and pressure support than shallow injection, as deep reinjection strategies allow the injectate to reside longer and heat up in the reservoir (e.g. Kawerau (Milicich et al., 2016), Momotombo (Kaspereit et al., 2016)).

In other cases, reservoir pressure increase from reinjection has been used to halt/mitigate the natural recharge in some reservoirs by creating or upholding a pressure barrier between the natural inflow and the reservoir and eventually prevent crossflow (e.g. Tongonan (Uribe et al., 2015), Momotombo (Kaspereit et al., 2016), Mori (Diaz et al., 2016)).

However, when the reinjection is not properly managed, a pressure differential between the production and the reinjection sites can induce thermal breakthrough, when cold injectates flow towards the production wells (e.g. Beowawe (Kirby et al., 2015), Hatchobaru (Diaz et al., 2016)).

Some reports in a few fields noted that; reinjection gives no to little pressure support even though the distance is close enough to the production zone (e.g. Zunil (Diaz et al., 2016), Takigami (Diaz et al., 2016), Casa Diablo (Report, 2017)). This happened as the injectates are diverted to the outflow zone instead of flowing towards the production part of the hydrothermal system. Also, less pressure support occurred in some geothermal fields when the injection wells are concentrated in one region, resulting in the lack of available fluid for the other parts of the system where it is needed (e.g. Lahendong (Prabowo et al., 2015)), or when reinjection is moved outfield (e.g. Beowawe (Kirby et al., 2015)).

4.2. Cooling mitigation

One of the ways of reducing the harmful effects of infield reinjection is controlling the reinjection rate, which is implemented effectively as a reservoir management tool in many geothermal fields. For example, in The Geysers (Diaz et al., 2016), and Gunung Salak (Diaz et al., 2016) injection rates are reduced to lower the reservoir pressure, thus increasing boiling and the enthalpy of the system, effectively increasing energy recovery. Likewise, in Tongonan (Diaz et al., 2016), Olkaria (Ouma et al., 2016), Mak-Ban (Diaz et al., 2016), and Patua (Murphy et al., 2017), the rate change is critical for mitigating the reservoir cooling when the reinjection wells are located near production wells or have a direct connection to production wells. Setting reinjection rate limits in individual wells (e.g. Tiwi (Diaz et al., 2016)) and monitoring water chemistry (e.g. Mori (Diaz et al., 2016)) can also balance rate management. Reinjection rate control is also suggested for Lahendong from the results of tracer testing (Prabowo et al., 2015).

Another strategy is to divert or relocate injection wells to a further/near boundary site or incorporating some outfield locations as a compensation (e.g. Gunung Salak (Libert, 2017), Bac-Man (Espartinez and See, 2015), Tongonan (Uribe et al., 2015), Coso (Eneva et al., 2018), Ulubelu (Siahaan et al., 2015), Palinpinon (Solis and Taboco, 2015), Tiwi (Sicad, 2015), Sumikawa (Diaz et al., 2016)). Likewise, moving the production site away from reinjection sites has been reported in Otake and Pauzhetsky (Diaz et al., 2016). The strategy of repositioning wells has successfully recovered some production wells that were previously affected by the cooling effects (e.g. Kakkonda (Diaz et al., 2016), Tongonan (Omagbon et al., 2016), Uenotai (Diaz et al., 2016)). In Kamojang, it is common practice to adaptively and continuously change injectors when surrounding production wells have been affected negatively (Sofyan et al., 2019).

As temperature decline can also be caused when downward gravity-driven flow occurs, change from shallow to deeper reinjection depths has also been attempted in many systems (Rotokawa (Addison et al., 2017), Sumikawa (Diaz et al., 2016)). This has had a positive impact on temperature changes.

4.3. Injectivity

In many fields, hot injection of brine and cold injection of condensate are separated in different injection clusters where the hot injection is placed near production areas while cold reinjection is put at a greater distance at a zone of lower reservoir temperature (e.g. Uenotai (Diaz et al., 2016)). Another way is to separate this type of injection into different depths where the cold and hot injection is usually performed at shallow and great depth, respectively, as experienced in Rotokawa (Addison et al., 2017) and Hellisheidi (Gunnarsson et al., 2016).

In some cases, the injectivity depends on the temperature of the injected fluid. This is often the case, such as in Hellisheidi (Gunnarsson, 2013). Probably due to expansion or contraction of the reservoir rocks (thermal stimulation) so that injectivity increases with declining temperature and vice versa.. The injectivity index is of concern in many geothermal fields because the decline in injectivity will require higher injection pressures or the drilling of new injection wells. The decline in the well injectivity can be a result of various processes; including mineral scaling in the reservoir and wellbore, increased reservoir pressure in reinjection zones, particle plugging due to fine-grained material in the injected fluids, or clay swelling in the reservoir if the reinjected fluids has low concentrations of dissolved solids (Bodvarsson, 1989; Xu and Pruess, 2004).

Several reported cases show that hot reinjection tends to be accompanied by injectivity drop, possibly due to mineral deposition in saturated conditions (e.g. Maibarara (Maturgo et al., 2015), Las Pailas (Nietzen et al., 2015)). Hence, cold water injection is often temporarily used as a cheap and effective method to improve reinjection capacity or permeability or minimise scaling in some production wells (e.g. Sumikawa (Diaz et al., 2016), Maibarara (Maturgo et al., 2015), Los Humeros (Luviano et al., 2015), Desert Peak (Dempsey et al., 2015), Raft River (Bradford et al., 2017)). Although it is not as common as thermal stimulation, hydraulic stimulations (water enhancement) using cold injectates have also been successfully utilised in a few production wells (e.g. Wayang Windu (Diaz et al., 2016), Las Pailas (Zúñiga, 2012), La Bouillante (Diaz et al., 2016)). This phenomenon is likely related to the higher density of cooler water resulting in high hydrostatic head (pressure) on the injection formation.

Alternatively, cooling leads to the shrinkage of the reservoir rock and the expansion of existing fractures, thus improving the reservoir permeability and reducing the required injection pressure. Nevertheless, this cold injection strategy should be monitored as it can lead to the risk of a thermal breakthrough. When cold reinjection returns are observed, prompt actions should be taken, to move reinjection further away from production wells after cold water stimulation (e.g. Uenotai (Diaz et al., 2016)), reinjecting intermittently or stopping cold reinjection once thermal breakthrough occurs (e.g. Olkaria (Ouma et al., 2016)), or using cold reinjection only in an emergency (e.g. Tiwi (Sicad, 2015)).

4.4. Scaling and solid deposition

Some mineral deposition in several geothermal systems is highly related to the reinjection practice. The common scaling type is silica, which occurs in numerous geothermal systems, especially in ME-LDS to HE-LDS as the higher temperature of produced fluid brings more silica concentration than in lower temperature geothermal systems. This is mainly due to the more aggressive water-rock interaction at higher temperatures, which results in a high potential for mineral deposition after the hot fluids are extracted and brought to the surface at target separation pressures. The potential problem of mineral deposition worsens if the hot reject brine is further cooled down, to further extract energy using bottoming plants (e.g. binary plant) prior to disposal. As silica tends to deposit at a certain saturation index associated with the temperature range of the brine (Addison et al., 2015), the lowered brine temperature after separation and before reinjection will lead to silica precipitation that blocks reinjection pipelines, wells, and the pores and fractures in the reinjection target formation (e.g. Hellisheidi (Van den Heuvel and Benning, 2016), Mt Amiata (Diaz et al., 2016), Cerro Prieto (Miranda-Herrera, 2015), Dieng (Pambudi et al., 2015), Bagnore (Diaz et al., 2016), Sumikawa (Ikeda and Ueda, 2017), Maibarara (Maturgo et al., 2015), Hatcobaru (Diaz et al., 2016), Onikobe (Diaz et al., 2016), Yamagawa (Diaz et al., 2016), Kawerau (Lawson et al., 2016), Sibayak (Diaz et al., 2016), San Jacinto (Valle et al., 2016)).

The first and foremost silica scaling prevention method in geothermal fields is to control the temperature of hot fluid injectate to prevent the brine from exceeding the silica saturation index (SSI). This 'hot brine' is usually brought to the reinjection line directly after separation (e.g. Mutnovsky (Diaz et al., 2016), Pico Alto (Franco et al., 2017), La Bouillante (Traineau et al., 2015), and Yamagawa (Diaz et al., 2016)).

In some geothermal fields, silica scaling can be observed even when hot reinjection is implemented (e.g. Dieng (Diaz et al., 2016), Tiwi (Sicad, 2015), Dixie Valley (Benoit, 2015)). Changing the strategy from hot to cooled injectate is often conducted by using large retention storage ponds to polymerise silica prior to reinjection (e.g. Dieng (Pambudi et al., 2015), Cerro Prieto (Miranda-Herrera, 2015), Bacman (Diaz et al., 2016), Maibarara (Maturgo et al., 2015), Hatchobaru (Diaz et al., 2016)). The retention pond can only be used as scaling mitigation, but also when pH modification of the separated geothermal water is not adequate for reinjection, like in Kawerau (Diaz et al., 2016).

A specific injectate temperature is set to prohibit the occurrence of scaling. Table 4 summarises available data related to reinjection temperature used to prevent silica scaling for the different types of geothermal system. The data is taken from geothermal fields which do not have silica scaling prevention method, such as pH adjuster, inhibitor, etc. From Table 4, it is clear that for HE-LDS, the reinjection temperature of hot brine is higher than for the rest of the systems. This is probably due to higher silica concentration in the produced fluid that leads to a higher SSI index, so the minimum hot brine temperature is more constrained. On the other hand, ME-LDS and LE-LDS have a similar hot reinjection temperature range to avoid silica saturation, which is around 100–165 °C. This range is slightly wider and lower than HE-LDS. This less constrained range is most likely relate to the lower silica concentration in produced fluid, compared to HE-LDS.

Table 4 also provides the typical brine temperature after leaving the evaporation pond to be injected. In general, the cooled brine temperature range is from 30 to 95 °C for LDS.

Calcite deposition can also be associated with reinjection due to the heating of reinjected fluid by the reservoir formation (e.g. Kizildere (Senturk, 2019), Bad Blumau (Diaz et al., 2016)). The other type of scaling is metal sulphide, especially for geothermal systems with a higher concentration of heavy metals, though it is not common. For example, the Antimony sulphide deposition was reported inside the casing of one reinjection well in Mt Amiata (Diaz et al., 2016).

The simplest method to control scaling during reinjection is by diluting the brine with condensate (e.g. Sumikawa (Diaz et al., 2016), Svartsengi (Diaz et al., 2016), Maibarara (Maturgo et al., 2015)), which helps to prohibit silica scaling. This method is also proven to clean the scale in some production wells (e.g. Darajat (Suryanta et al., 2015)). Another way is to add chemicals, inhibitors, or pH modifiers (e.g. Bagnore (using NaOH) (Diaz et al., 2016), Berlin (Mayorga and L.S.A.D.C., 2012), Roosevelt Hot Springs (using sulphuric acid) (Diaz et al., 2016), Sumikawa (Ikeda and Ueda, 2017), Las Tres Virgenes (Lopez and Torres-Rodriguez, 2015), Salton Sea (using pH controller) (Diaz et al., 2016), Miravalles (Arias Hernández et al., 2015), Mori (using pH controller) (Diaz et al., 2016), Kizildere (Senturk, 2019), Hatchobaru (applying pH modifier) (Diaz et al., 2016), Bad Blumau (using calcite inhibitor) (Diaz et al., 2016), and Salavatli (Serpen et al., 2015)).

If scaling has been already developed in reinjection formation, acid stimulation is often conducted to improve the injectivity of wells (e.g. Salavatli (Serpen et al., 2015), Wayang Windu (Diaz et al., 2016), Los Azufres (Diaz et al., 2016), Kawerau (Lawson et al., 2016), San Jacinto (Valle et al., 2016), Svartsengi (Diaz et al., 2016), Pamukoren (Karahan et al., 2015)).

Table 4
Reinjection fluid temperature for controlling silica scaling, based on published data (Appendix A-F).

System	Temperature (°C)	
	Hot reinjection	Cooled injectates from the pond
HE-LDS	130 - 170	40 - 55
ME-LDS	110 - 162	40 - 95
LE-LDS	100 - 165	30 - 80
Hot water	60 - 100	–

4.5. Injection and microearthquake

There is an increased public concern regarding how injection and hydraulic fracturing stimulation practices lead to a high risk of microseismicity. Induced seismicity can have a very detrimental effect on public support for geothermal operations as it can occur in densely populated areas. For example, in South Korea, a 5.5 moment-magnitude earthquake in 2018 has been believed to be caused by the Enhanced Geothermal System (EGS) operations (Grigoli et al., 2018).

Higher risk of microearthquakes is usually associated with EGS development, the hydrothermal systems can also have a strong link between microearthquake activity and reinjection activity, especially when deep injection is introduced (e.g. Mokai (Sherburn et al., 2015)), rapid change of injection rate (e.g. Hellisheidi (Kristjansdottir et al., 2016), Los Humeros (Urban and Lermo, 2017), Berlin (Kwiatek et al., 2014)). Change from deeper to shallower reinjection (e.g. Brady Hot Springs (Cardiff et al., 2018)), and maintaining a stable and constrained rate of reinjection (e.g. Salton sea (Crandall-Bear et al., 2018)) may limit seismicity.

VDS (e.g. Darajat (Paramitasari et al., 2018), The Geysers (Trugman et al., 2016; Majer et al., 2017), Kamojang (Hendriansyah and Wicaksono, 2015), Larderello (Diaz et al., 2016)), and HE-LDS (e.g. Krafla (Flóvenz et al., 2015), Gunung Salak (Diaz et al., 2016), Mt Amiata-Piacastagnaio (Mazzoldi et al., 2015), Okuaizu (Okamoto et al., 2018), Kakkonda (Diaz et al., 2016), Cerro Prieto (Sarychikhina et al., 2016), Los Azufres (Diaz et al., 2016), Rotokawa-Nga Awa Purua (Sewell et al., 2015), Coso (Trugman et al., 2016), Salton sea (Crandall-Bear et al., 2018)) are more prone to seismicity than other systems, based on this review. One reason for the high-temperature system being in jeopardy to induce seismicity is because of the thermal contraction of the reservoir rock. This refers to when cold injectate interacts with the hot rock resulting in declining thermal stress and causing slips (Majer et al., 2017). This mechanism is prone to occur in lower permeability and easily-stressed accumulated rocks, which is the common rock characteristic in VDS and HDS (Majer et al., 2017). The high-temperature difference of injectate to the reservoir also promotes more thermal contraction, exacerbating the stress of reservoir rocks.

In relatively lower temperature systems, such as HWS, LE-LDS, and ME-LDS, induced seismicity has also been reported (e.g. Hellisheidi (Kristjansdottir et al., 2016), Svartsengi (Flóvenz et al., 2015), Salavatli (Serpen et al., 2015), Unterhaching (Diaz et al., 2016), Brady hot springs (Cardiff et al., 2018)). For these systems, along with VDS and HE-LDS, the amount of injectate has been promoting localised stress by increasing pore-fluid pressure in the fault system (e.g. Desert Peak (Benato et al., 2016)). This mechanism is arguably the most common in geothermal exploitation (Geothermal ERA-NET, 2016), as many systems develop seismicity as soon as reinjection strategies were changed (such as location and rate).

In most cases, it is difficult to deduce whether the seismicity is natural or man-induced due to the complex parameters of production/reinjection, reservoir properties, and geological setting. Some of the VDS or HE-LDS have contributed to natural seismicity and existing high stressed rock conditions (e.g. Larderello (Diaz et al., 2016)). In other systems, seismicity is activated by a combination of reinjection/production activity and a complex tectonic environment (e.g. Cerro Prieto (Sarychikhina et al., 2016)). In summary, it is generally agreeable that reinjection activity can pose a higher chance to develop stress that already exists in reservoirs, leading to stronger or more frequent seismic activities.

In general, it has been reported that the seismic activity can possibly increase the reservoir porosity (e.g. Darajat (Diaz et al., 2016)), open up fractures (e.g. Krafla (Flóvenz et al., 2015)), thus enhancing the permeability (e.g. Larderello (Diaz et al., 2016)), and inducing stress changes in the reservoir rock (e.g. Los Azufres (Diaz et al., 2016)).

4.6. Interchangeable use of production and injection wells

The interchangeable well use strategy is positively implemented in some geothermal fields. In some fields, reinjection wells have been successfully converted into production wells after a period of heat up (e.g. Uenotai, San Jacinto, Palinpinon) (Diaz et al., 2016). In addition, old or poor production wells have been successfully used for reinjection in VDS (e.g. Kamojang (Sujarmaitanto et al., 2015), Larderello (Diaz et al., 2016), The Geysers (Diaz et al., 2016)), HE-LDS (e.g. Hellisheidi (Kristjansson et al., 2016), Olkaria (Diaz et al., 2016), Krafla (Mortensen et al., 2015), Maibarara (Maturgo et al., 2015), Coso (Buck, 2016)), LE-LDS (e.g. Ribeira Grande (Diaz et al., 2016), Kizildere (Senturk, 2019)), and HWS (e.g. Soda Lake (Lovekin et al., 2017)). This strategy can reduce the capital cost and risk of drilling additional wells. Nonetheless, the adverse effects of infield reinjection must be kept in mind when considering reinjection close to production wells. Therefore, monitoring and evaluation of the production wells response to reinjection is highly recommended (Diaz et al., 2016).

4.7. Surface deformation

Injection-induced surface deformation usually occurs as subsidence or uplifting in the ground surface. In general, reinjection will reduce subsidence that is caused by a pressure drop from geothermal exploitation (e.g. East Mesa, Wairakei-Tauhara, Takigami) (Diaz et al., 2016). However, injection-induced subsidence can happen due to the contraction of hot formations by cold reinjection, as reported in Mokai (Bromley et al., 2015), and Casa Diablo (Report, 2017). Partial reinjection (lack of full reinjection) can possibly lead to subsidence as the extracted mass is not adequately replaced, as reported in Yangbajing (Li et al., 2016), and Cerro Prieto (Sarychikhina et al., 2016). Thus, increasing injection rates can be beneficial to reduce subsidence (e.g. Svartsengi (De Freitas, 2018)). Shallow reinjection can also preserve shallow pressure and lessen the impact of subsidence, as reported in Wairakei (Diaz et al., 2016).

On the other hand, increasing injection or high reinjection rates can be a factor contributing to the ground inflation/uplifting (e.g. Heber (Diaz et al., 2016), Raft River (Feigl et al., 2018), San Emidio (Diaz et al., 2016), Mutnovsky (Kiryukhin et al., 2015)). The mechanism is that reinjection can cause an increase in pore pressure and fault slip that leads to surface deformation (e.g. Hellisheidi (Juncu et al., 2018)). The solution to the problem can be to redistribute the total amount of injection over a larger area (e.g. Imperial Valley (Sanyal et al., 1995)). This can be achieved by increasing the spacing between injection wells or reducing the injection rate per well.

4.8. Reinjection and non-condensable gas (NCG)

In most cases, reinjection involves working fluid with low gas content compared to the higher gas content of the deep geothermal fluid. This can slowly reduce NCG content in the produced fluid and improve the power plant efficiency with less gas going with the geothermal steam to the turbines (e.g. Alasehir (Aydin et al., 2018)). A lower NCG content has been reported when makeup freshwater has been injected in some systems (e.g. Larderello (Diaz et al., 2016), The Geysers (Enedy and Ca, 2016), Coso (Buck, 2016)) thus increasing the conversion efficiency of the power plants.

Nonetheless, in certain fields, the loss of NCG can lead to a slight pressure drop (e.g. Ngawha (Sherburn et al., 2015)). Similarly, CO_2 has a considerable role in reservoir performance and energy production, as reported in Umurlu (Yucetas et al., 2018). In addition, environmental and health concerns regarding NCG emission have been on the rise, for example in Iceland where the amount of H_2S released can be felt by the people of Reykjavik city after the start of a geothermal power plant (Ingimundarson et al., 2015). These reasons encourage developers to consider NCG injection along with geothermal fluids in geothermal wells. Many studies have proposed NCG geological storage/injection, especially CO_2 and H_2S, as a strategy to decrease the release of those gases to the atmosphere (Kaya et al., 2018).

A few fields have been reported with NCG reinjection experience (e.g. Hellisheidi (Ingimundarson et al., 2015), Coso (Kolar et al., 2015), Umurlu (Yucetas et al., 2018)). Nevertheless, NCG reinjection should be conducted with care as it may harm the steam production. For example, in Coso reinjected NCG's broke through to several production wells, causing the power generation level to decline due to an increase in the gas content in the produced steam (Kolar et al., 2015).

4.9. Geological structure for reinjection

The geological setting of the reservoir considered as a reinjection target plays a vital role. For example, some faults in a system could be used as a natural barrier to prevent reservoir cooling (e.g. Gunung Salak (Diaz et al., 2016), Rotokawa (Hernandez et al., 2015)). While, other unique geological features can also provide a setting that is highly advantageous for induced recharge from reinjection, such as 'U-tube path' faults (e.g. McGuinness Hills (Lovekin et al., 2016)) or high vertical permeability (e.g. Los Azufres (Diaz et al., 2016)). These particular settings allow deep injectate to flow along a longer path and heat up before returning to the production wells.

In contrast, some structures can put the field management into jeopardy. When production and injection wells intersect with highly permeable faults, then close monitoring of reinjection should be conducted regularly to detect cooling indications (e.g. Alasehir (Aydin et al., 2018), Mak Ban (Diaz et al., 2016)). Faults can also contribute to a higher risk of cooling, even when the distance between production and injection is relatively long (e.g. Mt Apo (Diaz et al., 2016)). Other geological features can have localised permeability between a shallow or intermediate aquifer and deep reservoir, so injection should be managed in such a manner that the pressure drawdown will not lead to downflow of shallow fluids (e.g. Ngatamariki (Clearwater et al., 2015)).

4.10. Lack of suitable reinjection sites

Injection sites are mainly chosen through an adaptive approach based on the characteristics of each reservoir. However, in several geothermal fields, lack of suitable injection sites can be the case during development and exploitation phases. Injection wells may not penetrate the fractured zone that often can accept commercial flow capacity. For example, only infield injection is performed due to limited injection capacity outside the field in Lihir (Diaz et al., 2016). The Lihir geothermal system is an integral part of the large open-pit gold mine project on Lihir Island (Papua New Guinea) and infield injection strategy was implemented to help cool down the hot bottom pit of the mine. Shallow dE–Watering wells were also drilled in the area to help relieve the pressure of the shallow steam reservoir (Sullivan et al., 2011).

External factors might determine the decisions when considering reinjection. For example, infield and edgefield reinjection is applied in Hellisheidi due to permit issues which do not allow to drill outside the license area (Gunnarsson et al., 2016).

4.11. Reinjection wellhead pressure

In several geothermal systems, reinjection can be carried out by gravity flow (e.g. Wayang Windu (Diaz et al., 2016), Los Azufres

(Gutiérrez Negrín and Lippmann, 2016), Ulubelu (Mubarok and Zarrouk, 2016), Tiwi (Sicad, 2015), Bruschal (Diaz et al., 2016)). Gravity flow is desirable, as it does not require additional pumps and results in lower investment and maintenance costs. This strategy is attainable when geothermal systems are located in highly fractured areas, so formation pressures encountered in those areas are usually abnormally low due to pressure gradients below hydrostatic, as reported in The Geysers (Diaz et al., 2016). At the same time, topography can also create favourable conditions when the water table remains below the wellhead (Serpen and Aksoy, 2014).

In contrast, excessive reinjection wellhead pressure has been reported in several geothermal fields, mainly due to injectivity decline or continuous scaling (e.g. Dieng (Diaz et al., 2016)). This phenomenon might create a serious economic problem for pumping (e.g. Heber (Kaya et al., 2015)) and operational issues if it exceeds the design pressure of the surface equipment and causes environmental concerns, as the rest of the wastewater needs to be disposed at the surface, and other issues such as hydro-fracturing or induced microseismicity (e.g. The Geysers (Kaya et al., 2015)).

4.12. Tracer testing

The early application of injecting back colder waters raised some concerns on the possible detrimental effects to the reservoir such as premature thermal breakthrough (Zarrouk and McLean, 2019). It is for this main reason that a number of reservoir tracer tests in the 1980s were implemented in New Zealand, USA, Japan, Philippines, Mexico, Italy and Iceland. The tracers are selected to not react with the reservoir rock or fluid as they travel between wells. They should also degrade/decay slowly with time, so they do not leave a long-lasting signature that impacts the outcome of possibly future tracer testing. Initially, radioactive tracers including Tritium (^{3}H), Barium (^{82}Br) and Iodine (^{131}I) isotopes were used. Lately conservative chemical tracers mainly naphthalene sulfonates and disulfonates have become more commonly used (Zarrouk and McLean, 2019). The successful application of these liquid reservoir tracers is an integral and critical part in finalising/revising the injection strategies when siting outfield and infield injectors.

Carrying out reservoir tracer tests prior to full-scale exploitation of the resource has become an important compulsory reservoir monitoring activity to sustain and manage geothermal fluid production. Quantifying and modelling the amount of positive tracer returns and corresponding travel times observed in production wells have provided the critical basis in balancing injection strategy between the detrimental effects of thermal breakthrough and pressure support.

Tracer testing have shown clear reinjection returns in many fields (e.g. Nesjavellir, Coso, Mak-Ban, San Jacinto-Tizante, Las-Pailas, Wairakei-Tauhara, Ribeira-Grande and Olkaria III (Diaz et al., 2016)), no returns in Los Humeros (Arellano et al., 2015a) and Svartsengi (Rangel et al., 2017). They have also helped identify unfavourable areas for reinjection (e.g. Kawereu (Aydin et al., 2018)) and resulted in reduced/controlled returns (e.g. in Lahendon (Yeh, 2019) and Reykjanes (Axelsson et al., 2015)).

5. Conclusions

Reinjection is now considered a vital practice in geothermal development as it provides environmentally friendly wastewater disposal and sustainable reservoir management tool. This notion has been observed by a rapidly increasing reinjection trend in the last decades. Moreover, a full reinjection strategy has been adopted in at least half of the geothermal fields utilized globally.

Reinjection has been proven as a way to supply additional recharge/pressure support, maintain steam production, and restrain/manage subsidence. However, several undesirable effects on steam production can be caused by reinjection, such as chemical or thermal breakthrough, boiling suppression, and recharge by cold reinjected water. Furthermore, reinjection can raise public concern regarding ground lifting, subsidence, and induced microseismicity.

This updated review points out that it is necessary to understand the type of geothermal system before setting the reinjection strategy and designing the reinjection system. For example, injecting within the producing area (infield) and additional supplementary water is needed in a vapour-dominated system, which often lack natural recharge and undergo significant mass loss in the cooling tower. Liquid-domnated systems and hotwater systems often require a combination of infield, edgefield, and outfield reinjection to achieve pressure maintenance but still hinder cooling. Peripheral sites are usually chosen in an earlier phase of development to avoid the risk of negative reinjection return, however, there are also cases where developers start infield and later move to peripheral injection (e.g. Ahuachapan).

It is difficult to determine the optimum depth of reinjection as it highly depends on the geological setting, particularly structure (faults/loss zones). However, injecting at deeper than or the same level as production is often preferable to provide better pressure support and give residence time for injectates to heat up before returning to production wells. In addition, shallow reinjection may promote gravity downflow, which leads to temperature decrease, but it may be beneficial at small rates to mitigate subsidence.

Experience has shown that a reinjection strategy should be as flexible as possible to accommodate the change of the geothermal system during the exploitation phase. Converting production wells to reinjection wells or vice versa has been performed in many geothermal fields. Another flexibility also includes relocating injection/production wells, controlling the injection rate, stopping reinjection in particular wells, and changing the depth of reinjection to mitigate temperature and steam decline in some reinjection practices.

In most cases, the temperature of reinjection is associated with the separator pressure and silica saturation. However, supersaturated brine reinjection might result in silica scaling. Therefore, several techniques have been used to minimise the effects of scaling, such as using cooling ponds, brine dilution with condensates or surface water, adding chemical inhibitors and acid dosing. Condensate injection has been used to improve injectivity and help breakdown formation plugging at relatively low cost.

Surface deformation (subsidence and lifting) and induced microearthquakes have been the concerns of geothermal developers and the public. Shallow reinjection has the advantage over deep injection as it averts subsidence and is associated with less microseismicity. Also, limiting the rate of injection and spreading reinjection can help to distribute pressure support uniformly and hamper overpressure in areas that would otherwise be prone to seismicity or ground heaving.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Funding for the last stage of this work was provided by the MBIE Research Programme, GNS-MBIE00150 “Geothermal: Next Generation” project, New Zealand.

Appendix A. Two-phase, vapour-dominated systems (VDS)

Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Indonesia	Darajat	Darajat	1994 (DiPippo, 2016)	270 (Adi et al., 2018)	270 (Diaz et al., 2016)	240 (Paramitasari et al., 2018)	2569 (Diaz et al., 2016)	1764 (Paramitasari et al., 2018)	448 (Paramitasari et al., 2018)	Reinjection comprises the additional water and full condensates (Diaz et al., 2016). Starting in late 2011, an infield reinjection well was terminated and transferred to the edgefield in the northeast part of the boundary. Before 2011, injection in the central portion (infield), as well as deep and shallow depth, was implemented for almost 20 years (Paramitasari et al., 2018)	New edgefield strategy prevents further cooling due to the hastening of boiling at the central and southern parts of the reservoir, which resulted in a higher contribution of boiled condensate in the steam produced. But chemical breakthrough now is observed in the northern part of the field. MEQ cluster shows that the injectate condensate at the periphery of the system appears to move into the deeper part of the reservoir. Overall improvement of field wide production performance as the decline rate is decreasing (Paramitasari et al., 2018). Injection-induced MEQ occurs deep below the injector (Paramitasari et al., 2018).	Condensate reinjection has improved productivity and cleaned the scale (Suryanta et al., 2015). It is confirmed that the marginal recharge supplies the liquid in the central part of the producing area, where the old infield area is located (Simatupang et al., 2015).
Indonesia	Kamojang	Kamojang	1978 (DiPippo, 2016)	235 (Adi et al., 2018)	235 (Adi et al., 2018)	235 – 245 (Pambudi, 2018)	2800 (Sujarmaitanto et al., 2015)	1429 in 2017 (Adi et al., 2018)	300 - 400 For 200 MW (Yani, 2015)	Reinjection consist of additional water and full condensates (Sofyan et al., 2019). Four out of eight infield unproductive wells available have been used as injection wells (Sujarmaitanto et al., 2015) and located in low-medium permeability deeper zone so that condensate is expected to move slowly and gradually heat and infiltrate the production zone (Suryadarma and Dwikorianto, 2010) [141]. The injection strategy change over time by implementing injection wells reposition and injection	Overall, the current injection strategy helps to impede the steam decline of Kamojang field (Diaz et al., 2016). But the amount of reinjection condensate is not enough to maintain stable production (Sofyan et al., 2019). Depending on the location of injection wells, injection had a variable effect (no impact, loss, minimising decline) on productivity, affecting some wells positively and others negatively (Febriani et al., 2015). MEQ events near injection wells due to thermal contraction cracking. Little injection breakthrough has occurred in production	Kamojang faces the challenge of a significant lack of water injection mass (naturally from the reservoir and artificially from other sources) compared to the produced mass, leading to a decline in field mass production and unsustainable production (Sofyan et al., 2019).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										rates variation (Diaz et al., 2016).	wells from 1983-2003 (Diaz et al., 2016).	
Indonesia	Karaha-Talaga Bodas	Karaha	2018 (Adi et al., 2018)	30 (Adi et al., 2018)		250 – 350 (Prabata and Berian, 2017)				No records available	No records available	No records available
Indonesia	Patuha	Patuha	2014 (Adi et al., 2018)	60 (Adi et al., 2018)	54 (ThinkGeoEnergy, 2020a)	220 – 260 (Elfina, 2017)	2400 – 2700 (Pambudi, 2018)	411 in 2017 (PT Geo Dipa Energy, 2017)		2 reinjection wells are located at the southeast boundary (eastern part). Most of the production wells are located at the eastern part (Elfina, 2017)	No records available	No records available
Italy	Larderello-Travale/ Radicondoli	Larderello	1913 (DiPippo, 2016)	594.5 (EGEC, 2019)	487.1 (Enel Green Power, 2019)	Shallow = 220 - 250 Deep = 300 – 350 (Diaz et al., 2016)	2770 (Diaz et al., 2016)	3700 in 2007 (Diaz et al., 2016)	1437 in 2007 (Diaz et al., 2016)	Reinjection consist of additional water and full condensates. Injection has been performed mostly in the central part of the field at Valle Secolo since 1979, since it has good permeability and superheating conditions. Effective shallow reinjection is accomplished by excellent vertical permeability (Diaz et al., 2016). On the contrary, deep peripheral injection gives a less rapid response to liquid accumulation and steam recovery (Diaz et al., 2016). After 1994, reinjection was conducted in the zones where the wells produced considerable amounts of fluid in the initial phase and where the well spacing is closest; reinjection was continued at the top of the reservoir, using wells that were good producers (Diaz et al., 2016).	Since 1970, the current shallow reinjection strategy has been beneficial, especially in the depleted area, which made it possible to increase the reservoir pressure and steam production and decrease the steam/gas ratio (Diaz et al., 2016). Generally, no liquid water breakthrough; however, it is inferred that pressure in the upper reservoir was recovered by the formation of liquid plumes, slightly decreasing the temperature (Diaz et al., 2016). Some chemical breakthrough was observed. MEQ events recorded at low magnitude after reinjection started (Diaz et al., 2016). Reinjection performed in non-fracture formation is not effective, since water does not penetrate to depth, forming liquid plumes. Such liquid plumes evaporated after lowering the injection rate (Diaz et al., 2016).	The subsidence rate in the system is 25 cm/year. Boron is a critical component in the steam present as boric acid. As the system is linked with natural seismicity, the reservoir is likely to be critically stressed (Diaz et al., 2016). In 1994, experiments alternating the use of single wells as both injection and production wells resulted in positive results (Diaz et al., 2016).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Italy	Larderello-Travale/Radicondoli	Travale/Radicondoli	1973 (DiPippo, 2016)	200 (EGEC, 2019)	153.4 (Enel Green Power, 2019)	190 - 250 (Diaz et al., 2016)	2820 (Diaz et al., 2016)	1296 in 2008 for 160 MW (Diaz et al., 2016)		Up to 2009, reinjection had not been adopted in the Travale/Radicondoli geothermal area because of its high-pressure nature. Condensates are reinjected into the outfield by a 20 km long pipe (Diaz et al., 2016).	No records found	NCG content is 4–8 %/wt (Diaz et al., 2016)
Japan	Matsukawa	Matsukawa	1966 (DiPippo, 2016)	23.5 (DiPippo, 2016)	10.79 in 2014 (Yasukawa and Sasada, 2015)	260 (Diaz et al., 2016)	2748 (Jalilinasrabady and Itoi, 2015)	201 for 23.5 MW (Diaz et al., 2016)	10-130 from 1988 to 2003 (Diaz et al., 2016)	Full condensate started in 1988, then continued with additional water (Diaz et al., 2016). Based on a map from 2002, injection was performed in the middle of the field (infield) and relatively at the same level as production (Hanano, 2003). Government regulations determined some injection well's location (Diaz et al., 2016).	Generally, the reinjection operation has brought pressure support and maintained the steam production (Diaz et al., 2016). Cooling was observed when injection wells were placed in highly fractured low heat areas (Fukuda et al., 2018). In 2000, reinjection returns were found in production wells near the reinjection area (Diaz et al., 2016).	Currently, most production wells produce superheated steam. But at the initial stage, the reservoir has the liquid that slowly decreases over time (Fukuda et al., 2018).
New Zealand	Wairakei-Tauhara	Poihipi	1996 (DiPippo, 2016)	55 (DiPippo, 2016)	45 (Contact Energy Ltd., 2018)	180 (Diaz et al., 2016)	Initial: 2750 (Diaz et al., 2016) Current: 2770 (Kaya et al., 2018)	200 for 25MWe (Diaz et al., 2016)	75 for 25MWe (Diaz et al., 2016)	Full condensate reinjection. Outfield location at the western side of the field is used to inject condensates of the power plant into one injection well (Diaz et al., 2016).	Injection rises the shallow groundwater level in 2 wells (Diaz et al., 2016).	There is no vapour-dominated reservoir in Wairakei. However shallow steam zone in the Te Mihi area formed because of pressure decline. This zone is then utilised to generate steam production from two shallow production wells to Poihipi plant (Diaz et al., 2016).
USA	The Geysers	McCabe, Ridge Line, Eagle Rock, Cobb Creek, Big Geysers, Sulphur Spring (Sulfur Spring), Quicksilver, Lake View, Socrates, Calistoga, Grant, Bottle Rock II, Sonoma, NCPA I, NCPA II, Bear Canyon, West Ford Flat, J. W. Aidlin	1971 (Akar et al., 2018)	1477 (California Energy Commission, 2018)	710 (California Energy Commission, 2018)	300 (Diaz et al., 2016)	2650 (Diaz et al., 2016)	6350 in 2015 (Enedy and Ca, 2016)	5443 in 2015 (Enedy and Ca, 2016)	Currently, infield injection is performed, and the condensate injection is added with augmented water (Enedy and Ca, 2016). Previously, surface discharge, from 1960-1969. From 1969-1982, injection of condensates was performed (25% of mass-produced). In 1982, the injection rate was increased by the addition of rainwater	Recovery of wells productivity over the years. Reservoir pressure was stabilized by external municipal waste waters (artificial recharge) that helped to arrest continued decline of the resource.. In many parts of the system, reinjection has diluted the NCG in produced steam, hence improving generation efficiency and lessen the greenhouse gases	Seismic events have been reduced, indicating a near-equilibrium in thermal stress (Majer et al., 2017). EGS tests have been performed in the NW of the field (Stimac et al., 2017). There were three significant injection augmentation programmes: from excess rainwater in 1980, then stream

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										and water from. NW region had the highest rate of reinjection (Diaz et al., 2016). The reinjection depths are in the shallow and deep injection. Immense fracture permeability makes gravity-fed injection possible. Most injection wells were production wells (Diaz et al., 2016).	discharge (Enedy and Ca, 2016). The number of induced seismic events has increased after massive external injection, especially for deep injection. There is a clear correlation between injection rates and seismic events of M > 1.5 in the NW of the field, where most injections are performed and where the temperatures are higher (Diaz et al., 2016) (Trugman et al., 2016) (Majer et al., 2017). Temperature decrease was related to a high-volume injector at the NW of the field. Pressure variations also have been experienced (Diaz et al., 2016). Release of radiogenic helium from the matrix of reservoir rocks (magmatic source) caused by fracturing associated with injection (Diaz et al., 2016).	water into SE geysers starting in 1997, and community wastewater (SRGRP) in 2002 (Enedy and Ca, 2016).

Appendix B. Two-phase, liquid dominated, high-enthalpy systems (HE-LDS)

Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Guatemala	Zunil I and II	Orzunil	1999 (Akar et al., 2018)	24.6 (Diaz et al., 2016)	12 (Diaz et al., 2016)	260 (Diaz et al., 2016)	1750 (Diaz et al., 2016)			Full reinjection. The reinjection wells are located infield (approximately 500 m from producing wells). Planned to reallocate reinjection for better pressure support (Diaz et al., 2016).	Injected water was possibly diverted to outflow on the east as no observed pressure support by reinjected brine and condensate (Diaz et al., 2016).	Low field permeability in the system has led to the production declining (Diaz et al., 2016).
Iceland	Hengill	Hellisheidi	2006 (Akar et al., 2018)	303 (EGEC, 2019)	303 (Kristjansdottir et al., 2016)	303 (Diaz et al., 2016)	Initial 1750 (Kristjansson et al., 2016) Current 1570 (Kristjansson et al., 2016)	3780 in 2015 (Kristjansson et al., 2016)	2948 in 2015 (Kristjansson et al., 2016)	Full reinjection (Gunnarsson et al., 2016). There are 2 deep reinjection zones in the faulted periphery of the volcanic area (edgefield). The condensed steam flows to shallow wells (Gunnarsson et al., 2016). Infield reinjection is added to incorporate the temporary capacity limit issue in the reinjection zone, using unproductive producers to convert into injector wells. The injectate temperature is normally 60 – 80 °C but can be 120 – 173 °C during thermal plant maintenance (Kristjansson et al., 2016).	Reinjection capacity tends to decline over time (Kristjansson et al., 2016), possibly due to scaling (Van den Heuvel and Benning, 2016). The injection is governed by fractures (Diaz et al., 2016), so the overall capacity varies depending on injectate temperature (the lower T, the higher permeability and down-hole water flow) (Gunnarsson, 2013). Reinjection in 2 edgefield zones seems to be benefitting the vicinity well performance without cooling. However, at infield zones, the wells nearby reinjection wells show a rapid change in enthalpy, indicating thermal breakthrough (Gunnarsson et al., 2016). Rising pressure may suppress boiling and prevent higher enthalpy (Gunnarsson et al., 2016). The rapid change in the injection rate would increase seismicity (Kristjansdottir et al., 2016). Reinjection causes an increase in pore pressure and fault slip that leads to the surface deformation (Juncu et al., 2018).	This field has a high production density of 40 MW/km^2 in most productive areas (Gunnarsson et al., 2016). The Hellisheidi has been experiencing a significant decline in output. Thus, the operation is planned to be connected with new resources in the Hverahlid field to reach near full capacity generation. (Kristjansson et al., 2016). A pilot-scale gas separation station was built as a part of geothermal gas (NCG) re-injection projects (Gunnarsson et al., 2015).
Iceland	Hengill	Nesjavellir	1998 (Akar et al., 2018)	120 (EGEC, 2019)	120 (Atlason et al., 2015)	300 (Diaz et al., 2016)	2100 – 2700 (Diaz et al., 2016)	1872 in 2011 (Diaz et al., 2016)	1152 in 2011 (Diaz et al., 2016)	Partial reinjection is performed with a range of 0.6–3 km distance from the	Wastewater disposed into shallow wells affected the chemical composition and temperature rise of the	Tracer test performed (2004) in warm aquifer reinjection studies

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										producing zone (infield and outfield). A retention tank is used as a silica polymerisation method before brine and condensate are injected by a pump at 55 °C into a deep and warm aquifer. The excess is pumped to a shallow well connected to groundwater (Diaz et al., 2016).	water in shallow aquifer, which is used for cooling. This can cause lower productivity. Deeper reinjection wells would stop these effects (Diaz et al., 2016).	proved that the injected water did not enter the geothermal reservoir (Diaz et al., 2016).
Iceland	Krafla	Krafla	1978 (Akar et al., 2018)	60 (EGEC, 2019)	60 (ûorsteinsdóttir et al., 2016)	320 (Ármannsson et al., 2015)	Initial 1750 (Diaz et al., 2016) Current 1800 (Ármannsson et al., 2015)	1221 in 2015 (Drouin et al., 2017)	479 in 2015 (Drouin et al., 2017)	Partial reinjection is performed to 3 wells (Mortensen et al., 2015). One poor deep production well was successfully converted as an excellent injector that holds 18% capacity from total mass extraction (Mortensen et al., 2015). The other injection well is located SE to provide pressure support (Juliusson et al., 2015) and IDDP well to inject water into the deeper superheated zone so the steam will condense and the acid in steam can be neutralised (Markusson and Hauksson, 2015)	Overall field performance shows little change in enthalpy (no significant cooling) (Juliusson et al., 2015). MEQ events near injection are large (Flóvenz et al., 2015), especially in deeper depth, associated with fractures closures, and openings (Flóvenz et al., 2015)	An IDDP well is used for reinjection because it can't be produced due to the very high-temperature fluid and high acidity that damaged the casing (Juliusson et al., 2015).
Iceland	Namafjall	Bjarnarflag	1969 (Akar et al., 2018)	3.2 (EGEC, 2019)		300 (Diaz et al., 2016)	1825 (Diaz et al., 2016)	228 in 2015 (Drouin et al., 2017)	N/A	Surface discharge - water from the power plant has been disposed on the surface where it mixed with groundwater (Ólafsson et al., 2015)	N/A	Pressure monitoring has shown no pressure drop at least down to 600 m (Ólafsson et al., 2015). This is due to the limited fluid take for a very small operation (3.2 MWe)
Iceland	Peistareykir	Peistareykir	2017 (IEA, 2019)	90 (IEA, 2019)		270-290 (IEA, 2019)				No information available	No information available	No information available

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Indonesia	Dieng	Dieng	1980 (Akar et al., 2018)	60 (Akar et al., 2018)	44 In 2017 (ThinkGeoEnergy, 2020a)	240 – 333 (Pambudi et al., 2015)	2560 (Diaz et al., 2016)	324 of steam (Adi et al., 2018)	700 (PT Geo Dipa Energy, 2017)	Injection wells are located infield at the northeast and southwest sectors (Sirait et al., 2015). Brine is cooled down in a pond to maintain a certain temperature and pH to prevent silica scaling (Pambudi et al., 2015).	Reinjection has already been proven to be effective in supporting the reservoir pressure during exploitation (Sirait et al., 2015). The new application (cold brine injection) has been used to avoid scaling (Pambudi et al., 2015).	Hot injection was once implemented, but continuous scaling problems were experienced (caused pump damage) (Diaz et al., 2016).
Indonesia	Gunung Salak	Gunung Salak	1994 (Akar et al., 2018)	377 (Akar et al., 2018)	377 (Libert, 2017)	240 – 316 (Panggabean et al., 2018)	1842 (Diaz et al., 2016)	2814 of steam in 2017 (Adi et al., 2018)	8165 for 377 MWe (Diaz et al., 2016)	Full reinjection (Yoshioka et al., 2015). Injection wells are mostly located infield for brine (with 1.5 km min distance) and others located outfield for condensate (with 2 km from production) (Libert, 2017). Deep reinjection (Diaz et al., 2016). Faults play an essential role as flow barriers between production, and injection wells exist. Change in strategy based on performance or chemical monitoring (Diaz et al., 2016).	Change in strategy has managed to raise the energy recovery. However, a drop in temperature and enthalpy over time has been recorded due to infield injection (Libert, 2017). Production wells partially discharged injectates and varied according to changes in injection rates and location. Boiling process occurred due to pressure reduction when the injection rate lowered. MEQ events recorded close to the reinjection zone (Diaz et al., 2016).	The reservoir was initially fully liquid dominated when it was first developed but has since formed a large steam cap in the eastern half of the system(Putri and Julinawati, 2018). Reservoir modelling suggests that more distant injection will improve reservoir performance (Diaz et al., 2016).
Indonesia	Lahendong	Lahendong	1992 (Akar et al., 2018)	120 (Adi et al., 2018)	91 (Pertamina Geothermal Energy, 2017)	280 – 320 (Prabowo et al., 2015)	2670 (Diaz et al., 2016)	692 of steam in 2017 (Adi et al., 2018)	500 (Prasetyo et al., 2016)	Full reinjection (Diaz et al., 2016). Lahendong implements a cold reinjection system with brine and condensate in one peripheral NE area (1.5Km from the nearest production cluster) (Prabowo et al., 2015). Injection wells are close to a fault and have the lowest temperature in the fields (110 °C max) (Diaz et al., 2016).	Tracer test predicts thermal breakthrough in the northern area due to reinjection. Injection to only northern part could affect the lack of recharge and pressure in the south area based on tracer (Prabowo et al., 2015).	Based on the current tracer test, it is suggested to control the injection rate in the northern area around 25–50 kg/s (Prabowo et al., 2015). Fluids in the northern fields are acidic (Permana and Hartanto, 2015).
Indonesia	Wayang Windu	Wayang Windu	1999 (DiPippo, 2016)	227 (Adi et al., 2018)	227 (ThinkGeoEnergy, 2020b)	260 – 325 (Pambudi, 2018)	2700 (Diaz et al., 2016)	1544 of steam in 2017 (Adi et al., 2018)	576 (Diaz et al., 2016)	Condensate and brine reinjected by gravity in the southernmost part of the resource (close to reservoir boundary with 2 km distance	Hydraulic fracturing with cold water injection improved production (Diaz et al., 2016).	Freshwater pumping, and acidising have helped to recover well productivity (Diaz et al., 2016).

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										from nearest production wells) (Diaz et al., 2016).		The condensate pipeline has experienced thinning and leaking due to corrosion (Zatnika et al., 2016).
Italy	Mt. Amiata	Bagnore	1945 (Akar et al., 2018)	61 (EGEC, 2019)	57.6 (Enel Green Power, 2019)	150 in shallow reservoir (Diaz et al., 2016) 300–350 in deep reservoir (Diaz et al., 2016)	2600 (Diaz et al., 2016)			Full reinjection in infield location into shallow wells to solve the problem of brine disposal. In 1999, the amount of entrained water accompanying the steam at wellhead was comparatively small and could be disposed of by reinjection (Diaz et al., 2016).	in 1995, Silica scaling in reinjection lines was reported. The Antimony sulphide deposition was present inside one reinjection well casing, Thus, a mix of water and NaOH was injected at very low flow rates and successfully improve injectivity (Diaz et al., 2016).	
Italy	Mt. Amiata	Piancas-tagnio	1969 (Akar et al., 2018)	60 (EGEC, 2019)	57.6 (Enel Green Power, 2019)	150 in shallow reservoir (Diaz et al., 2016) 300–350 in deep reservoir (Diaz et al., 2016)	2600 (Diaz et al., 2016)			Total infield reinjection in Mt. Amiata region is performed into shallow wells (11 reinjection wells) to solve the brine disposal problem. In 1999, the amount of entrained water accompanying the steam at wellhead was comparatively small and could be disposed of by reinjection (Diaz et al., 2016).	Seismicity recorded (Mazzoldi et al., 2015). Silica scaling in reinjection lines reported in 1995. The Antimony sulphide deposition was found inside the casing of one reinjection well. Thus, a mix of water and NaOH was injected at very low flow rates to improve injectivity with positive results (Diaz et al., 2016).	
Japan	Okuaizu	Yanaizu-Nishiyama	1995 (Akar et al., 2018)	65 (DiPippo, 2016)	28.41 in 2014 (Yasukawa and Sasada, 2015)	270 – 320 (Diaz et al., 2016)	Initial 1,882 (Diaz et al., 2016) Current 2,385 (Jalilinasrabady and Itoi, 2015)	500 in 2009 (Diaz et al., 2016)	200 in 2009 (Diaz et al., 2016)	Partial but almost full reinjection. Currently, additional injection was drilled in infield location, complementing edgefield configuration. Shallow recharge location was avoided, and a deep part was selected as a drilling target (Okabe et al., 2016). Edgefield reinjection has a minimum separation of 1.25 km. The injection and production zone are	Severe interference such as a production stop has occurred when production feed points are at the same level as injection feeds or shallower (suggesting the fractures exist in the shallow region). However, the recharge effects tend to become small when the injection depth is deeper. The recharge effect is not necessarily proportional to the injection rate (Okabe et al., 2016). There is a correlation between injection operations and MEQ events (increase near	Continuous previous reservoir management strategy leads to the change of fluid nature to the EGS condition/decrease in steam and its pressure. Therefore, it was decided to establish technology for water recharge for EGS nature (Okabe et al., 2016).

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										formed of fault systems with NW-SE strikes and a steep dip to the NE (Diaz et al., 2016).	injection) (Okamoto et al., 2019).	
Japan	Kakkonda	Kakkonda 1 & 2	1978 (DiPippo, 2016)	80 (DiPippo, 2016)	35.16 in 2014 (Yasukawa and Sasada, 2015)	Initial: 230-260 for shallow reservoir (Kaya et al., 2015) Present: 210–240 for shallow reservoir 300–350 for deep reservoir (Kaya et al., 2015)	2000 (Kaya et al., 2015)	2917 (Diaz et al., 2016)	2625 from 1978 to 1990 (Unit 1, 50 MWe) (Diaz et al., 2016)	At first, reinjection wells were located infield, at a shallower depth than production wells (700 m for injection wells and 1000 m for production wells). Then, additional injectors were drilled into the producing depth (same depth), but about 1.5 km away from the production area (Diaz et al., 2016).	Change in vertical pressure gradient response to production and injection. Reinjection raised shallow pressures while production decreases the deeper pressures. Production decline occurred greatly in wells with good connectivity with 4 infield injection wells; therefore, injection in those sites was stopped. Production was recovered by offsetting reinjection wells to the southeast and production to the northwest. In 1988, MEQ events were recorded in the injection area. Cooling & chemical breakthrough due to shallow reinjection in 1990 (Diaz et al., 2016).	Acidic conditions two-phase flow in deep reservoir contains (Diaz et al., 2016).
Japan	Kujyukannko	Kuju	1998 (DiPippo, 2016)	0.99 (DiPippo, 2016)	0.338 (Yasukawa and Sasada, 2015)		2719* (Jalilinasrabady and Itoi, 2015)			No records found	No records found	The power plant is in a hotel (Jalilinasrabady and Itoi, 2015).
Japan	Suginoi	Suginoi	1981 (DiPippo, 2016)	1.9 (DiPippo, 2016)	0.884 (Yasukawa and Sasada, 2015)	200 (Jalilinasrabady and Itoi, 2015)	2633* (Jalilinasrabady and Itoi, 2015)			Surface discharge. Waste fluid used for space heating and baths (Diaz et al., 2016).	N/A	
Japan	Hachijojima	Hachijojima	1999 (DiPippo, 2016)	3.3 (DiPippo, 2016)	1.66 (Yasukawa and Sasada, 2015)	Up to 325 (Diaz et al., 2016)		44 (Diaz et al., 2016)		Water is reinjected via two pump units (Diaz et al., 2016).	The chemical composition of hot water has changed a little (Matsuyama et al., 2011).	
Japan	Uenotai	Uenotai	1994 (DiPippo, 2016)	28.8 (DiPippo, 2016)	20.56 (Yasukawa and Sasada, 2015)	210-300 (Diaz et al., 2016)		240 in 2003 (Diaz et al., 2016)		In 1993, injection started at southern production (1 km from producing wells). By 1995, the current strategy adopted: brine injected at the centre of the fields (high-temperature area/ infield) and condensates at 1 km south (lower temperature area) of	Condensate reinjection wells rose in injectivity after continuous cold-water injection (30 °C), but it lowered the enthalpy and produced a chemical front to the producer 250 m away from injection. So, this injection well was switched further to the SW, recovering production. In 2001, a	In 2001, one injection well in the centre of the field became a producer after a period of heating (Diaz et al., 2016).

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										the main production area. Deviated reinjection wells were mostly directed towards lower temperature areas (Diaz et al., 2016).	well interference, at the centre of the field, between injection wells, was experienced, possibly due to fractures in reservoir (Diaz et al., 2016).	
Kenya	Olkaria	Olkaria I (East) Olkaria IAU	1981 (DiPippo, 2016)	185 (Ouma et al., 2016) (with wellhead unit)	185 (Ouma et al., 2016) (without wellhead unit)	250 – 290 (Leech, 2017)	Initial 2,270 (Diaz et al., 2016) Current 2,000–2,300 (Ouma et al., 2016)	1970 (Ouma et al., 2016) (without wellhead unit)	785 (Ouma et al., 2016) (Gitobu, 2017) (without wellhead unit)	For Unit 1–3, Partial infield reinjection has been imposed since 1993; the rest of the brine is sent to an open disposable lagoon where it is pumped and used for drilling (Gitobu, 2017). Reinjection wells are retired production wells located ~600 m south of the high-temperature zone. Reinjection consist of hot (158 °C) and cold injection. During 1996 and 1997, cold infield reinjection (20 °C and 100 T/h) was performed at the centre of the fields using water from Lake (Diaz et al., 2016). For unit 4-5 (IAU), Reinjection contains 3 shallow wells (600 m) for cold reinjection and 7 hot reinjections ranging from 900 - 1700 m (approximately full). Brine temperature is 188 °C, while condensate is 20 – 23 °C (Gitobu, 2017).	Reinjection has helped to minimise the rate of pressure decline. The pressure drop in Olkaria East has been moderate ≈12 bar. In summary, reinjection in Olkaria East field has increased the well output but resulted in a drop in enthalpy which then recovers with the stoppage of cold injection intermittently (Ouma et al., 2016). Hot reinjection has prevented a steam decline in nearby wells and in some cases, has increased steam and brine rates. Meanwhile, cold reinjection has both positive and negative effects in some wells (Diaz et al., 2016).	in 2011, part of the steam from production wells in Olkaria I supplied power plant Olkaria II due to excess of production enthalpy (Diaz et al., 2016) Wellhead units in East field supply 38.3 MW (Ouma et al., 2016).
Kenya	Olkaria	Olkaria II (North-East)	2003 (DiPippo, 2016)	105 (DiPippo, 2016)	105 (Ouma et al., 2016)	250 – 290 (Diaz et al., 2016)	Initial 2100 (Ouma et al., 2016) Current 1,700 – 1800 (Ouma et al., 2016)	1280 (Ouma et al., 2016)	641 (Ouma et al., 2016)	Full hot infield reinjection is located 600−1000 m south and north of production. Since 2009, furthest reinjection wells received twice the rate of closer injection wells. An injection well is in the buffer zone	Reinjection has helped to minimise the rate of pressure decline. The pressure decline in Olkaria North East has been moderate ≈13 bar and has maintained enthalpy and minimised the requirement for makeup wells (it has kept some production wells at a	Production drilling is on-going to increase the capacity of the field to 140 MW (Omenda and Mangi, 2016).

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										between Olkaria II and I, to stabilise the reservoir pressure in the Olkaria I. Cold condensates are injected 500−1000 m west of production field (Diaz et al., 2016) (Ouma et al., 2016).	steady increase in both steam and water flow) (Ouma et al., 2016). The north reinjection zone has lower enthalpies than the rest of the system (because of the deeper target which produces more liquid than shallow steam zones). No negative effects have been reported for the cold reinjection (Diaz et al., 2016).	
Kenya	Olkaria	Olkaria IV (Domes)	2014 (DiPippo, 2016)	140 (DiPippo, 2016)	140 (Ouma et al., 2016)	250 – 290 (Wamalwa, 2016)	1850 (Ouma et al., 2016)	1350 (Ouma et al., 2016)	1000 (Ouma et al., 2016)	There are hot injection and cold injection located in infield area (Ouma et al., 2016).	Reinjection has helped to minimise the rate of pressure decline. Field average enthalpy for Domes has been fairly steady during the operation (Ouma et al., 2016).	Wellhead unit in Domes field supply 42.8 MW (Ouma et al., 2016). The pressure decline in Olkaria Domes has been moderate ≈1.2 bar (Ouma et al., 2016).
Kenya	Olkaria	Wellhead Unit	2013	81 (Ouma et al., 2016)	81 (Ouma et al., 2016)	250 – 290 (Wamalwa, 2016)	2000 (Ouma et al., 2016)	1000 (Ouma et al., 2016)	370 (Ouma et al., 2016)	No information available	No information available	No information available
Mexico	Cerro Prieto	Cerro Prieto	1973 (Akar et al., 2018)	570 (Romo-jones et al., 2016)	570 (Romo-jones et al., 2016)	280 – 350 (González et al., 2015)	1725 (Diaz et al., 2016)	11,934 in 2009 for 720MWe (Diaz et al., 2016)	2,237 in 2009 for 720MW (Diaz et al., 2016)	Partial reinjection. Most of the brine is hot-injected, and the rest is sent to evaporation ponds via open channels, where the brine cools down and allows the silica to precipitate before it is pumped and reinjected. However, some of the separated water is reinjected either hot or cold (Miranda-Herrera, 2015). Initially, this field performed surface discharge into evaporation ponds. In 1989, partial infield reinjection was started using former production wells in sector CP I. Then, reinjection was relocated to the west of CP I at 500-2600 m deep. In 2005, hot reinjection (150 °C)	Reinjection has decreased the decline rate of steam production in some wells even though there was a chemical breakthrough (Diaz et al., 2016). Nonetheless, gradually, CP I has experienced a decrease in enthalpy production due to cold reinjection and natural recharge (Diaz et al., 2016). By the year 2012, there was a lack of about 4000 T/year steam to maintain electrical production of 570 MW (Miranda-Herrera, 2015). Some wells have undergone the injection capacity drop as the high concentration of solids presented in the injected water, whereas other wells have constant injection capacity for years. These varied behaviours are influenced by the permeability of the	Reinjected water in the northwest area moves more rapidly horizontally than vertically, whereas the southwest injection fluid performs contrarily. The field is divided into 4 sectors: CP I (in the west), CPII (in the southeast), CP III (in the north) and CP IV (to the east of CP III) (Diaz et al., 2016).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										was started. It was found that the best injection zone was NW of the CP I sector. The acid injection has been performed to recover the injection capacity in some wells (Diaz et al., 2016).	rock formation in each well (Diaz et al., 2016). Subsidence and triggered seismicity have occurred (due to injection/production combined with complex tectonic environment) (Sarychikhina et al., 2016)	
Mexico	Los Azufres	Los Azufres	1982 (Akar et al., 2018)	252 (Romo-jones et al., 2016)	224.8 (Romo-jones et al., 2016)	240-280 (Beardsmore et al., 2017)	2220 (Diaz et al., 2016)	2209 in 2014 (Gutiérrez Negrín and Lippmann, 2016)	763.5 In 2014 (Gutiérrez Negrín and Lippmann, 2016)	Full reinjection (Hernández et al., 2015). Brine & condensate injection started in 1983 (Diaz et al., 2016). Two production zones are located at the North and South of the fields, while reinjection wells are located on the west of each production site: 4 wells in the north (1 km distance from producing area) and 2 in the south (about 800 m distance from producing area) (Arellano et al., 2015b). One reinjection well in the south has greater depth than production wells. The north reinjection zone has the largest amount of brine injected (Diaz et al., 2016). The separated water is cooled in ponds prior to being reinjected by gravity and at atmospheric conditions of 40 °C (Gutiérrez Negrín and Lippmann, 2016,Diaz et al., 2016). Old production well was assessed to be place infield in the NE field to stop pressure decline. Acid treatment, performed in injectors, raise injectivity rates (Diaz et al., 2016).	There has been a chemical and thermal breakthrough, especially in the southern part, which was linked with the distance between production and injection. In the south zone, the injection return as a liquid or steam. Some wells might be constant and intermittent in other wells. In contrast, wells in the north zone produce steam or condensed steam from the boiling of reinjection fluids began to produce in an intermittent way after 2005 (Arellano et al., 2015b). Between 2000-2005 one reinjection well in the southern field triggered a drop in the temperature and enthalpy of the reservoir, thus changing in production fluid phase from vapour to 2-phase. Thus, few actions were taken. In 2004, injection rate in the south was lowered, and enthalpy inclined. And in 2005, reinjection operation in the south was relocated further, which turned production fluid into a vapour dominated fluid again (Diaz et al., 2016).	Another study in a deeper well revealed that due to good vertical permeability, thermal interference may have been prevented as injectates boil enough at depth generating steam up-flow (Diaz et al., 2016). Infield reinjection trials performed in the northeast of the field resulted in good hydraulic connection with nearby producers, possibly through geological faults (Diaz et al., 2016). Seismic events recorded nearby reinjection (Diaz et al., 2016).

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Mexico	Los Humeros	Los Humeros I & II	1990 (Akar et al., 2018)	94 (Romo-jones et al., 2016)	68.6 (Romo-jones et al., 2016)	> 300 (Luviano et al., 2015)	2600 (Luviano et al., 2015)	670 in 2012 (Gutiérrez Negrín and Lippmann, 2016)	33 in 2014 (Gutiérrez Negrín and Lippmann, 2016)	Partial reinjection (Arellano et al., 2015a). Two main reinjection wells located in the north-central part of the field (infield) (Arellano et al., 2015a). Even though the injection wells are in the center of the field, a map of the temperature distribution in the north showed that the main development area in that zone is allocated around a high-temperature gradient area, with the reinjection wells at the south rim of less hot zones. From 1999-2004, different injection rates adopted for injection wells, but in 2005, both rates became the same (Diaz et al., 2016).	Tracer test suggest that most of the injected fluid, perhaps flows to the deep reservoir, recharging the energy (Iglesias et al., 2015). Tracer in One reinjection well in the southern area indicates that there is a negligible risk of thermal interferences in the surrounding prod well (Iglesias et al., 2015). Reinjection return as a liquid phase might be found in some well in the northern part (based on the isotope data) although it is not clearly identified. However, the production of steam or condensed steam from boiling of reinjected fluid was identified to occur in several production wells (Arellano et al., 2015a). Fluid injection is related to the generation of seismicity and aligned with the increase of injection rate (Urban and Lermo, 2017).	Thermal fracturing was successfully implemented in several wells which improve permeability characteristics of the wells (Luviano et al., 2015).
New Zealand	Mokai	Mokai I, Mokai II & Mokai IA/III	1999 (DiPippo, 2016)	111 (DiPippo, 2016)	110 (Soengkono, 2014)	326 (Diaz et al., 2016)	1525 (Diaz et al., 2016)	1335 (Buscarlet et al., 2017)		Currently, full reinjection located in the outflow sectors (edgefield, about 1.5 km or more of separation between injection and production zone) at North and NW of the field (Bromley et al., 2015; Diaz et al., 2016). Historically, reinjection was initially shallow to the northwest while production in the south. Deep reinjection began in 2008 to prevent the increase of fluid flow in the surface (Sherburn et al., 2015). The	Subsidence near one reinjection well between 1999–2005 when shallow injection was performed, probably by contraction of rock due to cool injection (20 mm/year) (Bromley et al., 2015). Shallow injection also led to gravity-driven flow in the same area, replacing 2-phase fluid by colder water in the shallow part. Increased pressure rates in the reinjection zone (Diaz et al., 2016). Moving to peripheral deep reinjection has caused a decline of the flow rate and pressure in the shallow aquifer, thus diminished cooling effects	Timing of micro-seismicity coincident with the start of deep reinjection (Sherburn et al., 2015).

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										injected water is 100 °C cooler than formation (Bromley et al., 2015).	due to shallow aquifers (Bromley et al., 2015).	
New Zealand	Rotokawa	Nga Awa Purua	2010 (DiPippo, 2016)	140 (DiPippo, 2016)	138 (Hoepfinger et al., 2015)	>330 (Clearwater et al., 2016)	1560 (Hoepfinger et al., 2015)	2083 (Addison et al., 2017)	1380 (Addison et al., 2017)	Full reinjection (Addison et al., 2017). At first, the deep brine injection was into 2 wells in the southern part with the intention to use central field fault as a natural barrier (Addison et al., 2017). Then, in late 2010, 60% of total reinjection was transferred from the south of DZR2 to the northern part (Diaz et al., 2016). Since early 2011-2015, the deep brine injection was moved to the south-eastern part, although before mid-2013, condensate was injected into both shallow wells and deep southeast well. This strategy is to minimise the risk of cooling in the west area (Addison et al., 2017). In 2015, it was decided to use 3 wells to spread injection and to attempt to move as much injection into the deep geothermal system, but one well was injected with half of its capacity to reduce the risk of cooling in the western area. The minimum distance between reinjection well and production well is 1.5 km. No condensate is injected into deep well (Addison et al., 2017).	A pressure response was observed in the monitoring wells on the west side, indicating a potential permeable connection between one injector and the western part of the reservoir. So the injection was moved to the southern part to minimise cooling (Addison et al., 2017). To date, neither the central and northern wells have shown any indication of cooling. Transient test results indicated that injection fluid was able to dissipate quickly and outflow to the lower compartment, or the other possibility is that the Central Field fault (CFF) prohibits injectate to return to the production area (Addison et al., 2017). The pressure in the deep reservoir has been stable after an initial fast decrease (Addison et al., 2017). Since 2012, the injection capacity has reduced to the original value before stimulation (can be caused by a change of injection temperature, increase of pressure, and silica) (Hernandez et al., 2015). MEQ events recorded near the injection well (at the same depth of the permeability zone in the injection wells) (Sewell et al., 2015).	In 2010, the capacity of injection wells increased, likely due to thermal stimulation (injecting with a temperature difference >150 °C), allowing the full reinjection of NAP brine into just one well (Addison et al., 2017). NAP injects the high silica amount with using sulfuric acid. However, no sulphate return to production is seen, indicating anhydrite formation within the reservoir (Winick et al., 2016).

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New Zealand	Rotokawa	Rotokawa	1997 (DiPippo, 2016)	34 (DiPippo, 2016)	34 (Addison et al., 2017)	>330 (Clearwater et al., 2016)	Initial 1,550 (Diaz et al., 2016) Current 1,340 – 1870 (Hoepfinger et al., 2015)	625 (Addison et al., 2017)	287 (Hernandez et al., 2015)	Currently, Most of the brine is injected through well in SE peripheral area, targeting deeper than production zone, while condensate and the rest of injection are going to shallow intermediate aquifer (Addison et al., 2017). Previously, shallow reinjection was imposed in center of infield (<1000 m). In 2005, reinjection was moved to a deep zone in the SW of the reservoir to control the pressure build-up in the shallow aquifer. In 2008 the reinjection wells were diverted to the SE of the reservoir to lessen the chemical breakthrough. In late 2010, 60% of total reinjection was transferred from the south to the northern part (Diaz et al., 2016).	The pressure in the deep reservoir has been stable after the initial fast decrease. The western area has been affected in regards to pressure response but no major indication of cooling in 2013–2015 (Addison et al., 2017). To date, neither the central and northern wells have shown any indication of cooling (Addison et al., 2017). MEQ events recorded near the injection well (at the same depth of permeability zone in the injection wells) (Sewell et al., 2015). Between 2003 – 2005, chemical breakthrough and gravity changes in shallow thermal aquifer were occurred because of shallow reinjection (Diaz et al., 2016).	Transient test results indicated that injection fluid was able to dissipate quickly and outflow to the lower compartment. The other possibility is that the Central Field fault (CFF) prohibits injectate to return to the production area (hydrological advantage) (Addison et al., 2017).
Papua New Guinea	Lihir	Lihir	2003 (Akar et al., 2018)	56 (DiPippo, 2016)	50 (Bertani, 2016)	>300 (Kuna and Zehner, 2015)	2250 (Diaz et al., 2016)	830 for 36 MW (Diaz et al., 2016)		Infield reinjection at the same depth as the production zone. Recently two outfield wells were drilled for reinjection, but permeability was not favourable for injecting (Diaz et al., 2016).	No records found	Production of high salinity water (possibly coming from seawater). Problems with anhydrite scaling (Diaz et al., 2016).
Philippines	Luzon	Bacon-Manito (BacMan)	1993 (Akar et al., 2018)	131.5 (DiPippo, 2016)		260-280 (Diaz et al., 2016)	Initial 1990 (Diaz et al., 2016) Current Palayan = 1400 – 1600 Cawayan = 1300 Botong = 1900 (Espartinez and See, 2015)	2917 In 2012 (Espartinez and See, 2015)	1,944 In 2012 (Espartinez and See, 2015)	Currently, there are two infield injection (Pads RA and pads RC/RD) and outfield injection (Pad RE) sinks in Palayan Bayan, while one infield injection sink is located in the Cawayan sector to accommodate the separate brine (Espartinez and See, 2015). Before,	Injection breakthrough in the northern Palayan Bayan sector from infield injection (the temperature started to decline). Therefore, it was decided to transfer 360 kg/s brine to outfield injection (current strategy) and balance reinjection was accommodated. In the Cawayan sector, the enthalpy is stable,	1 new area (Tanawon) has 1 reinjection well via cold reinjection system. This is located near Cawayan area (Espartinez and See, 2015).

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										reinjection was performed outfield (2 km from production zone) in 3 different parts.	suggesting that infield reinjection is providing mass recharge and pressure support that is still beneficial for the exploitation (Espartinez and See, 2015).	
Philippines	Leyte	Leyte (Tongonan)	1977 (Akar et al., 2018)	523.18 (DiPippo, 2016)		290-310 (Diaz et al., 2016)	Initial 1750 (Diaz et al., 2016)	5,417 In 2013 (Uribe et al., 2015)	2083 In 2013 (Uribe et al., 2015)	There are 3 injection zones: 2 outfield (2 km south and NW of the main production area) and the other infield (700 m to production) (Uribe et al., 2015,Diaz et al., 2016). Historically, from 1983-1996, just 50% of total extraction was injected, first infield and later on the outfield. From 1996-1997, the extraction increased, and the percentage of injection dropped to 40%. Increases and declines of rates have occurred (partial injection) since 1997.	from 1983 to 1996, reinjection caused pressure support, chemical breakthrough and injection returns. From 1996–1997, (commissioning of new plants) brine injection maintained discharge enthalpy of production wells in the south region. In 2001, the centre of the fields experienced injection returns. Chemical fronts and enthalpy decreased after increasing the injection rate in the zone. When reinjection was moved further away, production started to recover. In 2003, condensates in the north leaked into some production zones, action partially contained by a high-pressure barrier formed by the brine injection zone between condensates-injection and production areas. Eventually, brine leaked into production as well and an optimization of injection rates helped to recover the production. In the south, brine injection returns from infield injection were observed in producers closest to the injection wells (Diaz et al., 2016; Omagbon et al., 2016). In general, reinjection has stabilized the decrease in enthalpies and outputs by giving pressure support to the system, minimising the	.

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
											invasion of cooler ground fluids coming from the NE. On the other hand, injection has contributed to the gradual decline in steam supply from 2000-2005 at certain levels (Uribe et al., 2015).	
Philippines	Sto Tomas	Maibarara	2014 (Akar et al., 2018)	20 (DiPippo, 2016)	20 (Maturgo et al., 2015)	300 – 320 (Maturgo et al., 2015)	1600 (Diaz et al., 2016) Current 1500 – 2300 (Maturgo et al., 2015)			In total, 3 injection wells are used: 2 wells to inject brine (mai-9D and mai-11D), while another well (MB-14RD) is to inject effluent or condensate from power plants. The closest distance between production and injection well is around 500 meters. All depths of reinjection wells are still the same level with production zones. The initial scheme of the reinjection system is to use mai-9D and mai-11d as hot reinjection wells. For the first period, the wells accepted the hot brine, but the reinjection capacities were continuously declining with time. Then, the strategy changed to use a thermal pond to let it cool to 40 °C before it was reinjected into two wells. The dilution of freshwater also helps to minimise the amount of silica (Maturgo et al., 2015).	The reinjection capacity decreased for two reinjection wells during hot brine injection. After changing to use cooler brine, the cold reinjection system is operationally effective. There is no information regarding thermal or chemical breakthrough at the moment (Maturgo et al., 2015).	One injection well was originally a producer well during field operations before it was converted to an injector well to accommodate the combined brine flow that gradually increased over time (Maturgo et al., 2015)
Philippines	Laguna	Makiling-Banahaw (Mak-Ban)	1979 (Akar et al., 2018)	458.53 (DiPippo, 2016)	240 (Sunio et al., 2015)	337 (Diaz et al., 2016)	1990 (Diaz et al., 2016)	6901 for 425.73 MWe (Diaz et al., 2016)	2,812 for 425.73 MWe (Diaz et al., 2016)	Between 1979–1987, brine injection was focused on edgefield sites in the east and west. In 1987, the injection was diverted 2−3 km west of the production area due to thermal front experience.	in 1987, thermal breakthrough experienced from edgefield injection wells, thus outfield injection was included later. Injection rate control and outfield injection has solved the thermal front issue and allowed temperature	The confluence of several faults in the middle of the geothermal system coincides with the central up-flow.

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
											recovery. Edgefield hot reinjection has experienced an injection breakthrough. Brine has contributed to produce fluids. Also, the reservoir has been affected by injectate, with a decrease in average steam flashed. Tracer tests have shown that sufficient heating of injected fluids could be occurring (Diaz et al., 2016).	
Philippines	Mindanao	Mt. Apo/ Mindanao	1996 (Akar et al., 2018)	108.48 (DiPippo, 2016)		300 (Diaz et al., 2016)	1513 (Diaz et al., 2016)	2285 (Diaz et al., 2016)		10 reinjection wells are available: 2 infield east of the field (brine injection), 6 at <2 km NW of main production zone (hot brine), and 2 at 2 km west of the production zone (cold condensates). From 1997–2009, 65% of the mass extracted has been injected back to the reservoir. Shallow injection wells have been drilled to minimise brine returns. Location of one injection well in the NW has been re-evaluated, since it has affected production, despite its distant location from the producers (hydrological communication through faults) (Diaz et al., 2016).	In 1998 reinjection returns and enthalpy declines were noted. In 1999, chemical changes were experienced. The reduction of injection loads has alleviated the persistent progress of injection returns. In 2009, a balance between mass extraction and mass injection was noted. Returns and chemical fronts are still seen in the centre of production due to injection, especially from the NW and west zones. Infield injection has prevented natural recharge from the hot reservoir in the SE to the centre of the production field (Diaz et al., 2016).	
Russia	Mutnovsk/ Mutnovskaya	Verkhne-Mutnovskaya/ Verkhne-Mutnovsky	2002 (Akar et al., 2018)	12 (Svalova and Povarov, 2015)	12 (Svalova and Povarov, 2015)	250 – 300 (Kolesnikov et al., 2015)	1600 (Diaz et al., 2016)	374.4 in 2004 (Diaz et al., 2016)		Full reinjection (Diaz et al., 2016). Reinjection wells located in the production zone (infield) (Kiryukhin et al., 2015)		
Russia	Mutnovsky /Mutnovskaya	Mutnovskaya/ Mutnovsky	1998 (Akar et al., 2018)	50 (Svalova and Povarov, 2015)	50 (Svalova and Povarov, 2015)	250 – 300 (Kolesnikov et al., 2015)	1600 (Diaz et al., 2016)	885.6 in 2004 for 36 MWe produced	811 in 2005 for 62 MWe	Partial infield reinjection. Reinjection is performed in the	While reinjection has caused changes in the reservoir pressure, there is an absence of significant	in 2010 poorly cemented, abandoned wells might have

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								(Diaz et al., 2016)	(Diaz et al., 2016)	northern part of the production site at a minimum distance of 1.2 km (Kiryukhin et al., 2015).	injection returns to productive wells (Diaz et al., 2016). Ground deformation experienced in the injection zone: positive deformation from 2006-2008, and negative from 2009-2010. Ground deformation could be correlated with injection rates increasing from 2006-2008, and decreasing from 2009-2010 (Kiryukhin et al., 2015).	conducted infiltration of meteoric water into the reservoir, cooling production zones resulting in a negative impact on production (Diaz et al., 2016).
USA	Coso	Navy I & II and BLM	1987 (Akar et al., 2018)	302 (California Energy Commission, 2018)	153 (California Energy Commission, 2018)	200 – 328 (Eneva et al., 2018)	840-2800 (Diaz et al., 2016)	2383 (Eneva et al., 2018)	1276 (Eneva et al., 2018)	Full injection with additional water since 2009 (Eneva et al., 2018). Infield and edgefield injection in the east flank of production with a distance of approximately 700 – 1500 m. Injection and production depths are similar (Kaven et al., 2014). For the first 22 years, injection was limited to indigenous sources (brine and condensate), so power generation started to decline. The addition of water pumped by March 2008 represents close to 20% of the total injection (Buck, 2016).	Seismicity induced by injection (Trugman et al., 2016). Reinjection with brine and condensate only resulted in the injection rates to reduce overtime, hence, to make generation decline. Adding additional water prevents it from further significant decline (Buck, 2016). Increased steam flow rate along with a subsequent decline in NCG was noticed shortly after the conversion of a producer to injector (Buck, 2016). Tracer returns were recorded in production wells at the east flank. A decrease in injection rates after 5 to 7 years of service was due to mineral deposition in fractures surrounding the wells (Diaz et al., 2016). Reinjected NCG's broke through several production wells, causing the power generation level to decline due to an increase in the gas content of the production steam. NCG injection was stopped, and abatement systems were installed (Kolar et al., 2015).	Shallow magma chamber at a depth of 5–8 km. Now, supercritical fluid project was held in western flank area of the field (Stimac et al., 2017)
USA	Salton Sea	Salton Sea, Vulcan, A. W. Hoch, J. J.	1982 (Akar	403.4 (California Energy	369 (California Energy	302-315 (Diaz et al., 2016)		12,945 for 350MWe	10,353 for 350MWe	Since 1989, injection has been about 80 % of brine produced (	Ground deformation was observed around production and injection	The brine is hypersaline which contains nearly

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		Elmore, J.M Leathers & Hudson Ranch, CE Turbo	et al., 2018)	Commission, 2018)	Commission, 2018)			(Diaz et al., 2016)	(Diaz et al., 2016)	Barbour et al., 2016). Some injection wells are close to production wells. A high volume of solid deposition occurred but it was mitigated by changing brine pH or extracting solids prior to injection (Diaz et al., 2016).	wells (Diaz et al., 2016). Seismicity, induced by injection, has increased the pore pressure (decrease effective stress). Seismicity rates show apparent sensitivity to changes in the rate of injection and production (Crandall-Bear et al., 2018).	every element in the periodic table (Diaz et al., 2016). Injection and production are performed at similar depths (Diaz et al., 2016).

Appendix C. Two-phase, liquid dominated, medium-enthalpy systems (ME-LDS)

Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
El Salvador	Berlin	Berlin	1992 (Escobar, 2018)	109 (Escobar, 2018)	100 (Escobar, 2018)	>300 (Diaz et al., 2016)	1300 (Diaz et al., 2016)	3132 (Monterrosa and Montalvo López, 2010)	2340 (Monterrosa and Montalvo López, 2010)	Full reinjection. Shallow/ intermediate reinjection for condensates is performed either at the centre and NW of field, or peripheral part. Deep reinjection for brine at depth > 2 km. The number of injection wells is high due to the low/med permeability of the reservoir. Use inhibitor to reduce scaling (Mayorga and L.S.A.D.C., 2012).	Scaling or mineral deposition in the reservoir (Portier et al., 2010). Also, wastewater from binary plants increased the potential for scaling. Signs of chemical breakthrough and cooling effects due to reinjection in central part of the field (Diaz et al., 2016). Seismicity recorded during high injection rates of reinjection wells in NE area (Kwiatek et al., 2014)	Reinjection has been started since the first operation (Mayorga and L.S.A. D.C., 2012). Reinjection wells at the NW and centre of field (infield) (Diaz et al., 2016).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Ethiopia	Aluto-Langano	Aluto-Langano	1998 (DiPippo, 2016)	8.5 (DiPippo, 2016)	8.5 (DiPippo, 2016)	>300 (Gherardi et al., 2014)	1397 (Diaz et al., 2016)			Reinjection well is located 1−2 km away from producers (Gherardi et al., 2014).	No information recorded	One reinjection well in the west side of the field (Gherardi et al., 2014)
Guatemala	Amatitlan	Ortitlan	1997 (DiPippo, 2016)	20 (DiPippo, 2016)	20 (Diaz et al., 2016)	285 (Asturias, 2012)	1300 (Diaz et al., 2016)	340 (Asturias, 2012)		Full reinjection in binary plant (Asturias, 2012). Infield reinjection (Diaz et al., 2016)	No records found	
Iceland	Reykjanes	Reykjanes	1983 (Akar et al., 2018)	100 (EGEC, 2019)	100 (Matthiasdottir et al., 2015)	270 – 310 (Oskarsson et al., 2015)	1290 (Diaz et al., 2016)	1872 (Matthiasdottir et al., 2015)	504 (Matthiasdottir et al., 2015)	Partial reinjection (Diaz et al., 2016). The rest of the water is dumped into the sea at 57 °C. Inject to one well (located within 800 m from production zone) as a mitigation against drawdown (Matthiasdottir et al., 2015).	Chemical breakthrough in some wells. Some wells which are located at 250 m within an injection well seem to experience cooling (Oskarsson et al., 2015). Injection could have limited support to the deeper reservoir in the western part of the system, and moderate support for the shallower feed zones could be achieved as it leaves at moderate depth (based on tracer tests) (Matthiasdottir et al., 2015).	Seawater in the reservoir fluid. (Axelsson et al., 2015).
Indonesia	Sarulla	Sarulla	2017 (Adi et al., 2018)	330 (Adi et al., 2018)		275 – 310 (Wolf and Gabbay, 2015)				Full reinjection (Wolf and Gabbay, 2015).	No records found	No records found
Indonesia	Sibayak	Sibayak	1996 (Akar et al., 2018)	11.3 (Adi et al., 2018)		240 – 275 (Mohammadzadeh Bina et al., 2018)	Initial 1150 (Diaz et al., 2016) current 1100 (Sinaga and Manik, 2018)	44.7 of steam for 6.875 MWe (Diaz et al., 2016)	286 of brine in 2011 (Diaz et al., 2016)	Reinjection wells are about one km away from production wells and close to faults. The temperature for injection of separated brine from the 10 MW plant was 162 °C in SBY-7 and SBY-10. 100 % of brine is reinjected (Diaz et al., 2016).	Reinjection experience from the 2MWe plant around 1997 resulted in silica deposition in reinjection wellbores and pipes, (due to the low temperature of injected water (98 °C)) (Diaz et al., 2016).	
Indonesia	Ulubelu	Ulubelu	2011 (Akar et al., 2018)	220 (Adi et al., 2018)		265 (Pambudi, 2018)	1160 (Pambudi, 2018)	1163 of steam in 2017 (Adi et al., 2018)	2800 (Yuniar et al., 2015) (Agani et al., 2015)	5 injection wells (4 hot reinjection wells and 1 cold reinjection well for condensate) (Yuniar et al., 2015) are located 1.5-2Km from the nearest production wells in southern part (Diaz	Temperature decline may link to thermal breakthrough in the reservoir (Yuniar et al., 2015). Chemical breakthrough was also observed by initial chemical monitoring in one production	6 reinjection wells are prepared to accommodate relocation clusters for units 3 and 4 (new units). The current reinjection is planned to be moved further to the south (Siahaan

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										et al., 2016) and intersect 2 faults (Trianggo et al., 2015). Injection wells are at a lower elevation than production wells (shallow feed zone) (Diaz et al., 2016). The strategy is to inject as far as possible, but still be within the reservoir boundary, yet the current cluster is still near-production zone (Yuniar et al., 2015).	cluster/area that is near the reinjection cluster (Giriarso et al., 2015)	et al., 2015). Some injection clusters use gravity injection (Mubarok and Zarrouk, 2016).
Japan	Ogiri	Ogiri	1996 (DiPippo, 2016)	30 (DiPippo, 2016)	25.85 in 2014 (Yasukawa and Sasada, 2015)	50-130 (shallow reservoir)/ 230 (deeper reservoir) (Diaz et al., 2016)	1209 (Diaz et al., 2016)	1210 (Fukuda et al., 2015)	958 (Fukuda et al., 2015)	Full infield reinjection (around 79.5 % of production) ~0.8–1 km of the production area (Diaz et al., 2016). Reinjection wells are in the western part of the field whereas production wells are in the eastern part (Nishijima et al., 2016). The reinjection operation takes advantage of topography for gravitational flow since reinjection wells are at a lower elevation than production wells (Takayama et al., 2014).	Quick reinjection returns as production wells located relatively adjacent to reinjection zones (same fault) showed a high ratio of reinjected water to produced fluid (Hirayama et al., 2015; Takayama et al., 2014). Three reinjection wells significantly affected production with temperature drop (Diaz et al., 2016). From 1997 to 1999, the reinjection wells with higher connectivity with production wells were used to recover the pressure in the system. However, this affected the steam production by a thermal front (Diaz et al., 2016).	
Japan	Otake-Hatchobaru	Hatchobaru	1977 (DiPippo, 2016)	112 (DiPippo, 2016)	77.12 (Yasukawa and Sasada, 2015)	250 – 290 (Mia et al., 2018)	initial 1,125 (Kaya et al., 2015) current 1164 (Jalilinasrabady and Itoi, 2015)	2520 for 110 MW (Diaz et al., 2016)	1800 for 110 MW (Diaz et al., 2016)	Since 1982, reinjection and production wells were arranged in a "side by side" configuration (reinjection in the northwest and production in the southeast). Reinjection and	The pressure difference that drives the fluid flow in the reservoir from SE to NW is disturbed when production reduces the pressure NW, while the injection increases the pressure in the SE, allowing	

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										production are at the same depth, since it was unable to find another permeable level for the injection. The minimum distance between reinjection and production wells was 140 m underground. In 1992, reinjection wells were moved 500 m from the nearest production well. Recently, reinjection takes place as far to the north as feasible to avoid interference with production wells. Reinjection wells are in the outflow zone of the reservoir. Separated water and excess condensate are injected into the reservoir at about 90 °C and at atmospheric pressure. About one-third of the waste brine from the field has for many years been sent via pipeline to the Otake field to be reinjected there. There is a settling pond at the reinjection line to mitigate the problem of silica scaling due to supersaturated brine with amorphous silica (Diaz et al., 2016).	cold injectate to find its way back into production zone causing the demise of some previously excellent production wells (e.g. H-4). The rapid return of cool water was through the fault system. Chemical fronts were also experienced. Relocation of wells further out allowed recovery of the production. Loss of injectivity issues due to silica deposition were successfully reduced by pH modification of brine. From 1992–2002 water level rose in injection site reducing injectivity, therefore, side-tracked wells targeted deeper zones along a fault, resulting in a decline of water level.	
Japan	Sumikawa-Onuma	Sumikawa	1995 (DiPippo, 2016)	50 (DiPippo, 2016)	34.24 (Yasukawa and Sasada, 2015)	200 (Diaz et al., 2016)	Initial 1600 (Diaz et al., 2016) Current 1,309 (Jalilinasrabady and Itoi, 2015)	878 (Diaz et al., 2016)		Currently, Reinjection has been moved to outfield (Kondo et al., 2017), and into deeper formations to promote convection (Diaz et al., 2016). Injection rates are varied to disrate thermal fronts. Initially, infield	Earlier Infield strategy Increase of gravity due to reinjection. In 1995–2000, injectivity decreased due to scaling, hence, a mix of brine a condensate was pumped to recover the injectivity (Diaz et al., 2016). Steam decline	Reinjection wells are side-tracked to act against scaling rocks (Diaz et al., 2016). Silica problem is now being investigated and treated with inhibitor (Ikeda and Ueda, 2017).

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										injection of brine (140 °C) and condensates are located at the north of the field (low temperature and low permeability). Condensate reinjection wells are around 400-1000 m away from production, while hot brine reinjection is within 500 m of production zones. New reinjection wells had to be drilled due to the increase of water separated compared to the steam production over the years, plus the decrease of injection capacity (Diaz et al., 2016).	occurred due to thermal and chemical breakthrough (chemical breakthrough varies over seasons). The closest production well to condensate reinjection wells experienced a fast return of injected fluid (Diaz et al., 2016).	
Japan	Yamagawa	Yamagawa/ Yamakawa	1995 (Akar et al., 2018)	30 (DiPippo, 2016)	12.1 in 2016 (Wulaningsih et al., 2017)	>350 in some wells (Diaz et al., 2016)	Initial 1870 (Diaz et al., 2016) Current 1,204 (Jalilinasrabady and Itoi, 2015)		350 in 2000 (Diaz et al., 2016)	The reinjection area is located east of the production area (infield) at a minimum distance of 200 m from the production zone. Reinjection zone is in a lesser hot zone than the production area (west area/opposite area). Reinjection zone is linked with lost circulation zones associated with faults. The separated hot water is divided into hot-water lines (neutral and acidic lines) and reinjected at 180 °C to prevent silica scale (Diaz et al., 2016).	Reinjection caused chemical breakthrough of chloride contents in the shallow reservoir. There is an injection capacity problem in reinjection wells is because of silica scale precipitation of. In 2005, a return of reinjected hot water was seen in several production wells (Diaz et al., 2016).	Permeable zones by natural and drilling-induced fractures are used as the main reinjection zones (Diaz et al., 2016).
Kenya	Eburru	Eburru	2012 (Akar et al., 2018)	2.5 (DiPippo, 2016)		300 (Mangi, 2017)				No records found.	No records found.	Kenya now planning an expansion that would bring the total installed capacity of the plant to 25 MW over the next few years

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
												(ThinkGeoEnergy, 2016).
Kenya	Olkaria	Olkaria III (West)	2000 (Akar et al., 2018)	150 (DiPippo, 2016)	134 (Ouma et al., 2016)	Up to 262 (Diaz et al., 2016)	1355 (Diaz et al., 2016) Current 1,354 (Ouma et al., 2016)	400-500 in 2010 for 48 MW (Diaz et al., 2016)	380-475 in 2010 for 48 MW (Diaz et al., 2016)	Full infield injection at 1–1.25 km south, west and SE of production. Condensates from Olkaria II are injected 3 km NE of Olkaria III field (Diaz et al., 2016).	In 2009, tracer tests indicated direct hydrological connection of injection well ORP-B1 to two production wells. It was concluded that injection in ORP-B1 should eventually terminate and be transferred to a more southerly location. Results also determined that reinjection water moves towards the south of the field, out of the production sector. No negative effects have been reported for the cold reinjection in OW-204 and OW-201 (Diaz et al., 2016).	The eastern and western halves of Olkaria field are divided by a permeable N–S feature, the Ololbult fault (Diaz et al., 2016).
Mexico	Domo de San Pedro	Domo de San Pedro	2016 (Romo-jones et al., 2016)	35.5 (Romo-jones et al., 2016)	25.5 (Romo-jones et al., 2016)	280 (Gutiérrez Negrín and Lippmann, 2016)				No records found.	No records found.	
Mexico	Las Tres Virgenes	Las Tres Virgenes	2002 (Romo-jones et al., 2016)	10 (Romo-jones et al., 2016)	10 (Romo-jones et al., 2016)	274 (Diaz et al., 2016)	1203 (Diaz et al., 2016)	95 of steam (Lopez and Torres-Rodriguez, 2015)	273 (Lopez and Torres-Rodriguez, 2015)	Currently, all brine and condensed steam are reinjected back to the reservoir through one injection well which is located south of the field. (approximately 1.8 km) (Lopez and Torres-Rodriguez, 2015). Initially, reinjection wells are located north (LV-02 former production well), NE (LV-08) and east (LV-07) of the production zone, with a minimum distance of 1.8 km to the nearest production well. All the injection wells are adjacent to geological	Few seismic events recorded along faults that are close to an injection well (Antayhua-Vera et al., 2015). There is a reduction in injection capacity due to scaling issues. A pH control to the brine has reduced this issue (Lopez and Torres-Rodriguez, 2015).	

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										faults (Diaz et al., 2016).		
New Zealand	Kawerau	TG1, TG2, Tasman BP, KA24, Kawerau and TOPP1	1961 (Akar et al., 2018)	142.2 (DiPippo, 2016)	140 (Buscarlet et al., 2017)	Up to 315 (Diaz et al., 2016)	1280 (Diaz et al., 2016)	4371 (Buscarlet et al., 2017)	2577 (Buscarlet et al., 2017)	Partial reinjection (Milicich et al., 2016), about 75% of all the fluid produced into the reservoir (Askari et al., 2015). Historically, infield reinjection started at a shallow depth (150 - 300 m) in 1992 to mitigate the effects of cooling and dilution in early production wells. By 2008, after KGL plant commissioned, the development a deep peripheral (northeast) reinjection strategy was adopted to prevent the overloading of the shallow aquifer while also in hoping to provide pressure support: (Distance: 1 km limitation. Reinjection pads located NE < 1.5Km from production zone) (Sherburn et al., 2015). The injection strategy has been iteratively revised, such as adjusting the injection flow rate and stimulating the wells by switching the condensate injection (Askari et al., 2015). In 2013, three new deep reinjection wells were completed and located outside the boundary (Clark et al., 2015). The brine temperature is 190 °C while condensate is 40 °C. Shallow reinjection temperature is 161 - 176 °C while deep reinjection temperature is 115 –	Deep injection provides Pressure support (Milicich et al., 2016). Prior to 2008, There were small changes of shallow aquifer chemistries by shallow reinjection (Milicich et al., 2016). After 2008 (deep reinjection), apparent responses from the deep injection can be seen in the production wells, with injection returns observed in both NTGA and MRP production wells, but no or little injection return in the south area. However, these returns have not significantly impacted the enthalpies of the production wells. It is suggested that there is sufficient time for the injection fluids to be reheated before reaching the production area (Lawson et al., 2016). The north eastern of the field seems to have a finite conductive fracture network; the transmissivity of this type of fracture network tends to reduce from over injection and/or mineral deposition (Lawson et al., 2016). Silica precipitation at Kawerau has been a concern since the design phase. Silica scaling clogs in wells (Lawson et al., 2016).	Partial reinjection in powerplant TG1, TG2 and TOPP1, while Full reinjection in Kawerau plant in deep wells (Diaz et al., 2016). Tracer testing and reservoir analysis have shown that vector distance (total distance in a straight line between feed zones) is the main factor controlling fluid return times in greywacke. This indicates that there is little additional benefit drilling deeper so long as the vector distance is enough (Lawson et al., 2016). Te Ahi o Maui 25 MW Binary power plant will be estimated to be commissioned at the end of 2018 (in the western side of Kawerau field) with supply from 3 production wells and 2 injection wells (White and Clotworthy, 2018). The retention pond is used when the modified pH level of the separated geothermal water is not adequate for reinjection. This allows the silica to precipitate before reinjecting (Diaz et al., 2016).

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										120 °C (Milicich et al., 2016). Acidising to control silica polymerization (Lawson et al., 2016). The tracer suggests that the north-eastern area is unfavourable for future injection. The more western has the potential for future make-up injection well. The next well target is in outflow and reach deeper in greywacke basement to give sufficient vector distance between feed zones to minimise risk of cooling (Askari et al., 2015).		
New Zealand	Ngatamariki	Ngatamariki	2013 (DiPippo, 2016)	82 (DiPippo, 2016)	82 (Quinao et al., 2017)	275 – 290 (Quinao et al., 2017)	1450 (Diaz et al., 2016)	1726 in 2014 (Buscarlet et al., 2015)		Full reinjection in deep wells located in the northern and southern part boundary of reservoir (1.25–2 km) from the production wells (Clearwater et al., 2015). Injection was split 60% to the northern area and 40% to the southern area (Buscarlet et al., 2015).	Injection return was observed, but until now, there is no decrease in downhole reservoir temperature (Buscarlet et al., 2016). The presence of anhydrite scales in monitoring well located in halfway along the pathway of reinjection and production well, provides additional evidence of the hypothesis of redeposition and mobilization (Buscarlet et al., 2016).	A key feature of the reservoir is a cool “intermediate aquifer” sitting above the deep reservoir and the localised permeability pathway between them known as “the leak”. Thus, the risk of cold water downflow because of pressure drawdown in the main reservoir was identified as an important development risk (Clearwater et al., 2015).
New Zealand	Ohaaki	Ohaaki	1988 (DiPippo, 2016)	46 (DiPippo, 2016)	40 (Van Campen and Archer, 2017)	>300 (Van Campen and Archer, 2017)	1150 (Diaz et al., 2016)	1004 for 40 MWe (Diaz et al., 2016)	525 for 40 MWe (Diaz et al., 2016)	Early production and reinjection were performed by using shallow infield strategy (500 m away from production), then goes to the deeper edge of resistivity boundary (Diaz et al., 2016). Relocation of injection to outfield of	By 1993, reinjection returns to production affected negatively by shallow reservoir (enthalpy decline), thus reinjection was moved to edge/out of resistivity boundary (Diaz et al., 2016). Rapid returns of the deeply-reinjected fluids into production	Now, 60–70 % reinjection, the rest vents through cooling towers (Sherburn et al., 2015).

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										resistivity boundary in 1993 (Sherburn et al., 2015).	wells. This caused adverse effects such as enthalpy decline. Therefore, reinjection moved into the shallower part again outside the boundary (Sherburn et al., 2015).	
Nicaragua	Momotombo	Momotombo	1983 (Akar et al., 2018)	77.5 (Akar et al., 2018)	22.5 (Kaspereit et al., 2016)	330 (Diaz et al., 2016)	1200 (Diaz et al., 2016)	1400 in 2009 (Diaz et al., 2016)	1200 in 2009 (Diaz et al., 2016)	7 reinjection wells mostly located in the eastern part of the field. 100 % of residual waters reinjected since 2002 (Kaspereit et al., 2016). Hot reinjection at 105 °C at <800 m from production. Eastside of the system is characterised by a constant pressure boundary with low formation temperature. Cold reinjection at 30 °C is located in the west of the field at 100-200 m from production (infield). The cold injection rate is lesser than the hot injection, as it is only used for managing overflow of brine from weir boxes (Diaz et al., 2016). Previously, partial reinjection of 12-30% from 1984-1997. Percentage of reinjection increased from 1997-2002. During partial reinjection periods temperature of injected fluid was 170 °C (Diaz et al., 2016).	Rapid injection breakthrough in the shallow and intermediate reservoir from east reinjection, which produced the decline of enthalpies from 1991 to 2003. It is assumed that fractures played an important role in this behaviour, together with the high permeability formation between the east and the production zone (west) (Diaz et al., 2016). Moreover, the depressurisation of the production field that allowed entry of cold water from the cold eastern part (Kaspereit et al., 2016). During the same period, the deep reservoir experienced injection breakthroughs but with less impact. Pressure support was experienced until 2006 due to changes in the reinjection strategy in 2002 (Diaz et al., 2016).	Simulation shows further optimization could be achieved with strategic deep injection (mostly below the bottom producing zones in the deeper reservoir). It also can move two shallow injectors well inside the ring structure to outside the ring structure to minimise thermal breakthrough (Kaspereit et al., 2016).
Nicaragua	San Jacinto-Tizante	San Jacinto-Tizante	2006 (Akar et al., 2018)	72 (Akar et al., 2018)	59 – 63 (Aráuz-torres et al., 2015)	260 – 300 (Malate et al., 2016)	1200 (Diaz et al., 2016)			Edgefield reinjection. 4 injection wells located in the north (1.5 km from production) and south sector of the field	Moderate Injection return in some wells from southern wells into one production wells based on tracer tests (Malate et al.,	Acid stimulation with mechanical workover was applied in 4 reinjection wells to recover lost injection capacity caused by

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										(<1.8 km from production zone). The production zone is in the centre. Reinjection wells in the north feature a second leg and has the highest capacity of injectivity (Diaz et al., 2016). Reinjection was started in 2005 with infield reinjection (400-500 m to production). In 2006, one infield injection became producer to increase production and part of the reinjection was sent south outfield at cold conditions (2.2 km). In mid-2006, cold reinjection in the south was switched to hot temperature. A few years later, all infield reinjection was ceased and sent 1.8 km south of production (Diaz et al., 2016).	2016). Cold reinjection experienced injection declines due to solid deposition (Diaz et al., 2016).	mineral (silica) deposition along the wellbore (Valle et al., 2016).
Philippines	Leyte/ Mahanagdong	Mahanagdong	1997 (Akar et al., 2018)	199.5 (Akar et al., 2018)		250 – 330 (Diaz et al., 2016)	1482 (Diaz et al., 2016)	4300 for 198 MWe (Diaz et al., 2016)	2900 for 198 MWe (Diaz et al., 2016)	100 % brine reinjection (Diaz et al., 2016). Currently, reinjection is located at edgefield at the south and the north of the field (both 1.5 km to production) (Daco-ag et al., 2015). Reinjection zones are characterized by high permeability. Separated brine is reinjected at 160 °C (Diaz et al., 2016). Initially, reinjection was performed in the west field (low permeability) (Diaz et al., 2016).	The development of the two-phase zone was slowed down by cooler groundwater and brine returns from northern and southern injection areas (Omagbon et al., 2016) (Daco-ag et al., 2015). In 1997, slight overpressure was observed in the northern injection area, while very minimal drawdown occurred in the southern injection area. In 1998, injection returns contributed to the decline of steam production as boiling	

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
											was minimized. In 1999, northern production experienced enthalpy and temperature drops due to reinjection. Thermal recovery was achieved in such wells after reducing injection rates and stopping injection in those wells closest to production. In 2010, brine returns from the southern and northern injection zones have contributed to the cooling of the reservoir, however, northern injection has not had a significant impact (Diaz et al., 2016).	
Philippines	Southern Negros	Palimpinon/ Palinpinon 1; Palimpinon/ Palinpinon 2 (Songonan and Nasuji)	1993 (Akar et al., 2018)	222.5 (Akar et al., 2018)		>320 (Diaz et al., 2016)	1450 (Diaz et al., 2016)	3500 for 192.5 MWe (Diaz et al., 2016)		For Pilinpinon II, injection was located infield in Nasuji sector (brine), whereas for Palinpinon I, reinjection located NE and West of the field performed 2Km away for their main production zones (Solis and Taboco, 2015). In 2011, 1 deep well TWD started to dispose cooling tower condensate (Torres and Aqui, 2015). From 1983-1989 infield (centre) injection. In 1983, injection was switched further away (1 km NE from production) to avoid injection breakthroughs. In 1997, injection in this zone was halted and sent further toward the current location. In 2007, former injection wells were converted into production wells.	In 2015, injection return was observed in five Nasuji (Palinpinon II) wells and all of the wells in the Sogongon sector, thus maintaining pressure drawdown. Even though a chemical breakthrough was observed, there is no indication of a thermal breakthrough yet. There is a need to drill new well further to the north of Nasuji, as the reinjection capacity is less than full load operation brine, and to avoid thermal breakthrough (Solis and Taboco, 2015). From 1980-1989, infield injection produced a substantial output decline, causing it to relocate injection. In 1989, critical pressure drawdown occurred	Pilinpinon III sector: Balasbalas, Nasuji, Sogongon, Nasulo (Solis and Taboco, 2015).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										The injection loads have been established to avoid adverse effects (Diaz et al., 2016).	due to injection relocation, but it also induced the recovery of the production wells. In 1997, the central zone experienced a significant mass flow decline in steam outputs and an increase of enthalpies after the second relocation of injection. West reinjection also affected the reservoir by temperature reduction, but the optimization of injection rates made some wells recovered. Chemical breakthrough has increased the pH of some wells. Reinjection of condensates in deep well TWD has increased fluid acceptance over time by the dissolution of quartz and opening of cracks (Diaz et al., 2016).	
Philippines	Tiwi	Tiwi	1979 (Akar et al., 2018)	234 (Akar et al., 2018)	140 (Calibugan et al., 2015b)	310 – 350 (Calibugan et al., 2015b)	1050 – 2800 (Diaz et al., 2016)	3297 (Calibugan et al., 2015a)	2289.6 (Sicad, 2015)	100 % brine injection and 100 % brine and condensate injection were achieved in 1993 & 2000 (Diaz et al., 2016). Currently, the southeast Hot Brine Injection System (SEHBIS) is the main disposal system for brine produced in the Nag and Kap areas (including both edgefield and outfield) (Sicad, 2015). The separate brine disposal system in west Tiwi is referred to as MatRidge Brine Disposal System (MRBDS) in the	Initially, there was a quick cooling observed, and even one producer ceased steam flow, due to a 22 °C-decrease in temperature (Diaz et al., 2016). Temperature and steam flow recovered after switching reinjection to outfield and no significant thermal breakthrough has been reported (Sicad, 2015). Limits in reinjection rates have contributed to the low negative reinjection impact (Diaz et al., 2016). Southeast	Currently in the SEHBIS area, aside from hook-up idle wells, another round of workover of injection well is being proposed to provide additional capacity in outfield wells and reduce utilization of edgefield wells. (Sicad, 2015).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										northwest part/outfield from Mat Bar brine (Calibugan et al., 2015a). Previously, MRBDS brine flowed into ponds before flowing by gravity to the injection wells (referred as "cold brine"). But some wells in the west have been changed from cold to hot reinjection, and injection rates are limited in certain wells until one injection well has been re-drilled to increase the injection rate. Right now, the ponds are not totally abandoned, but occasionally used for well start-ups or high-level upsets of separator (Sicad, 2015). Some of the brine is mixed with dry superheated well to be de-superheated (Sicad, 2015). Deep reinjection is one of the strategies used in Tiwi (Diaz et al., 2016). Condensate reinjection is only used in emergency situations (now only used in brine disposal). Silica saturation is always monitored (Sicad, 2015). Historically, Surface discharge from 1979-1983, then partial infield reinjection from 1983-1993 at the East of the field to recover from pressure drawdown in Nag. The first brine injectors were idle, corrosive,	reinjection has caused an increase of mass flow and constant enthalpy south of the field, even though they have little communication (Calibugan et al., 2015a). In the NW area of the field, some of the dry and superheated steam wells have turned two-phase since 2003, which is associated to infield and outfield reinjection in Mat area.	

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										well production wells within the Nag area (Diaz et al., 2016). In 1984, injection was relocated to the SE edgefield first, and subsequently to outfield (4 km) as the capacity of edgefield was not enough (Sicad, 2015). From 2003-2013 infield reinjection (400 m from production) tests were performed to mitigate dry-out of some wells (Diaz et al., 2016).		
Portugal	Pico Alto	Pico Alto	2017 (Franco et al., 2017)	3.5 (Franco et al., 2017)		270 – 300 (Franco et al., 2017)	1550 (Franco et al., 2017)		86.4 (Franco et al., 2017)	One reinjection well is located around 500–800 m in the western part of the field. All the brine and condensate were fully injected (except for NCG that is released to the atmosphere). The temperature of brine is maintained at 95 °C to prevent silica scaling (Franco et al., 2017).	No records found.	Additional wells were drilled in 2018. Plan to expand capacity up to 10 MW if the drilling campaign is successful (Franco et al., 2017).
Russia	Baranskogo (Iturup)	Okeanskaya (Okeansky)	2000 (Svalova and Povarov, 2015)	3.6 (Svalova and Povarov, 2015)	3.6 (Svalova and Povarov, 2015)	>300 (Svalova and Povarov, 2015)				No records found.	No records found.	No records found.
USA	Roosevelt Hot Springs	Blundell 1 & 2	1984 (Akar et al., 2018)	37 (DiPippo, 2016)		245 (Simmons et al., 2018)	1122 (Simmons et al., 2018) Current 1,066 (Simmons et al., 2018)	1027 in 2012 (Diaz et al., 2016)	879 in 2012 (Diaz et al., 2016)	Full reinjection. Reinjection depth is ~2100 m with injection temperature 100 °C (Diaz et al., 2016). 3 reinjection wells are located east of the production area with distance 0.75 - 1 km (infield) (Simmons et al., 2018). Sulphuric acid is used to reduce the risk of silica scaling in the injection system (Diaz et al., 2016).	Pressure support in wells near injection (Diaz et al., 2016). However, there are chemical breakthrough and modest reservoir cooling from initial temperature 265 °C to 235-245 °C (Simmons et al., 2018).	One well has been used in the FORGE project to create a fracture network in impermeable rock (Simmons et al., 2018).

Appendix D. Two-phase, liquid dominated, low-enthalpy systems (LE-LDS)

Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
China	Yangbajing (Yanbajain)	Yangbajian (Yangbajing)	1977 (DiPippo, 2016)	26.18 (Zhu et al., 2015)	26.18 (Zhu et al., 2015)	Shallow wells: 157 (Shengtao et al., 2015) Deeper wells: 247 (Shengtao et al., 2015)	Shallow Wells: 640 (Diaz et al., 2016) Deep well: 1053 (Diaz et al., 2016)	2853 for 25 MWe (Diaz et al., 2016)	770 (Diaz et al., 2016)	Partial reinjection. Around 37 % of wastewater reinjected in the south and southwest of system boundaries, about 1.5 km away from the main production area. The rest of the water is surface discharged (to Zangbo river) (Diaz et al., 2016). The temperature of reinjected water is 55 °C. The reinjection zone and the reservoir production zone of the southern field are almost at the same depth. Utilizing water at 130 - 170 °C (Zhu et al., 2015).	Pressure drawdown reduced and became stable. Cooling of production, mainly in the south part of the reservoir. Chemical breakthrough (increase of HCO_3 content) (Diaz et al., 2016). Subsidence is observed as the extraction is much more than mass injected (Li et al., 2016).	The wastewater contains high concentrations of Arsenic, which is unfavourable to be disposed on the surface (Guo et al., 2015).
Costa Rica	Las Pailas	Las Pailas	2011 (Akar et al., 2018)	96.6 (Nietzen and Solis, 2019)	35 in 2015 (without the newest installed power plant) (Nietzen et al., 2015)	240 - 245 (Torres-Mora and Axelsson, 2015)	1090 (Diaz et al., 2016)	1181 (Nietzen and Solis, 2019)	922 (Nietzen and Solis, 2019)	Due to the reservoir is located in law national park (need permit to drill outside the boundary) and lack of permeability in the peripheral area, the injection wells are located in the infield area (Torres-Mora and Axelsson, 2015). Two types: hot reinjection (140 °C) (Torres-Mora and Axelsson, 2015) and cold reinjection wells (30 - 80 °C) (Diaz et al., 2016). In cold injection, the condensed water and other liquid	Thermal and chemical breakthrough in wells close to hot reinjection in the centre of field (Torres-Mora and Axelsson, 2015) (Diaz et al., 2016). Some of the hot injection wells are decreasing in injection capacity (Nietzen et al., 2015). Injection tests using cold water, in some producing wells, improve the permeability of production wells and increase the injectivity index, leading to an increase of	The Las Pailas field has different aquifers. These have different chemical characteristics and temperatures. The importance of knowing the existence of these aquifers is important. These peripheral aquifers can invade production wells during exploitation, causing cooling processes, and thereby decreased output. This process could be mistaken as an effect of reinjection (Torres-Mora and

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										from the main catchment lagoon are sent to 2 injecting wells (further away from the field at a minimum distance of 1000 m). The capacity of cold injection wells is low, so the level of gaps and potential sources of liquid must be strictly controlled (Nietzen et al., 2015). 2 of 3 Hot reinjection wells (~140 °C) are closer to production zone, while the other well is located further away (minimum distance is 800 m) (Nietzen et al., 2015).	output generation (Zúñiga, 2012).	Axelsson, 2015). There is a need to move reinjection to the east based on the tracer test because it shows a direct/rapid connection between one injection well and two producing wells in the surrounding area (Torres-Mora and Axelsson, 2015).
Costa Rica	Miravalles (Dr. Alfredo Mainieri Protti)	Miravalles & Miravalles Boca de Pozo	1994 (Akar et al., 2018)	166 (Nietzen and Solis, 2019)	166 (Nietzen and Solis, 2019)	220 – 250 (Diaz et al., 2016)	1100 (Diaz et al., 2016)	3964 (Nietzen and Solis, 2019)	3046 (Nietzen and Solis, 2019)	Full reinjection since the beginning (Nietzen and Solis, 2019). Some reinjection wells are located within 1 km of production zones and others further than 1.5Km away (Diaz et al., 2016). Reinjection is divided into several sectors: hot injection (eastern injection sector, western injection sector, southern injection sector), and cold reinjection (southwestern sector) (Nietzen et al., 2015). For cold reinjection, it combines fluid	Chemical breakthrough in production by injection in the west side, however, it provides good pressure support. In the south zone, reinjection also produces chemical fronts but in less quantity. Also, there is temperature and enthalpy reduction, with an SW to NE trend, due to thermal fronts after 8 years because of the production increments and reinjection water	It is estimated an enthalpy increases in the reservoir over the year due to pressure drop. This would affect (decrease) the production of the binary plant (Nietzen and Solis, 2019). There are 4 wells out of 56 wells drilled which have acidic fluid characterization (Arias Hernández et al., 2015). The reinjection depth is about 1700-1400 m (Diaz et al., 2016).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										from condensed vapor, separated brines from acidic wells and deliverability test, and commissioning productive systems (Nietzen et al., 2015). Injection rates varied and depended on operating conditions (Nietzen et al., 2015). Five different ponds, from higher elevation to lower elevation transport cold water (Nietzen and Solis, 2019). Neutralization system, by injecting NaOH, has been applied to acidic wells to maintain brine pH and avoid scaling (Arias Hernández et al., 2015). Historically, from 1994-1998, the main reinjection zone was in the west of the field, with contribution from the south, southwest and east. In 1998, the reinjection well in the east became a producer. Injection in the west decreased and injection in the south became the main reinjection zone. In 2002, reinjection in the west was incremented to give pressure	reaching production zones. In the North zone, pressure increased in some wells during reinjection tests, particularly in the north side of the field with no thermal front. (Diaz et al., 2016). There is a relationship between the increase in seismicity and the decrease in total mass injected (due to maintenance period) (Nietzen and Solis, 2019).	

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										support, however, the south remained the main injection zone. Since 2003, little reinjection is performed in the north to recover pressure. It is sought to shift reinjection to north for pressure support (Diaz et al., 2016).		
El Salvador	Ahuachapan	Ahuachapan	1975 (Escobar, 2018)	95 (Escobar, 2018)	81 (Escobar, 2018)	230 (Diaz et al., 2016)	1050 (Diaz et al., 2016)	2880 (Diaz et al., 2016)	2329 (Diaz et al., 2016)	In 1975–1983, reinjection was performed in centre of the field (~47% of total brine produced). From 1982–1999, surface discharge to the ocean. Since 1999, full reinjection performed. Cold reinjection in the northeast of the field at 4Km from production (Chipilapa area/ outside the low permeability boundary). Condensates reinjected in shallow aquifer. Hot reinjection is produced infield around 1 km from production. New reinjection wells are aimed to intersect faults to enhance injectivity due to the increase of mass and generation. Initial reinjection operated only at atmospheric pressure. However, since the pressure is very low, a pumping	During earlier development, cooling of wells during reinjection in the centre of the field. But when it stopped in 1982, wells thermally recovered after 5 years. Since 1999, reinjection at the east of the field has provided pressure support. However, silica scaling problems have arisen. In, 2006 light thermal front in production wells was observed. In summary, the injection strategy can increase the steam rate without significant pressure decline (Diaz et al., 2016).	Main zones have higher temperatures than central zones. (Diaz et al., 2016).

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										system is installed to increase the reinjection pressure to achieve the same amount of total water mass required for injection (Diaz et al., 2016).		
Guadeloupe	La Bouillante	La Bouillante	1986 (DiPippo, 2016)	15.5 (DiPippo, 2016)	15 (Boissavy et al., 2016)	250 (Traineau et al., 2015)	1100 – 1150 (Diaz et al., 2016)	576 (Traineau et al., 2015)	274 (Traineau et al., 2015)	Partial reinjection. Discharge 80 % from total brine to provide pressure support. The remaining brine after LP separator is cooled down below 40 °C through mixing with seawater (used as cooling fluid) before discharged into Bouillante Bay. The temperature 163 °C is used to prevent silica scaling and avoid the risk of cold front breakthrough and cooling of the production well. The depth of reinjection well is between 300–330 m, and located very close to the reservoir fracture zone (Cocagne fault) and it is only at 500–700 m distance from two production feeding zones (Traineau et al., 2015).	The effect of reinjection wells in terms of pressure support and thermal/ chemical breakthrough has not been assessed yet (Traineau et al., 2015).	Coldwater injection/ stimulation induces thermal cracks which improve production by 50 % (Diaz et al., 2016).
Iceland	Svartsengi	Svartsengi	1978 (DiPippo, 2016)	76.4 (EGEC, 2019)		240 (De Freitas, 2018)	1075 (Diaz et al., 2016)	1756.8 (De Freitas, 2018)	1080 (Sigrún Brá Sverrisdóttir, 2016)	Partial reinjection has been applied since 2002 (approximately 60 % of the extracted fluid). One is in the central area with deeper formation,	Based on tracer results, it is considered unlikely that the current injection will cause long term cooling (Sigrún Brá	Saline brine utilised in this plant comes from seawater at a rate of 2/3, the other 1/3 is freshwater (Sigrún Brá

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										while the other is in the periphery with relatively shallower formation (Sigrún Brá Sverrisdóttir, 2016). From 1984 to 1988 intermittent infield reinjection, later on in 2002 reinjection site was shifted. Deep reinjection is performed to maintain the pressure in the system, while the shallow wells are for disposal purposes (Diaz et al., 2016).	Sverrisdóttir, 2016). The mean subsidence rate from 2004-2014 decreased to 11 mm/year from 14 mm year. This may be attributed to the increase of reinjection during this period (De Freitas, 2018). Pressure reacting strongly to reinjection (De Freitas, 2018). In 2010, inter-zonal flow observed in reinjection well, which produced an increase of pressure and reduction of power production. Setting a casing in the upper part of the well halted the pressure increase in the geothermal system, improving the steam cap and operating conditions of the plant. Cooling of the production well during infield injection in 1984-1988. Silica deposition problems solved by addition of condensates or freshwater to dilute. Acidising system also implemented (Diaz et al., 2016). MEQ events recorded near reinjection	Sverrisdóttir, 2016).

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											wells (Flóvenz et al., 2015).	
Indonesia	Mataloko	Mataloko	2010 (DiPippo, 2016)	2.5 (Adi et al., 2018)		150 – 160 (Mohammadzadeh Bina et al., 2018)		40 (Mohammadzadeh Bina et al., 2018)		No records found.	No records found.	
Indonesia	Ulumbu	Ulumbu	2011 (DiPippo, 2016)	10 (Adi et al., 2018)	10 (Nasution et al., 2016)	230 – 240 (Nasution et al., 2016)	1100 (Grant et al., 1997)			One reinjection well directionally drilled at depth of 951 m on the same pad of production well (Diaz et al., 2016) (Nasution et al., 2016).	No records found.	
Japan	Miyagi	Onikobe	1975 (DiPippo, 2016)	15 (DiPippo, 2016)	4.16 in 2014 (Yasukawa and Sasada, 2015)	200 for shallow reservoir (Diaz et al., 2016) 250 for deep reservoir) (Diaz et al., 2016)	Initial 2,050 (Diaz et al., 2016) Current 1,093 (Jalilinasrabady and Itoi, 2015)	625 since 1986 for 12.5 MWe (Diaz et al., 2016)	540 in 1986 (Diaz et al., 2016)	At the start, one injection well at atmospheric pressure was located at one end of the field at 1000 m depth. Now, reinjection wells are located in the south and east of the field. Reinjection wells in the south are at an underground distance of 200 m from the nearest production well, while the wells on the east are at 600 m from the nearest production well (Diaz et al., 2016).	In 1980, reinjection raised the ratio of separated water. And chemical breakthrough. The discharge enthalpies dropped due to insufficient steam and shallow reservoir temperature declined by local injection. During the 1990′s, hot acidic water from shallow wells was reinjected with no negative effects. But, after deep wells were exploited with neutral waters, silica scale became an issue. Thus, to tackle this problem, acidic brine is expanded to atmospheric pressure and injected afterward while neutral fluids are maintained at high pressure. From 1990–1995 production wells showed the	Acidic water in deeper reservoirs. In 1982, production was shifted to the deeper part of the reservoir with wells deviating away from the centre of the thermal anomaly (towards the west) with neutral or even alkaline waters. (Diaz et al., 2016).

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											effects of cold reinjected water from the proximate injection wells (Diaz et al., 2016).	
Japan	Mori	Mori	1982 (DiPippo, 2016)	25 (DiPippo, 2016)	9.36 in 2014 (Yasukawa and Sasada, 2015)	230-250 (Diaz et al., 2016)	Initial 1,199 (Diaz et al., 2016) Current 1,077 (Jalilinasrabady and Itoi, 2015)	1724 for 50 MWe (Diaz et al., 2016)	~1300 in 2005 (Diaz et al., 2016)	Full reinjection. In 1982, reinjection started in the centre of the field. In 1986, reinjection was distributed to the north of the field since the previous arrangement was cooling down the reservoir. Since 2005, reinjection is performed in 5 wells within the caldera (700−800 T/h) and 4 wells out of the caldera (400−500 T/h). The infield (SW) injection zone is 1300−1900 m deep (shallower than production depths) and 1000−1300 m deep in the outfield zone. (Diaz et al., 2016)	Severe scaling in reinjection wells soon after commissioning, now controlled with pH water control. In 1983, the average water to steam ratio increased, a chemical front was experienced, and enthalpy decreased due injection. Because of this situation, reinjection wells with stronger effects in production were relocated to the north in 1986. This change decreased injection breakthrough but reduced pressure. Due to the accelerated reservoir pressure decline, the shallow groundwater started to flow into producers, decreasing the enthalpy of production. Some wells stopped production in 1987 and 1988. To overcome the problem, the reinjection rate was distributed into many wells	Other strategies included: further separation of the injection zone from production and controlled injection in shallow zones.

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											as possible to reinject over a wider area instead of a single zone (Diaz et al., 2016).	
Japan	Otake-Hatchobaru	Otake	1967 (DiPippo, 2016)	12.5 (DiPippo, 2016)	7.86 in 2014 (Yasukawa and Sasada, 2015)	220 – 260 (Mia et al., 2018)	981 (Jalilinasrabady and Itoi, 2015)		460 in 1999 (Diaz et al., 2016)	Infield reinjection. From 1967–1972, surface discharge. In 1972, reinjection started in the production zone with low interconnectivity with producers. In 1980, the temperature of reinjected water was 95 °C and accepted water from the Hatchobaru power plant. During 1996–1998, the furthest cluster of reinjection wells, located in the north, had the highest rate of injection of the whole reinjection area. In earlier years, production had been moved further away from injection, with a range of 200−850 m between injection/production to minimise thermal risk. Production located south and reinjection north of the field (Diaz et al., 2016).	At the beginning of reinjection, the effect of injection was positive giving pressure support to the reservoir, but in 1975 it registered a thermal interference with a decrease in enthalpies and cessation of a production well. Before 1980, reinjection wells met a fault plane with high permeability, the reinjection of water resulted favourably in the increase of vapour flow from some production wells, but a production well situated nearby the fault was completely damaged. Reinjected water in the reservoir is considered to flow mainly into the northern portion of the reinjected area, further from the production zone. There are impermeable layers between the reinjection wells. Injectivity issues in 1980 were possibly due to silica	

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											deposition by supersaturated silica at atmospheric conditions (Diaz et al., 2016).	
Japan	Takigami	Takigami	1996 (DiPippo, 2016)	27.5 (DiPippo, 2016)	26.83 (Yasukawa and Sasada, 2015)	160 in the northeast (Diaz et al., 2016) 260 in the southwest (Diaz et al., 2016)	Initial 925 (Diaz et al., 2016) current 933 (Jalilinasrabady and Itoi, 2015)	1370 in 2010 (Diaz et al., 2016)	1164 in 2010 (Diaz et al., 2016)	Full outfield injection. The estimated distance between production and reinjection wells is about 2Km. Reinjection is performed at 130 °C. The reinjection depth is from 1000 m to 1500 m (Asada and Yamada, 2017). Reinjection was originally performed to halt subsidence. While production and reinjection are at the same reservoir level, the communication between them is small, due to the low permeable zone (Diaz et al., 2016).	Gravity increased was reported in some wells, where it was decreased in injection zones, indicating that reinjected water was mostly leaking out of the hydrothermal system (scarcely remained in the geothermal reservoir). Silica issues have reduced the injectivity (Diaz et al., 2016).	There is only one reinjection well that kept its initial injection capacity for three years, as it was used to reinject water separated at atmospheric pressure, and had a low silica concentration (Diaz et al., 2016).
Japan	Oguni	Hagenoyu, Oguni-Matsuya, Sugawara Binary Cycle, Takenoyu	1991 (Akar et al., 2018)	7.61 (Akar et al., 2018)		200 – 240 (DiPippo, 2016)				No information available	No information available	No information available
New Zealand	Northland	Ngawha	1998 (DiPippo, 2016)	25 (DiPippo, 2016)		230 (Diaz et al., 2016) Deeper reservoir >300 (Diaz et al., 2016)	975 (Diaz et al., 2016)	1035 (Diaz et al., 2016)	391.6 in 2002 from Unit 1 (10 MW) (Diaz et al., 2016)	Five reinjection wells at the periphery of the field are 1 km deep with a distance from production wells of 0.7–1.5 km. From 2008, supplementary injection of cold surface freshwater into deep wells (NG2) was	Prior to 2008, full reinjection without additional water, generates a small amount of mass loss (of NCG) resulting in a small pressure decline over the first 6 years. Then after extra water was pumped it maintained the	

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										undertaken in order to make up for a small net loss (2% NCG which went to the atmosphere), and to sustain pressure beneath culturally significant surface geothermal features (Ngawha Spring) (Sherburn et al., 2015).	pressure ratings to remain constant, thus maintaining surface features (Sherburn et al., 2015). There is a report of the decrease of injectivity 2 injection wells, and reinjection returns to production (Diaz et al., 2016).	
New Zealand	Wairakei-Tauhara	Te Huka (Tauhara)	2010 (DiPippo, 2016)	24 (DiPippo, 2016)	24 (Contact Energy Ltd, 2019)	270 (Harwood et al., 2015)	1086 (Diaz et al., 2016)	923 for 24 MW (Contact Energy Ltd, 2019)	923 for 24 MW (Contact Energy Ltd, 2019)	Injection strategy mixes infield and edgefield in north, east and south sectors. Injection is located in centre area to maintain deep pressures, whereas shallow reinjection is performed to avoid subsidence and sustain thermal springs. Finally, outfield injection was implemented to prevent negative effects of infield (Diaz et al., 2016).	Pressure increase of 2 bars has been recorded in deep reservoir. Reinjection in Wairakei at Karapiti South stopped pressure drop in Tauhara (Diaz et al., 2016).	Production fluid supplies for industrial/ domestic heat, and the binary power plant (Diaz et al., 2016).
New Zealand	Wairakei-Tauhara	Te Mihi	2014 (DiPippo, 2016)	166 (DiPippo, 2016)	150 (Contact Energy Ltd, 2019)	260 before the steam extraction began (Diaz et al., 2016)	1050 (Diaz et al., 2016)			All produced fluid reinjected (Diaz et al., 2016).	No records found.	
New Zealand	Wairakei-Tauhara	Wairakei	1958 (DiPippo, 2016)	174 (Contact Energy Ltd, 2019)	124 (Contact Energy Ltd, 2019)			10,208 for Poihipi, Wairakei, Wairakei Binary & Te Mihi (Contact Energy Ltd, 2019)	6,890 for Poihipi, Wairakei, Wairakei Binary & Te Mihi (Contact Energy Ltd, 2019)	Reinjection was started only after more than 40 years of production. Current reinjection is partial and combines infield and outfield. It also combines target depths (deep and shallow) (Dean et al., 2014). In 1988, deep injection tests were conducted near the centre of the	Thermal breakthrough in infield area. It started to recover once the reinjection wells were moved further away to outside the boundary. Pressure increased evenly throughout the Wairakei liquid Reservoir. Mass production fell by	A new reinjection site was commissioned in late 2011 in the Karapiti area. At WB formation, with good communication, between wells were proven by tracers. The outfield injection in the reinjection zone in the south of Wairakei is a key element used

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										eastern boundary. Large scale reinjection transferred in 1997 to the eastern boundary of the field between Tauhara and Wairakei, the Otupu reinjection area and the Karapiti south reinjection area), with shallow, deep, infield and outfield wells. Since 1998, 30% of reinjection has occurred. Condensate reinjection from Poihipi plant is injected at the west-shallow well (Diaz et al., 2016).	45 %, gravity increased, and a 40 °C temperature reduction was experienced near the injection well during reinjection at the centre of EB after the 1988-test. Since 1998, reservoir pressure and temperature in WB increased. Changes in gas ratios in production, and deposition of calcite were found in wells (Diaz et al., 2016) [84].	to avoid thermal breakthrough in production reservoirs (Diaz et al., 2016). The rest of the waste fluids are discharged into the Waikato river (Diaz et al., 2016).
Portugal	Ribeira Grande	Pico Vermelho	2007 (EGEC, 2019)	13 (EGEC, 2019)	13 In 2013 (Diaz et al., 2016)	240 (Rangel et al., 2017)	1100 (Diaz et al., 2016)	421.56 in 2007 (gross 12.6 MWe/ net 10 MWe) (Diaz et al., 2016)		Full reinjection in 3 injection wells at the NE of the field with a distance of 1.5 km (Rangel et al., 2017). Earlier, from 1980 - 2004, the strategy was to enable surface discharge. From 2005 - 2009, 2 reinjection wells were located ~700 - 1000 m from the main field, but very close to one production well (~350 m). Based on Tracer and simulation results, it was predicted that the configuration may lead to a thermal breakthrough risk. So, in 2009, 3 reinjection wells were drilled to replace the old	Tracer test shows tracer return but no thermal drop at the time. Simulation predicted that a temperature decline would appear, so the reinjection was moved further in 2009. Current simulations based on new tracer results, founded on a new reinjection strategy, suggest that no detrimental thermal decline will affect the development of the geothermal field (Rangel et al., 2017).	The rate in pressure drawdown is relatively low over the time (Diaz et al., 2016).

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										wells (current injection wells). Injection well zones are characterized by lower temperatures than production sites (Diaz et al., 2016).		
Portugal	Ribeira Grande	Ribeira Grande	1998 (EGEC, 2019)	15.8 (EGEC, 2019)	10 In 2013 (Diaz et al., 2016)	240 (Rangel et al., 2017)	1100 (Diaz et al., 2016)	334.1 in 2007 (gross 9.4 MW/ net 8 MW) (Diaz et al., 2016)		Full reinjection in two injection wells at the north of the field with a distance of 350–700 m (Rangel et al., 2017). Historically, from 1980 - 2004, the strategy was surface discharge. Prior to 2012, one injection well was used as the only injector (CL4) (Diaz et al., 2016). Then in 2012, another well (CL4A) was drilled to complement the previous well (Rangel et al., 2017). This new well was only 250 m further away from well CL4. This injection well was previously a production well (Diaz et al., 2016).	Minimal injection returns based on current tracer tests. Wells shows relatively constant enthalpy and production rates. Very little change in wellhead pressure has been detected, suggesting that reservoir pressure has remained quite stable (Diaz et al., 2016).	
Turkey	Germencik	Galip Hoca Germencik Efeler Efe-6	2009 (Mertoglu et al., 2016)	232.3 (Mertoglu and Basarir, 2018)	230.52 in 2019 (Aksoy, 2019)	232 (Diaz et al., 2016)		2303 for 162.3 MWe (only for Galip and Efeler PP) (Tureyen et al., 2016)	2085 for 162.3 MWe (only for Galip and Efeler PP) (Tureyen et al., 2016)	Nearly 90 % of brine is reinjected (Tureyen et al., 2016). At Germencik, the reinjection zone is located 1-2Km west of the current production zone. The closest distance between injection and production wells is	No cooling has been observed and the production has been sustainable so far (Tureyen et al., 2016).	

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										~600 m. The reinjection temperature is 118 °C (Aksoy, 2019).		
Turkey	Germencik	Kubilay, Ken 3, Mahmethan, Melih	2017 (ThinkGeoEnergy, 2018a)	106.8 (Mertoglu and Basarir, 2018)	97.31 in 2019 (Aksoy, 2019)	234 (Diaz et al., 2016)		225 for Kubilay PP (ThinkGeoEnergy, 2018b)	200 for Kubilay PP (ThinkGeoEnergy, 2018)	Reinjection temperature is 75 °C (Aksoy, 2019)		
Turkey	Gumuskoy	Gümüşköy	2014 (Mertoglu et al., 2016)	13 (Mertoglu and Basarir, 2018)	12.4 (Mertoglu et al., 2016)	182 (Diaz et al., 2016)				Full reinjection. At Gumuskoy, the production wells are located east, while the reinjection well was required to inject upstream into the recharge zone at the western boundary of the reservoir. A planned reinjection well intersects geological faults to achieve good permeability. Reinjection temperature is 75 °C. (Aksoy, 2019).	No cooling or injectivity problems at the moment (Diaz et al., 2016).	
Turkey	Hidirbeyli	Deniz, KenKipas, Karem JES, Maren	2011 (Akar et al., 2018)	116 (Mertoglu and Basarir, 2018)	105.79 (Aksoy, 2019)	234 (Diaz et al., 2016)				Full reinjection (Diaz et al., 2016). Reinjection temperature is 70 °C (Aksoy, 2019).	No records found.	
Turkey	Kızıldere	Kızıldere (Bereket) Kizildere 1,2,3 Greeneco	2007 (Mertoglu et al., 2016)	266.85 (Mertoglu and Basarir, 2018)	227.29 (ThinkGeoEnergy, 2018c) (Aksoy, 2019)	245 (Satman et al., 2017)	1047 (Diaz et al., 2016)	6600 (Senturk, 2019)	5000 (Senturk, 2019)	Full reinjection. Currently, almost 80 % of the fluid is being reinjected (Satman et al., 2017). The wells are located mostly at the west side cluster, and some are in the east side cluster surrounding the production cluster (Garg et al., 2015a). Reinjection temperature is	Some return was observed in production wells near injection (by observing the decline of CO2 content) (Senturk, 2019). In 1984, lack of reinjection along with scaling leads production decline, (Calcite precipitation concerns in the reinjection rock formation)	The first injection strategy was from shallow zones on the eastern side of the system. As interference and tracer tests conducted, results show that pressure support from these injection wells was limited. When KZD-III production wells started to produce, total net

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										110oC (Aksoy, 2019). An inhibitor is used to prevent scaling. Earlier, surface discharge from 1984-2002. Intermittent infield reinjection experiments performed around 1999. Formal reinjection scheme started in 2002 with an infield well at further distance from the production zone than the previous experiment. In 2010, 20% of the total produced fluid was injected in 4 wells. There is a combination of deep and shallow reinjection (Senturk, 2019).	(Lewis et al., 2015). In 1999, infield reinjection experiments affected production in well closest to injection (200 m), with a reduction of fluid production. Since 2002, the current infield injection scheme has given pressure support. Around 2004, cooling was observed in the nearest reinjection well, and eventually, it was shut-in. By 2009, infield reinjection had reduced the reservoir temperature by 4 °C (Senturk, 2019).	production increased considerably. In addition to this, KZD-III production wells are producing from deeper zones than KZD-I and KZD-II wells. With this kind of a change in production strategy, an urgent need is raised to revise the injection strategy as well. For this reason, at the end of 2018, as the first step of a new injection strategy, two former production wells which are in near-production region, were diverted to injection. The second step in the plan was deeper injection from 3 wells, located on the western side of the field. Soon, tracer test and interference tests will be conducted from these wells. The final step is to allocate another injection region close to the south-eastern production wells. With these changes, greater pressure support on production wells aims to be achieved (Senturk, 2019). Wastewater used

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
												for space heating and greenhouse (Halaçoğlu et al., 2018)
USA	Dixie Valley	Dixie Valley Dixie Valley binary	1988 (DiPippo, 2016)	66.7 (Rose, 2019)	64 (Rose, 2019)	285 (Diaz et al., 2016)		2185 in 2015 (Benoit, 2015)	1,581 for 62MWe (Diaz et al., 2016)	Currently, injection wells are located in two reinjection zones, (near area 7 and near area 33), both at approximately 1.2–1.5 km from production sites. Previously, injection was located 1.1 km from production sites. Augmentation of water from shallow cold injection wells was performed to stabilize water reservoir withdrawal and productivity (Benoit, 2015). Injection occurred at three different depths: ~1860 m (main fracture zone), ~2225 m (aquifer), and ~2800 m (Diaz et al., 2016). By 1997, there was enough excess injection capacity to allow an existing injector to be dedicated to cold water injection (shallow cold water). Dedicated cold injectors were required due to scale precipitation, when the hot brine and cold water are combined (Benoit, 2015).	Slight chemical breakthrough was registered in production wells, increasing the salinity of the produced water (Diaz et al., 2016). Reinjection returns have been recorded, but no cooling occurred. Before additional shallow cold water was added, the pressure declined. After additional water was added, the reservoir pressure stabilised (with an average augmentation rate of about 500 GPM). in the past 18 years, no new production well has been drilled as the system benefits from reinjection (Benoit, 2015).	Production wells produce from 3 to 6 individual fractures located between depth of 2500 and 3100 m (Benoit, 2015).

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Country	Field	Power plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	Injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
USA	Heber	Heber, Heber Second Imperial, Gould & Heber South	1985 (DiPippo, 2016)	142.5 (California Energy Commission, 2018)	98 (California Energy Commission, 2018)	200 (Diaz et al., 2016)	1010 (Diaz et al., 2016)	8,813 in 2013 (Diaz et al., 2016)	8,437 in 2013 (Diaz et al., 2016)	Full reinjection. Injection wells' average depth is at 1370 m (Diaz et al., 2016).	Ground inflation and possible scaling in the reservoir has occurred in the reinjection sector/zone (Diaz et al., 2016).	

Appendix E. Hot water systems (HWS)

Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Australia	Great Artesian Basin	Birdsville	1992 (Diaz et al., 2016)	0.12 (Diaz et al., 2016)	0.08 (Diaz et al., 2016)	98 (ErgonEnergy, 2014)		26 (Beardsmore et al., 2015)		Some amount of hot water goes to the lagoon. Other hot water is transferred to the cooling pond and water tank before being distributed to the town water system (ErgonEnergy, 2014).	N/A.	A local utility (Ergon Energy) in Queensland, Australia has decided to abandon plans to renew its small geothermal power station in favour of a solar PV and storage strategy (ThinkGeoEnergy, 2018d).
China	Fengshun /Guangdong	Dengwu/ Dengwo	1970 (Diaz et al., 2016)	0.3 (Diaz et al., 2016)	0.21 (Diaz et al., 2016)	91 (Diaz et al., 2016)		228 (Diaz et al., 2016)	228 (Diaz et al., 2016)	Surface discharge	N/A	
Austria	Altheim	Altheim	2002 (DiPippo, 2016)	1 (DiPippo, 2016)	0.5 in 2010 (Diaz et al., 2016)	106 (Tanase, 2016)	444 (Diaz et al., 2016)	294 (Tanase, 2016)	294 (Tanase, 2016)	Doublet configuration. The distance between injection and production is 1.7 km (Tanase, 2016). Injection well at	Reinjection practice has countered a decline in pressure and maintained formation water level (Diaz et al., 2016).	Output temperature is 70 °C. It is then served to use as district heating before reinjecting to the ground (Evans et al., 2012).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										65-70 °C is close/intersected to a geological fault, which is indicated by its very high permeability (Diaz et al., 2016).		
Austria	Bad Blumau	Bad Blumau	2001 (DiPippo, 2016)	0.25 (DiPippo, 2016)	0.18 in 2012 (Diaz et al., 2016)	110 (Diaz et al., 2016)	461 (Diaz et al., 2016)	103 (Zarrouk and Moon, 2014)	about 103 (Evans et al., 2012)	Doublet configuration. Almost all produced water is reinjected at 50 °C. Well separation of injection and production at reservoir depth is 1.8Km. Reinjection is performed in fractured carbonate rock. Calcite inhibitor is added to production fluid to avoid scaling in the system and injection well and injection formation (Diaz et al., 2016).	Chemical breakthrough and potential calcite deposition were observed in reinjection well formation (Diaz et al., 2016).	Potential corrosion issues due to the chemistry of the water produced (Diaz et al., 2016).
China	Huabei/ North oil	Huabei	2011 (DiPippo, 2016)	0.4 (DiPippo, 2016)	0.31 (Yue-feng et al., 2015)	110 (Diaz et al., 2016)		114 (Diaz et al., 2016)	114 (Wang et al., 2016)	Full reinjection (Wang et al., 2016). The distance is 2 km between the injector and one monitor well. Inject at 85-90 °C (Diaz et al., 2016).	Water levels in production wells raised. Formation pressure increased. Injection capacity increased due to cold reinjection (Diaz et al., 2016).	Pilot power plant that uses hot fluids co-produced from an oil reservoir (Wang et al., 2016).
China	Yangyi	Yangyi	2011 (DiPippo, 2016)	0.9 (DiPippo, 2016)	0.9 (Zheng et al., 2015)	upper <80 (Shengtao et al., 2015) lower >207 (Diaz et al., 2016)	920 (Diaz et al., 2016)			No records found.	No records found.	Construction of new power plant expansion based on the potential performance (Zheng et al., 2015).
Germany	Bruchsal	Bruchsal	2010 (Weber et al., 2016)	0.55 (Weber et al., 2016)	0.44 (Geotis, 2018a)	118 (Diaz et al., 2016)		81.7 (Evans et al., 2012)	81.7 (Evans et al., 2012)	Reinjection is performed by gravity flow (Diaz et al., 2016) and conducted in the same formation as a production well. The distance between reinjection and production wells is 1.4 km (Vidal and Genter, 2018)	The downhole pressure increases about 0.5 MPa above static pressure (Diaz et al., 2016).	Initially, the second well (GB2) is planned to be an injector well (targeted deeper formation). However, it is reactivated as a production well as it performs better than the shallower well (GB1) which is now an injector well (Vidal and Genter, 2018)

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Germany	Grünwald	Oberhaching-Laufzorn	2014 (Weber et al., 2016)	4.3 (Weber et al., 2016)	4.3 (Geotis, 2018a)			349 (Geotis, 2018b)		No records found.	No records found.	Main use is for district heating (Geotis, 2018b).
Germany	Landau	Landau	2003 (Weber et al., 2016)	3 (Weber et al., 2016)	0.79 (Geotis, 2018a)	160 (Diaz et al., 2016)	632 (Zarrouk and Moon, 2014)	278 (Evans et al., 2012)		Separation between injection and production wells is 1.3 km below the surface. Hydraulic stimulation is performed due to injection (Diaz et al., 2016).	The production rate increased from 65–70 L/s, and injection pressure increased from 40 bar to ~55Bar (Evans et al., 2012) (Diaz et al., 2016).	
Germany	München	Dürrnhaar/ Durrhaar	2012 (Weber et al., 2016)	7 (Weber et al., 2016)	6 (Geotis, 2018a)	141 (Geotis, 2018c)		446 (Geotis, 2018c)		No information recorded.	No information recorded.	No information recorded.
Germany	München	Kirchstockach	2013 (Weber et al., 2016)	7 (Weber et al., 2016)	6 (Geotis, 2018a)	141 (Geotis, 2018d)		432 (Heberle et al., 2016)		The temperature of the reinjected fluid is 51.5 °C. Temperature is maintained higher than 50 °C to prevent silica precipitation (Heberle et al., 2015).	No information recorded.	No information recorded.
Germany	München	Sauerlach	2013 (Weber et al., 2016)	5 (Weber et al., 2016)	5 (Geotis, 2018a)	140 (Geotis, 2018e)		428 (Geotis, 2018e)		The temperature of the reinjected fluid is 45 °C (Liwei and Boheng, 2018).	No information recorded.	No information recorded.
Germany	Taufkirchen	Taufkirchen/ Oberhaching	2016 (Weber et al., 2016)	4.3 (Weber et al., 2016)	4.3 (Weber et al., 2016)	136 (Geotis, 2018f)		465 (Geotis, 2018f)		The subsurface distance between two wells is around 940 at the top res and 1150 at the bottom res. In the future: the lower performing well (GT3a) will be used for reinjection. The thermal water will be cooled from 130 °C to 55 °C to increase the pressure gradient from well to formation (Fisch et al., 2015).	No information recorded	Water is also used as district heating (Fisch et al., 2015).
Germany	Traunereut	Traunereut	2015 (Weber et al., 2016)	5.5 (Weber et al., 2016)	5.5 (Geotis, 2018a)	120 (Geotis, 2018g)		496 (Geotis, 2018g)		No information recorded.	No information recorded.	Also used for district heating (Geotis, 2018g).
Germany	Unterhaching	Unterhaching	2009 (Weber et al., 2016)	3.36 (Weber et al., 2016)	3.36 (Geotis, 2018a)	123.7 (Geotis, 2018a)	504 (Richter, 2015)	536 (Geotis, 2018h)		Production and injection wells separated by 4 km at depth and intersect faults (Diaz et al., 2016)	After electricity production began, MEQ events were recorded within 1 km of injection (Diaz et al., 2016).	Following the decision to shut down the geothermal power plant of Unterhaching, the technology and equipment of the Kalina plant are now

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
												being sold (ThinkGeoEnergy, 2018e).
Iceland	Husavik	Husavik	2000 (DiPippo, 2016)	2 (EGEC, 2019)	1.7 in 2011 (Diaz et al., 2016)	121 (Diaz et al., 2016)		324 (Diaz et al., 2016)		Surface Discharge. Brine is used for district heating and direct use applications. The final hot fluid will be brought to a bathing lagoon with a temperature of about 35OC (Diaz et al., 2016).	N/A.	
Japan	Sumikawa-Onuma	Onuma	1974 (DiPippo, 2016)	9.5 (DiPippo, 2016)	6.33 (Yasukawa and Sasada, 2015)	215 (Diaz et al., 2016)	Initial 1,609 (Diaz et al., 2016) Current 794 (Jalilinasrabady and Itoi, 2015)	540 (Diaz et al., 2016)	383.5 from 1970-1987 (Diaz et al., 2016)	Based on a map, reinjection is performed infield, with 500 m or less between production and reinjection zones (Diaz et al., 2016). A further location for reinjection was pursued in the1980's due to enthalpy loss (Diaz et al., 2016).	In 1977, there was pressure interference due to reinjection operations so the reservoir pressures were maintained. Water flow increased while the steam flow rate remained the same, indicating production enthalpy net loss. In the same year, 2 injection wells located 300 m from 2 production wells, caused a greater loss of enthalpy and steam decline than in the rest of the field (Diaz et al., 2016).	Depths of reinjection wells around 600–1200 m. (Diaz et al., 2016)
Japan	Beppu	Beppu-Spring	2014 (DiPippo, 2016)	0.5 (DiPippo, 2016)		130 (Naritomi et al., 2015)				No records found.	No records found.	
Japan	Beppu	Goto-en	2014 (DiPippo, 2016)	0.09 (DiPippo, 2016)						No records found.	No records found.	
Japan	Tsuchiyu	Tsuchiyu Onsen	2015 (Akar et al., 2018)	0.8 (Akar et al., 2018)		100 (Renewable Energy World, 2015)				Surface discharge. The temperature of hot water after generation will be reduced to 70 °C (Renewable Energy World, 2015).	N/A.	The hot spring and mountain water are then mixed together to use at a nearby spa for visitors (Renewable Energy World, 2015).
Japan	Abo tunnel	Abo-Tunnel	2013 (DiPippo, 2016)	0.003 (DiPippo, 2016)						No records found.	No records found.	
Japan	Shichimi	Shichimi	2014 (DiPippo, 2016)	0.02 (DiPippo, 2016)						No records found.	No records found.	
Japan	Yumura	Yumura Spring	2014 (DiPippo, 2016)	0.03 (DiPippo, 2016)		90 (Renewable Energy World, 2015)				Water temperature goes down to 65 °C, then the hot water is used at spas and later	No records found.	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										injected back into the ground to be reheated (Renewable Energy World, 2015).		
Romania	Oradea	Oradea	2012 (EGEC, 2019)	0.05 (EGEC, 2019)		85 – 135 (Orkustofnum, 2017)		~34 for electricity, >300 for direct use (Bendea et al., 2015)		Brine output from ORC binary plant flows cascaded to the heat plant. A certain amount was reinjected back into the reservoir after heat use (Bendea et al., 2015).	Reinjection helps prevent pressure drawdown (Bendea et al., 2015).	Other wells are directly supplying direct use applications (heating, pool) (Bendea et al., 2015).
Russia	Pauzhetskaya	Pauzhetskaya (Pauzhetka)	1967 (DiPippo, 2016)	14.5 (Svalova and Povarov, 2015)	8 (Svalova and Povarov, 2015)	190 (Kolesnikov et al., 2015)	780 (Diaz et al., 2016)	900 (for 6.8 MWe) (Diaz et al., 2016) 100 t/hr steam in 2015 (Kolesnikov et al., 2015)	136.8 (for 6.8 MWe) (Diaz et al., 2016)	Partial reinjection. One reinjection well located 1.7 km NW from the production zone (edgefield). Previously, infield reinjection was implemented (close to the production sites) but eventually production was transferred further towards its current location SW of power plant. Between 1979–1981 hot reinjection was performed, then. cold reinjection in 1981-1984. Later, since 1985, hot reinjection was back at 100−120 °C (Diaz et al., 2016).	Infield reinjection has given pressure support and has established the mass balance. Later, the reservoir has a significant plunge in production enthalpy, so the production wells close to injection were taken out of service in 1999. But after production was moved towards the SE, there was still a significant temperature decline (Diaz et al., 2016).	
Thailand	Fang	Fang	1989 (DiPippo, 2016)	0.3 (Raksaskulwong, 2015)	0.2 (Raksaskulwong, 2015)	130-134 (Diaz et al., 2016)	487 (Diaz et al., 2016)	60 (Wood et al., 2016)	N/A (Wood et al., 2016)	No reinjection was performed (Surface discharge) (Wood et al., 2016).	N/A.	Fang binary plant generates 115–250 kWe that varies with each season (Wood et al., 2016).
Turkey	Afyonkarahisar	AfjetAfjes	2016 (Turboden, 2017)	2.76 (Mertoglu and Basarir, 2018)	2.46 (Aksoy, 2019)	110 (Sahin, 2016)				Reinjection temperature is 60 °C (Aksoy, 2019).		
Turkey	Pamukoren	Kuyucak	2017 (ThinkGeoEnergy, 2017)	18 (Mertoglu and Basarir, 2018)	16.67 (Aksoy, 2019)	170 – 175 (Aksoy, 2019)				Reinjection temperature is 70 °C (Aksoy, 2019).		
Turkey	Pamukoren	Pamukören 1,2,3,4	2013 (Akar et al., 2018)	99.51 (Mertoglu and Basarir, 2018)	92.15 (Aksoy, 2019)	191 (Karahan et al., 2015)		2700 for 90 MW (Pamuko-ren 1–2) (Karahan et al., 2015)	2700 for 90 MW (Pamiukoren 1–2) (Karahan et al., 2015)	Full reinjection. The temperature of injection is 80 °C. The injection wells are located at an actively diminished	Pressure support. Concentrated south reinjection has brought interference to some production wells. Acidising	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										zone in the southern area of the main production zone. Reinjection targets the same faults as production faults at deeper depths. The closest distance is 500, whereas the average distance is 1 km. At first, most of the injection wells are in the south. Upon interference of a well to production well, some of injection is allocated to the east side to mitigate breakthrough and minimise drawdown. Acidising at injection wells (Karahan et al., 2015).	improves injectivity (Karahan et al., 2015).	
Turkey	Sultanhisar	Sultanhisar	2014 (ThinkGeoEnergy, 2018f)	37.51 (Mertoglu and Basarir, 2018) (Aksoy, 2019)	34.13 (Aksoy, 2019)	170 (IRENA, 2017)						
Turkey	Salavatli	Dora 1,2,3,4	2006 (ThinkGeoEnergy, 2014)	68.45 (Mertoglu and Basarir, 2018)	65.92 (Mertoglu et al., 2016) (Aksoy, 2019)	165 – 180 (Serpen et al., 2015) (Aksoy, 2019)	700 – 750 (Serpen et al., 2015)	2620 (minus Dora IIIB and 4) (Serpen et al., 2015)	2620 (minus Dora IIIB and 4) (Serpen et al., 2015)	Full reinjection. For all power plants, a peripheral location was selected. For Dora 1, the distance between injection and production is about 1–1.5 km. For Dora 2 the distance between injection and production is about 1 km. Reinjection in Dora II is performed at the same level for one well and deeper for another injection well. For Dora 3 the distance from injection to production wells is as follows: Dora 3a unit is >1.5 km while Dora IIIB unit is 0.5–1.2 km. Acidising job at some injectors.	No reinjection returns or any negative effect in Dora I, II, and III. There is a correlation between bottom-hole pressures and reinjection rate (quick effect of pressure changes when injection is interrupted). Most of the MEQ is located 2–3 K m deep near the injection well. Acidising jobs have increased injectivity capacity (Serpen et al., 2015).	The CO_2 discharged from Dora I & II units is processed in commercial dry-ice and gaseous CO_2 facilities near the plant. After analysing MEQ events from reinjection operations it was concluded that reinjected water tends to flow outwards of the geothermal system, away from the main reservoir (Serpen et al., 2015).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										No contact of wastewater with air is allowed and an inhibitor is also injected into the brine within the wellbore to avoid scaling. Reinjection operations are monitored using a microseismic grid. The temperature of injection has been maintained at 75–80 °C to prevent silica buildup (Serpen et al., 2015).		
Turkey	Umurlu	Umurlu (karkey) Umurlu 2	2016 (ThinkGeoEnergy, 2014)	24 (Mertoglu and Basarir, 2018)	22.2 (Aksoy, 2019)	148 – 202 (Yucetas et al., 2018)				Full reinjection. Reinjection temperature is 74 °C (Aksoy, 2019). Initially, injection was performed without NCG reinjection. After a year, NCG reinjection was started in one well. The compressed NCG and cold water are mixed in an injector at an average temperature of 64 °C at a depth of more than 700 m. Injection wells are located between production wells (infield) (Yucetas et al., 2018).	Before NCG reinjection, the produced CO_2 rate declined over a year due to dilution by degassed injectate. After NCG reinjection, production wells, which were close to NCG injection wells showed an increase in CO_2 content, while further wells showed a stagnant amount of CO_2. For nearby production wells, CO_2 has a profound effect on reservoir pressure (Yucetas et al., 2018).	High CO_2 content in the reservoir. CO_2 has a role to maintain reservoir performance (Yucetas et al., 2018).
Turkey	Aydin	3S Kale JES 1	2018 (Aksoy, 2019)	25 (Aksoy, 2019)	23.15 (Aksoy, 2019)	145 (Aksoy, 2019)				The temperature of injection is 73 °C (Aksoy, 2019).		
Turkey	Tuzla	Tuzla	2010 (Akar et al., 2018)	7.5 (Mertoglu and Basarir, 2018)	7.29 (Aksoy, 2019)	175 (Diaz et al., 2016)		600 for 7.5MW (Diaz et al., 2016)	600 for 7.5MW (Diaz et al., 2016)	Full reinjection is performed. The temperature of injection is 74 °C (Aksoy, 2019).	No records found.	Production water contains very high salt component (Diaz et al., 2016).
Turkey	Alasehir	ALA-1, Alasehir 1,2,3, Enerjeo Kemaliye, Ozmen 1	2014 (Akin, 2019)	214.02 (Mertoglu and Basarir, 2018) (Aksoy, 2019)	189.42 (Aksoy, 2019)	190 (Akin, 2019)		ALA-1 = 2350 (Senturk, 2019)	ALA-1 = 2000 (Senturk, 2019)	Full reinjection (Akin, 2019). Reinjection temperature is 95.5 °C (Aksoy, 2019).	Pressure support in production wells. However, chemical breakthrough. Slight cooling has been detected in some wells (enthalpy has been declining to	In Alaşehir reservoir, E–W trending normal faults dominate the fluid flow direction. E–W trending faults are cut by S-N direction normal faults which creates a

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
											35 kJ/Kk), NCG reduction is also inevitable (Aydin et al., 2018).	highly intersected and strong fractured network. Thus, the production and injection wells are aligned on the same flow patterns. Since most of the wells are interconnected through intersected faults, the production and injection strategy of most operators in the field strongly affect each other (Aydin et al., 2018) (Senturk, 2019).
Turkey	Tuzla	Babadere	2015 (Akar et al., 2018)	8 (Mertoglu and Basarir, 2018)	6.81 (Aksoy, 2019)	175 (Diaz et al., 2016)				Reinjection temperature is 70 °C (Aksoy, 2019).		
Turkey	Aydin-Buharkent	Buharkent	2018 (ThinkGeoEnergy, 2018g)	13.8 (Mertoglu and Basarir, 2018)	13.06 (Aksoy, 2019)	147 – 153 (Mertoğlu et al., 2015)				Reinjection is performed using gravity. The outlet brine temperature is 70 °C (Mertoğlu et al., 2015).		
Turkey	Saraykoy	Greeneco Saraykoy Tosunlar	2016 (Mertoglu and Basarir, 2018)	60.77 (Mertoglu and Basarir, 2018)	50.93 (minus Saraykoy PP) (Aksoy, 2019)	145 (Aksoy, 2019)				Reinjection temperature is 70 °C (Aksoy, 2019).		
Turkey	Denizli	Denizli-Gerali	2014 (Aksoy, 2019)	3 (Aksoy, 2019)						No records available	No records available	
Turkey	Salihi	Sanko	2017 (Aksoy, 2019)	15 (Mertoglu and Basarir, 2018)	13.7 (Aksoy, 2019)	230-245 (Aksoy, 2019)						
USA	Beowawe	Beowawe 1 & 2	1985 (DiPippo, 2016)	20.6 (Simatupang et al., 2015)	14 (Rose, 2019)	210 – 216 (Kirby et al., 2015)	920 (Diaz et al., 2016)	891.6 for 16.6 MWe (Diaz et al., 2016)	762.4 for 16.6 MWe (Diaz et al., 2016)	Currently, declining temperatures have been balanced by maintaining injection without too much augmentation (keep it partial) (Benoit, 2014). From 1985-1993 partial injection was performed outfield (2.5Km) with no connection to the reservoir. In 1994, injection was shifted closer (1.75Km) to provide pressure support. Injection resumed in 2009 to	From 1985–1993 reinjection out of the system did not give pressure support to the reservoir, which allowed pressure to drop and cold groundwater to flow into the system and cooling it (Kirby et al., 2015). Moving reinjection towards production wells had a positive impact by reducing drawdown; however, enthalpy declined from 920KJ/Kg in 1986 to 760KJ/Kg between	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										date and by 2013 about 27% of total injection brine was reinjected into one injection well (distance 1.75 km) (Diaz et al., 2016).	1988 and 1998 (Kirby et al., 2015). Overall, current reinjection helps to increase the production rate, even though the temperature is declining (Kirby et al., 2015).	
USA	Blue Mountain	Faulkner 1 (Blue Mountain)	2009 (DiPippo, 2016)	63.9 (Rose, 2019)	38 (Rose, 2019)	210-250 (Diaz et al., 2016)	727 (Diaz et al., 2016)	1826.5 for 32.8 MWe (Diaz et al., 2016)	1826.5 for 32.8 MWe (Diaz et al., 2016)	Full reinjection with additional vapour condensate from secondary fluid (Power Technology, 2018). From 2009 to 2011, a deep Injection zone (down-dip) is located to the west of the production site, ~750 m to the nearest production well that has the highest enthalpy (the hottest well). A thermal breakthrough caused the reinjection strategy to change. In 2011, the production rate of the hottest wells was decreasing, making the generation lower, but slowing down temperature decline. In 2012, the western injection wells began to shut as much as possible diverting injection to the northern part. In 2013, the new strategy adapted and was able to inject low flows to 4 wells to the south and east of the current production wells, and one shallow well near the deep western injectors. In 2014, optimisation injection was	In 2009–2011, the western injection well had affected the hottest wells on the west side. These wells have a very strong connection to the two hottest production wells (located upflow zone), so it suppressed the outflow. Hence, the temperature decline is more than 10%. In 2012, the shifting of injection has allowed for production to be returned to its initial rate then increased. However, temperature decline continued at higher rates for the following 2.5 years. In 2013 to date, the Blue Mountain plant is able to reduce overall temperature decline by 70% compared to the initial rate of decline observed in 2009 – 2011 (Swyer et al., 2016).	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										conducted using trickle injection and by 2015, the deep western injectors were completely shut down by keeping the two injectors at low flows. The distance between the current injection and main production wells is 750 – 1200 (Swyer et al., 2016).		
USA	Brady Hot Spring	Brady I & II	1992 (DiPippo, 2016)	31.4 (Rose, 2019)	18 (Rose, 2019)	175-205 (Diaz et al., 2016)	750 (Diaz et al., 2016)	1664.2 for 21.1 MW (Diaz et al., 2016)	1295.2 for 21.1 MW (Diaz et al., 2016)	Currently, full reinjection. Most of the cooled brine flows into 3 much shallower injection wells located approximately 2 km northeast of the plant (edgefield), while a small proportion is redirected to a similarly shallow offsite injection well, approximately 6 km to the south of the geothermal plant, in a separate basin. A negligible amount of brine is pumped for direct use (Cardiff et al., 2018). From 1992-1998, partial reinjection was performed in shallow infield sites within the NE boundaries of the Brady Unit 1 project. In 1998, a new injection zone was explored at the south of the field (outfield) to avoid temperature decline. Therefore, by 2000, the injection was diverted to the south. Eventually, reinjection progressively returned to deeper infield NE of the field	Reinjection zones have a lower subsidence rate than the rest of the field. Current reinjection to shallower formation may limit the effect of seismicity (Cardiff et al., 2018). Complex injection flow networks isolate producers located further toward injection (Diaz et al., 2016). Short residence times for fluids occur between production and injection wells through faults and excessive drawdown in nearby production wells. The cooling effect was experienced over the years during shallow infield injection. While outfield injection reversed the temperature decline by 2 °C, the effect of a pressure support loss has affected production. In 2001 there was leakage of injection water to the surface in old southern injection fields (Diaz et al., 2016).	Production wells with depth range of 0.5–2 K m. One injection will be subjected to EGS stimulations (Cardiff et al., 2018).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										around 2001 where there were two injection wells located 1.5-2.5KM NE of production wells with depths of 0.5-1Km (Diaz et al., 2016).		
USA	Brawley	North Brawley	2010 (DiPippo, 2016)	50 (California Energy Commission, 2018)	13 (Ormat, 2018)	150-200 (Diaz et al., 2016)		2141 in 2013 (Llenos and Michael, 2016)	2141 in 2013 (Llenos and Michael, 2016)	Full reinjection (Llenos and Michael, 2016). Injection wells are located infield with a distance of 400 m to 1700 m approximately. Some injection and production wells are interchangeable and some wells were left to idle to improve understanding of geothermal resources (Llenos and Michael, 2016). The depths of fluid injection in the geothermal field varies between 0.6 km and 1.5 km (slightly deeper than the production zone) (Wei et al., 2015).	MEQ recorded in the vicinity of an injection well at a much deeper depth, has no direct relationship with geothermal reinjection activity (Wei et al., 2015).	Sedimentary rock. The shallow production reservoir is between depth of 457 - 1370. The deeper reservoir fluid can reach 273 °C but has not been developed yet due to severe scaling and corrosion potential (Ormat, 2018). Low efficiency of reinjection wells makes it difficult to not operate at full capacity (The Aerospace Corporation, 2011).
USA	Chena Hot Springs	Chena Hot Springs	2006 (DiPippo, 2016)	1.1 (Boyd et al., 2015)	0.4 (Leland et al., 2015)	74 (DiPippo, 2016)	306 (Diaz et al., 2016)	117.36 for 0.25 MWe (Diaz et al., 2016)	117.36 for 0.25 MWe (Diaz et al., 2016)	Two reinjection wells are used for 100 % reinjection (Leland et al., 2015), located “far enough” away from the main production well. A reinjection zone has high permeability and low pressure (Diaz et al., 2016).	No cooling was observed in the produced fluid. Nonetheless, temperature declines were observed in near shallow district heating well (Diaz et al., 2016).	Shallow production well (Diaz et al., 2016).
USA	Cove Fort	Cove Fort	1985 (DiPippo, 2016)	25 (DiPippo, 2016)		150 – 170 (Simmons et al., 2019)				100 % reinjection by using gravity. Downhole generator was installed at the bottom of injection well, improving cove fort’s efficiency to 8.8 % (Sacerdoti, 2015). There is a mix of infield and edgefield, with a minimum distance of	To date, operators have yet to see any temperature decline, pressure changes or other indication that the resource is experiencing any instability (Enel, 2015).	Further exploration to expand the next power plant is proposed and expects to add generation capacity (project cove fort 2) (Enel, 2015).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										500 m (for infield), and an average distance of 1.5 km between injection and production wells (for edgefield) (Diaz et al., 2016).		
USA	Desert Peak	Desert Peak 2 (Brady Complex)	1985 (DiPippo, 2016)	26 (Rose, 2019)	14 (Rose, 2019)	207 (Diaz et al., 2016)				Injection wells are located at NE of the field with a distance of 500−1000 m to production. One injector is used as a hydraulically stimulated (EGS) well DP 27-15, and is located 2Km NE of the production zone (furthest), with cold water injection (temperature 20–30) ̊C to stimulate/ fracture and improve injectivity (Dempsey et al., 2015)[1].	For injection wells (and EGS), localized stress recorded in injection zones promoted fractures and MEQ events of slight magnitude (Benato et al., 2016). There are recorded tracer returns in production wells. The good residence time for injectates in the reservoir makes it accumulate more heat (Diaz et al., 2016).	Faults play a role in the connections between wells (Diaz et al., 2016).
USA	East Mesa	GEM, ORMESA	1979 (DiPippo, 2016)	122.2 (California Energy Commission, 2018)	57 (California Energy Commission, 2018)	204 (Diaz et al., 2016)	697 (Diaz et al., 2016)	7393 in 2013 (Diaz et al., 2016)	6985 in 2013 (Diaz et al., 2016)	100 % of brine is reinjected infield (Diaz et al., 2016)	Reinjection returns resulted in a cooling of approximately ∼0.5 °C/year. There is a possible decrease in subsidence rate in the system due to injection operations (Diaz et al., 2016).	
USA	Honey Lake	Honey Lake	1989 (DiPippo, 2016)	6.3 (California Energy Commission, 2018)		121 (Diaz et al., 2016)		79.2 in 2012 (Diaz et al., 2016)		Used geothermal fluid will be disposed of in an injection well (Diaz et al., 2016).	No records found.	
USA	Honey Lake	Wineagle, Amedee	1985 (DiPippo, 2016)	3.7 (California Energy Commission, 2018)		104 (Diaz et al., 2016)	461 (Diaz et al., 2016)	W = 176 2006 A = 705.1 in 2013 (Diaz et al., 2016)	N/A	Surface Discharge (Diaz et al., 2016).	N/A.	
USA	Jersey Valley	Jersey Valley	2011 (DiPippo, 2016)	23.5 (Rose, 2019)	13 (Rose, 2019)	159-209 (Diaz et al., 2016)				The strategy combines infield (200 m) and peripheral infied (0.6–1 K m) injection (Diaz et al., 2016).	No records found.	Current localised exploitation zone is >165 °C (Diaz et al., 2016).
USA	Lightning Dock	Burgett Greenhouse	2008 (DiPippo, 2016)	0.4 (DiPippo, 2016)		107 (Diaz et al., 2016)				No records found.	No records found.	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
USA	Lightning Dock	Lightening Dock (Dale Burgett)	2013 (DiPippo, 2016)	4 (DiPippo, 2016)		140-157 (Diaz et al., 2016)				Full reinjection (Diaz et al., 2016). Reinjection target to the same horizon as they produce from (Crowell and Crowell, 2014). After tracer test, injection of cool water was decreased and then stopped completely as a precaution to avoid thermal breakthrough. Further tracer tests will decide the desirable rate of injection to prevent thermal breakthrough (Reimus et al., 2018).	Tracer results shows the risk/possibility of thermal breakthrough (Reimus et al., 2018).	Further development is undergoing to add 6 MW extra (Reimus et al., 2018)
USA	Long Valley/ Casa Diablo	Mammomth I & II, and PLES (all aka: Mammoth)	1984 (DiPippo, 2016)	47.5 (California Energy Commission, 2018)	37 (California Energy Commission, 2018)	170.5 (Diaz et al., 2016)	741 (Diaz et al., 2016)	3060 for 40 MW (Report, 2017)	2139 in 2013 (Diaz et al., 2016)	Full reinjection at ~85 °C (Report, 2017). The minimum distance between production and injection is 500 m. In the beginning, the injection was performed at a shallow level, but later shifted to a deeper zone (Diaz et al., 2016). Isobutane is occasionally injected into the reservoir when leaks occur in the heat exchanger, and its presence in fumarole gas emissions provides a means to track subsurface migration of injectate from the plant (Bergfeld et al., 2015).	The cooler reinjection has made aquifer cooling that resulted in local subsidence and expansion of hot ground into the surrounding forest (Report, 2017). At an earlier injection strategy, there was a temperature decline due to shallow infield reinjection. Shifting to deep injection improved temperature drop since most of the fluid flows away from the well(Diaz et al., 2016). A significant pressure drawdown has been reported (Report, 2017).	
USA	McGuinness Hills	McGinness Hill McGinneess Expansion	2012 (DiPippo, 2016)	216.9 (Rose, 2019)	106 (Rose, 2019)	151-193 (Diaz et al., 2016)		1814 for 102 MW (Lovekin et al., 2016)	1632 for 102 MW (Lovekin et al., 2016)	The production in a quarter-section of the north area while injection wells are in the south. The distance of injection wells is at least	Overall, injection has been successful in maintaining reservoirs. The temperature and production have stabilized over 5 years	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										1.6 km from production clusters. Wells target permeable zones (Lovekin et al., 2016).	due to the fact that the geological setting provide excellent condition for injection fluid to be heated and return back to the production well. Only modest pressure decline has been encountered (Lovekin et al., 2016).	
USA	Neal Hot Springs	Neal Hot Springs	2012 (DiPippo, 2016)	33 (DiPippo, 2016)		141 (Sifford, 2014)		2574 for 30 MW (Warren, 2016)		Full reinjection (Warren, 2016). Injection wells are located in the NW and south of production well clusters with a distance range of 700 - 1350 m. 92% of water is injected in fault sectors from 3 injection wells with a deeper depth than production. The brine temperature is 50 °C. There are deep and moderate depth injection wells, but moderate wells have been shut in based on cooling indication (Weijermars et al., 2017)	Earlier, injection was performed at moderate depths and in deep wells. But earlier cooling water has been observed, based on test and thermal response, in a production well near a moderately deep injection well, therefore moderately deep wells have been shut-in. Currently, there has been no further temperature decline as per current configuration (most injectate goes to deep well) (Warren, 2016).	
USA	Klamath Falls	Oregon Institute of Technology (OIT)	2010 (DiPippo, 2016)	2.03 (DiPippo, 2016)		89 (Sifford, 2014)		59 (Chiasson, 2013)		Full reinjection. Injection located 600 m west of the production site (Diaz et al., 2016).	No records found.	
USA	Paisley	Paisley	2014 (DiPippo, 2016)	2.5 (DiPippo, 2016)	1.3 in Aug 2016 (Openei, 2016)	110 (Sifford, 2014)		180 for 2.4 MWe (Mink et al., 2015)	180 for 2.4 MW (Mink et al., 2015)	Full reinjection strategy with injection well targeting fault in deeper elevation without additional injection pressure (Mink et al., 2015)	No records available.	Production wells are at depth of 415 m and 384 m. An Injection well depth is 824 m (Mink et al., 2015)
USA	Patua	Patua	2013 (DiPippo, 2016)	48 (DiPippo, 2016)	23 (Rose, 2019)	160-218 (Diaz et al., 2016)	Initial 668 (Garg et al., 2015b) Current 652	919 for 30 MW (Garg et al., 2015b)	919 (Garg et al., 2015b)	Full reinjection strategy with brine temperature of 65 °C. The strategy is divided based on the characteristics of the	Some wells have remained at a constant temperature while the others exhibit temperature decline. A west field	Injection wells target the reservoir (Cladouhos et al., 2017).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
							(Garg et al., 2015b)			reservoir compartment. (west field and east field). West main field includes edgefield with distance of 1.5–2.2 km. An infield well is added to the field (500–750 m) to support pressure. The east field has an edgefield well with a distance of 1.5–2.3 km, and one infield well with a distance of 500–750 m (Cladouhos et al., 2017).	compartment has shown temperature decline but has stabilized under reduced rates. The east field compartment shows a stable temperature. In general, the injection provides pressure support even though there is slight cooling in some production wells (in the west area) (Murphy et al., 2017).	
USA	Raft River	Raft River	2008 (DiPippo, 2016)	18 (DiPippo, 2016)		133 – 149 (Feigl et al., 2018)	589 (Diaz et al., 2016)	1080 for 13 MW (Rose et al., 2017)		Full reinjection (DiPippo and Kitz, 2015). All brine is reinjected to injection wells and one EGS well. Injection wells are located edgefield for EGS wells and east injection wells (1.7 km) and infield (750 m) (Feigl et al., 2018). During the summer months, additional reinjection is performed at 750 m west of the main production zone, to give pressure support (Diaz et al., 2016)	Significantly increased permeability and injectivity in injection wells after cold-water stimulation at low WHP (Bradford et al., 2017). Uplift that is caused by overpressure in the injection reservoir, but subsidence in the deeper production zone (Feigl et al., 2018). In 2011, there was tracer breakthrough between summer-injection wells and near-production wells (Diaz et al., 2016).	Geological features direct fluid pathways (Diaz et al., 2016).
USA	Salt Wells	Salt Wells	2009 (DiPippo, 2016)	23.6 (DiPippo, 2016)	16 (Rose, 2019)	190 (Diaz et al., 2016)		2063 for 20 MWe (Diaz et al., 2016)	2063 for 20 MWe (Diaz et al., 2016)	Total reinjection (Diaz et al., 2016).	No records found	Power plant uses fluid of ~140 °C (Diaz et al., 2016).
USA	San Emidio	San Emidio/ Empire	1987 (DiPippo, 2016)	12 (DiPippo, 2016)	10 (Rose, 2019)	155 (Diaz et al., 2016)		873 (Diaz et al., 2016)	873 (Diaz et al., 2016)	Edgefield full injection (Diaz et al., 2016) at 97-290 m deep (shallower level) (Warren and Gasperikova, 2018).	There is an established relationship between ground inflation and injection operations, and evidence that injection cooled some	The cooling water is discharged to a cooling pond for surface discharge in the wetlands (Diaz et al., 2016).

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
											part of the reservoir (Diaz et al., 2016).	
USA	Soda Lake	Soda Lake 1 & 2	1987 (DiPippo, 2016)	23.1 (DiPippo, 2016)	11 (Rose, 2019)	182 (Diaz et al., 2016)	799 (Diaz et al., 2016)	946 for 11.1 MW (Diaz et al., 2016)	946 for 11.1 MW (Diaz et al., 2016)	Total reinjection was implemented with a mix of infield injection and edgefield injection. The furthest injection well is 1 km from production to the NW, while the closest injection well is located between the production wells (Diaz et al., 2016). One injection well was moved further due to cooling and is now used occasionally. Production and injection wells are from and into a good variety of differing depths and formations (Benoit and Lake, 2016).	From 1995–2009, there was cooling due to injection and production operations occurred in a range between 187 - 167 °C (Diaz et al., 2016). Hence, changes were made to divert one injection well and have led to a positive impact on minimizing cooling (Benoit and Lake, 2016). Soda lake has successfully stimulated an initially unproductive well by over two years of injection followed by a long shut-in period to heat the well (Lovekin et al., 2017).	The current field layout is rather unique that there is no real cluster of concentrations of injector and production well (Benoit and Lake, 2016).
USA	Steamboat Springs	Steamboat	1986 (DiPippo, 2016)	47.8 (DiPippo, 2016)	21 (Rose, 2019)	165 (Diaz et al., 2016)	676 (Diaz et al., 2016)	5476 for 37.5 MWe (Diaz et al., 2016)	5476 for 37.5 MWe (Diaz et al., 2016)	Full reinjection (Sorey and Spielman, 2017). Injection wells are adjacent to production wells (Bjornsson et al., 2014).	Production and reinjection from the same shallow aquifer have caused a temperature decline. Most of the injected water remains within the reservoir (Sorey and Spielman, 2017). Land constraints prevented the transfer of reinjection wells further from production wells (Diaz et al., 2016).	Power plants produce energy from the Lower Steamboat Hills reservoir (300 m deep) (Diaz et al., 2016).
USA	Steamboat Springs	Steamboat Hills, Galena 1–2, Galena 3 (Richard Burdett)	1988 (DiPippo, 2016)	93.6 (DiPippo, 2016)	57 (Rose, 2019)	201 (deep reservoir)/ 165 (shallow reservoir) (Diaz et al., 2016)		4144.5 for 80.94 MWe (Diaz et al., 2016)	4552 for 80.94 MWe (Diaz et al., 2016)	Full reinjection (Sorey and Spielman, 2017). Infield reinjection (Bjornsson et al., 2014) for Steamboat Hill power plant was carried out by geothermal waste mixed with the municipal domestic	No records found.	

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Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
										waste (Diaz et al., 2016).		
USA	Stillwater	Stillwater 2	1989 (DiPippo, 2016)	47.3 (DiPippo, 2016)	22 (Rose, 2019)	160 (Diaz et al., 2016)		2235 for 28 MWe (Diaz et al., 2016)	2190.8 for 28 MWe (Diaz et al., 2016)	Injection was conducted into or below the production reservoir zone (Diaz et al., 2016).	No records found.	There are solar panels complementing power plant which have an installed capacity of 26 MW available during peak hours (Diaz et al., 2016).
USA	Thermo Hot Springs	Thermo Hot Springs (Hatch)	2013 (DiPippo, 2016)	14 (DiPippo, 2016)		175-180 (Diaz et al., 2016)				Full reinjection (Diaz et al., 2016).	No records found.	
USA	Tuscarora	Tuscarora	2012 (DiPippo, 2016)	30 (DiPippo, 2016)	20 (Rose, 2019)	172 (Chabora et al., 2015)		339 (Chabora et al., 2015)	339 (Chabora et al., 2015)	Full reinjection (Chabora et al., 2015). Reinjection wells are located at a distance of 500 m for infield and 1 - 1.3 km for further location to the north of the field. One injector is used to inject condensate in the southern part of the field with a distance of roughly 700 m (Chabora et al., 2015). After a thermal breakthrough and tracer evidence that shows a strong connection with previous injection wells, a change of injection well was adapted (Chabora et al., 2015).	Thermal breakthrough in the first 2 years of exploitation (3.5 Fahrenheit per year). After the change of injection well, nearly immediate temperature recovery was achieved (Chabora et al., 2015).	
USA	Wabuska	Wabuska 1 & 2	1984 (DiPippo, 2016)	5.6 (DiPippo, 2016)	2 (Rose, 2019)	104 (Diaz et al., 2016)	436 (Diaz et al., 2016)	607.6 (Diaz et al., 2016)	N/A	Surface Discharge (Diaz et al., 2016).	No records found.	
USA	Wild Rose	Don A. Campbell (Wild Rose)	2013 (DiPippo, 2016)	40 (DiPippo, 2016)	40 (Rose, 2019)	126.7 (Diaz et al., 2016)				Full reinjection. Injection wells are located to the east of producing areas with a distance of approximately 1.5–2.2 km (Orenstein et al., 2015).	No sign of temperature decline yet (Orenstein et al., 2015).	
USA	Tungsten Mountain	Tungsten Mountain	2017 (Rose, 2019)	43.5 (Akar et al., 2018)	29 (Rose, 2019)					No records found.	No records found.	

Appendix F. Unclassified systems

Country	Field	Power Plant	Start date	Installed capacity (MWe)	Current generation (MWe)	Reservoir Temp (C)	Average enthalpy (kJ/kg)	Produced mass (ton/hr)	injection mass (ton/hr)	Reinjection strategy	Effects of reinjection	Additional notes
Indonesia	Lumut Balai	Lumut Balai	2019	55	55	240				No records available	No records available	
Indonesia	Muara Laboh	Muara Laboh	2019	80		230 - 310				No records available	No records available	
Indonesia	Sokoria	Sokoria	2019	45						No records available	No records available	
Indonesia	Sorik Merapi	Sorik Merapi	2019	5						No records available	No records available	
Japan	Kagoshima	Kirishima/ Kirishima International	1996 (DiPippo, 2016)	0.1 (DiPippo, 2016)	0.027 (Yasukawa and Sasada, 2015)					No records available	No records available	
Kenya	Olkaria	Oserian	2004 (DiPippo, 2016)	3.2 (DiPippo, 2016)	3.2 (Ouma et al., 2016)					Reinjection back to field to maintain mass balance (Diaz et al., 2016)	No records available	
Kenya	Olkaria	Olkaria V	2019	185						No records available	No records available	
Russia	Mendeleevskaya-Goryachii Plyazh	Mendeleevskaya (Goryachii Playzh)	2004 (DiPippo, 2016)	1.8 (Svalova and Povarov, 2015)	1.8 (Svalova and Povarov, 2015)					No records available	No records available	
USA	Florida Canyon Mine	Florida Canyon Mine	2012	0.1						No records available	No records available	Co-production

References

Addison, S.J., Brown, K.L., Von Hirtz, P.H., Gallup, D.L., Winick, J.A., Siega, F.L., Gresham, T.J., 2015. Brine silica management at mighty River power, New Zealand. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, pp. 1–18, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/27028.pdf%0A%0A.

Addison, S., Azwar, L., Clearwater, J., Hernandez, D., Mountain, B., Blair, A., Siratovich, P., 2017. Improving the conceptual understanding through a recent injection of 200 GBq of iodine - 125 at the rotokawa geothermal Field, New Zealand. In: Proc. 42nd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=27843.

Adi, A.C., Lasnawatin, F., Indarwati, F., Committee, T., Indarwati, F., Anutomo, I.G., Thaib, Z., Ambarsari, L., Yusuf, M., Suzanty, V.M., Yuanningrat, H., 2018. Handbook of Energy & Economic Statistics of Indonesia by Ministry of Energy and Mineral Resources Republic of Indonesia. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia.pdf.

Agani, M., Patangke, S., Hartanto, D.B., Silaban, M., 2015. Opportunity and barriers to develop a bottoming unit by utilizing separated Hot brine in ulubelu, Indonesia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/26029.pdf%0A%0A.

Akar, S., Agustine, C., Kurup, P., Mann, M., 2018. Global Value Chain and Manufacturing Analysis on Geothermal Power Plant Turbines. http://www.manufacturingcleanenergy.org/pdfs/akar-et-al_grc-2017.pdf.

Akin, S., 2019. Geothermal re-injection performance evaluation using surveillance analysis methods. Renew. Energy 139, 635–642. https://doi.org/10.1016/j.renene.2019.02.075.

Aksoy, N., 2019. Personal Communication, Via Email 8 Mei.

Antayhua-Vera, Y., Lermo-Samaniego, J., Quintanar-Robles, L., Campos-Enríquez, O., 2015. Seismic activity and stress tensor inversion at Las Tres Vírgenes Volcanic and Geothermal Field (México). J. Volcanol. Geotherm. Res. 305, 19–29. https://doi.org/10.1016/j.jvolgeores.2015.08.005.

Aráuz-torres, M.A., Thorsteinsson, T., Fridriksson, T., 2015. Modelling H2S dispersion from San Jacinto-tizate geothermal power plant, Nicaragua. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2014-03.pdf%0A%0A.

Arellano, R.M., Barragán, V.M., Ramírez, M., López, S., Paredes, A., Aragon, A., Tovar, R., et al., 2015a. The response to exploitation of the Los humeros (méxico) geothermal Reservoir. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Arellano, V.M., Barragan, R.M., Remirez, M., Lopez, S., Paredes, A., Aragon, A., Casimiro, E., Reyes, L., 2015b. The Los azufres (Mexico) geothermal Reservoir: Main processes related to exploitation (2003 - 2011). In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Arias Hernández, J., Torres Mora, Y., Sánchez Rivera, E., 2015. Commercial production Wells acid 15 successful years of activity, miravalles geothermal. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14058.pdf.

Ármannsson, H., Fridriksson, T., Benjamínsson, J., Hauksson, T., 2015. History of chemical composition of geothermal fluids in krafla, northeast Iceland, with Special emphasis on the liquid phase. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Asada, H., Yamada, S., 2017. Takigami Binary Power Plant the Largest Geothermal ORC Plant in Japan. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033877.pdf%0A%0A.

Askari, M., Azwar, L., Clark, J., Wong, C., 2015. Injection management in kawerau geothermal Field, New Zealand. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pdfs.semanticscholar.org/a659/cd309722cde59f1c6f353f34ec047aede2e0.pdf.

Asturias, F.A., 2012. Status update of geothermal development in Guatemala. In: in: Short Course Geotherm. Dev. Geotherm. Wells, Santa Tecla, El Salvador. March 11-17. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-14-09.pdf%0A%0A.

Atlason, R.S., Gunnarsson, A., Unnthorsson, R., 2015. Turbine repair at Nesjavellir geothermal power plant: an Icelandic case study. Geothermics. 53, 166–170. https://doi.org/10.1016/j.geothermics.2014.05.015.

Axelsson, G., 2012. Role and management of geothermal reinjection. Short Course Geotherm. Dev. Geotherm, pp. 1–21. Wells, Santa Tecla, El Salvador, March 11-17. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-14-29.pdf%0A%0A.

Axelsson, G., Arnaldsson, A., Berthet, J.-C.C., Bromley, C.J., Gudnason, E.Á., Hreinsdóttir, S., Karlsdóttir, R., Magnússon, I.T., Michalczewska, K.L., Sigmundsson, F., Sigurdsson, O., 2015. Renewability assessment of the reykjanes geothermal system, SW-Iceland. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. http://georg.cluster.is/wp-content/uploads/2016/12/renewability-assessment-of-the-reykjanes-geothermal-system-sw-iceland.pdf.

Aydin, H., Akin, S., Tezel, S., 2018. Practical experiences about Reservoir monitoring in alaşehir geothermal Field. In: Proc. 43rd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 12-14.

Barbour, A.J., Evans, E.L., Hickman, S.H., Eneva, M., 2016. Sources of subsidence at the salton Sea geothermal Field. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24. https://pubs.er.usgs.gov/publication/70168522.

Beardsmore, G., Budd, A., Huddlestone-holmes, C., Davidson, C., 2015. Country update — Australia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://s3.amazonaws.com/academia.edu.documents/40822429/01032.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1505369940&Signature

=6oVibI5jvdvlhQtJchmNPrqvyjM%3D&response-content-disposition=inline%3Bfilename%3DTomas_Alva_Edison.pdf.
Beardsmore, G., Gutiérrez-negrín, L., Garduño-monroy, V., Almanza-, S., 2017. Trial deployment of a surface heat flow probe Over the Los azufres geothermal region, Mexico. In: Proc. 42nd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=27862.
Benato, S., Hickman, S., Davatzes, N., Taron, J., Spielman, P., Elsworth, D., Mejer, E., Boyle, K., 2016. Conceptual model and numerical analysis of the Desert Peak EGS project: reservoir response to the shallow medium flow-rate hydraulic stimulation phase. Geothermics. 63, 139–156. https://doi.org/10.1016/j.geothermics.2015.06.008.
Bendea, C., Rosca, M.G., Iacobescu, A., Bendea, G., Street, U., Street, V.A., 2015. Cascaded uses of geothermal Water in iosia District, Oradea, Romania. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/38008.pdf%0A%0A.
Benoit, D., 2014. The long-term performance of Nevada geothermal projects utilizing flash plant technology. GRC Trans. 38, 977–984. pubs.geothermal-library.org/lib/grc/1033648.pdf%0A%0A.
Benoit, W.R., 2015. A case history of the dixie valley geothermal field, 1963–2014. GRC Trans. 39, 3–12. pubs.geothermal-library.org/lib/grc/1032128.pdf.
Benoit, D., Lake, Soda, 2016. Geothermal field case history 1972 to 2016. GRC Trans. 40, 523–534. pubs.geothermal-library.org/lib/grc/1032367.pdf%0A%0A.
Bergfeld, D., Vaughan, R.G., Evans, W.C., Olsen, E., 2015. Monitoring ground-surface heating during expansion of the Casa Diablo production well field at mammoth lakes, California. GRC Trans. 39, 1007–1014. pubs.geothermal-library.org/lib/grc/1032246.pdf%0A%0A.
Bertani, R., 2016. Geothermal power generation in the world 2010-2014 update report. Geothermics. 60, 31–43. https://doi.org/10.1016/j.geothermics.2015.11.003.
Bjornsson, G., 2008. Review of Generating Capacity Estimates for the Momotombo Geothermal Reservoir in Nicaragua.
Björnsson, S., Gudmundsdottir, I., Ketilsson, J., 2010. Geothermal Development and Research in Iceland. https://doi.org/10.1109/PDP.2015.86.
Bjornsson, G., Arnaldsson, A., Akerley, J., Geothermal, R., 2014. A 3D numerical reservoir model for Steamboat, Nevada. GRC Trans. 38, 917–926.
Bodvarsson, G., 1989. Some theoretical and field aspects of reinjection in geothermal reservoir. Water Resour. Res. 25, 1235–1248 onlinelibrary.wiley.com/doi/10.1029/WR025i006p01235/pdf%0A%0A.
Boissavy, C., Rocher, P., Laplaige, P., Brange, C., 2016. Geothermal energy use, Country update for France. In: in: Proc. Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September.
Boyd, T.L., Sifford, A., Lund, J.W., 2015. The United States of America Country update 2015. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/01009.pdf%0A%0A.
Bradford, J., McLennan, J., Moore, J., Podgorney, R., Plummer, M., Nash, G., 2017. Analysis of the thermal and hydraulic stimulation program at Raft River, Idaho, Rock Mech. Rock Eng. 50, 1279–1287. https://doi.org/10.1007/s00603-016-1156-0.
Bromley, C.J., Currie, S., Jolly, S., Mannington, W., 2015. Subsidence: an update on New Zealand geothermal deformation observations and mechanisms. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/02021.pdf%0A%0A.
Buck, C., 2016. Cumulative injection effects on well 66A-7 in the Coso Geothermal Field. GRC Trans. 40, 491–494. pubs.geothermal-library.org/lib/grc/1032362.pdf%0A%0A..
Buscarlet, E., Moon, H., Wallis, I., Quinao, J., 2015. Reservoir tracer test at the ngatamariki geothermal Field, New Zealand. In: in: Proc. 37th New Zeal. Geotherm. Work. Taupo, New Zealand, 18-20 November.
Buscarlet, E., Richardson, I., Addison, S., Moon, H., Quinao, J., Zealand, N., 2016. Geochemical modelling of plant and Reservoir processes at the ngatamariki geothermal Field. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November.
Buscarlet, E., Calibugan, A., Siega, F., 2017. Applications of sulfur isotopes in characterizing Reservoir processes at the kawerau geothermal Field, New Zealand. In: Proc. 39th New Zeal. Geotherm. Work. Rotorua, New Zealand, 22-24 November.
Calibugan, A.A., Villaseñor, L.B., Menzies, A.J., Stark, M.A., 2015a. An evaluation of the impact of MatRidge injection to matalibong production, tiwi geothermal Field, Philippines. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Calibugan, A.A., Villaseñor, L.B., Molling, P., 2015b. Applications of sulfur isotopes in characterizing the acid fluids at the tiwi geothermal. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14075.pdf%0A%0A.
California Energy Commission, 2018. California Geothermal Energy Statistics & Data (accessed February 28, 2019). https://www.energy.ca.gov/almanac/renewables_data/geothermal/.
Cardiff, M., Lim, D.D., Patterson, J.R., Akerley, J., Spielman, P., Lopeman, J., Walsh, P., Singh, A., Foxall, W., Wang, H.F., Lord, N.E., Thurber, C.H., Fratta, D., Mellors, R.J., Davatzes, N.C., Feigl, K.L., 2018. Geothermal production and reduced seismicity : correlation and proposed mechanism, Earth Planet. Sci. Lett. 482, 470–477. https://doi.org/10.1016/j.epsl.2017.11.037.
Chabora, E., Lovekin, J., Spielman, P., Krieger, Z., 2015. Resource performance at ormat's tuscarora geothermal project, Nevada USA. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06025.pdf%0A%0A.
Chiasson, A., 2013. Geothermal use in Montana, Geo heat cent. Q. Bull. 31.
Cladouhos, T.T., Uddenberg, M.W., Swyer, M.W., Nordin, Y., Garrison, G.H., 2017. Patua geothermal geologic conceptual model. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033785.pdf..
Clark, J.P., Milicich, S.D., Sewell, S.M., Askari, M., Wong, C., 2015. Finding sufficient permeability for outfield injection and recent drilling at kawerau, New Zealand. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Clearwater, J., Azwar, L., Barnes, M., Wallis, I., Holt, R., 2015. Changes in injection Well capacity during testing and plant start-Up at ngatamariki. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06008.pdf%0A%0A.
Clearwater, J., Hernandez, D., Sewell, S., Addison, S., 2016. Model-based decision making to manage production in the western compartment at rotokawa. In: Proc. 38th New Zeal. Geotherm. Work. Melbourne, Australia, 19-25 April. http://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2016/111_Clearwater_Final.pdf.
Contact Energy Ltd, 2019. Personal Communication. via email 11 June.
Contact Energy Ltd, 2018. Annual Report, 2018. https://contact.co.nz/-/media/contact/pdfs/about-us/investor-centre/media-releases/annual-report-2018-contact-energyLtd.ashx.
Crandall-Bear, A., Barbour, A.J., Schoenball, M., 2018. Irregular focal mechanisms observed at salton Sea geothermal Field : possible influences of anthropogenic stress perturbations. In: Proc. 43rd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 12-14.
Crowell, J.J., Crowell, A.M., 2014. The history of lightning dock KGRA: identifying a blind geothermal resource. GRC Trans. 38, 77–84. pubs.geothermal-library.org/lib/grc/1033520.pdf%0A%0A.
Daco-ag, L.M., Cabahug, M.R., Fernandez, I.M., Dacillo, D., Alcober, E., 2015. Update on the stable isotope geochemistry of the leyte geothermal production Field. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14046.pdf%0A%0A.
De Freitas, M.A., 2018. Numerical simulation of the svartsengi geothermal Field, Sw-Iceland. In: 40th Anniv. Work. UNU-GTP. Reykjavik, Iceland.
Dean, A., Bixley, P., Lim, Y.W., Mroczek, E., 2014. Effects of reinjection at wairakei geothermal Field. In: Proc. 36th New Zeal. Geotherm. Work. Auckland, New Zealand, 24-26 November.
Dempsey, D., Kelkar, S., Davatzes, N., Hickman, S., Moos, D., 2015. Numerical modeling of injection, stress and permeability enhancement during shear stimulation at the Desert Peak enhanced Geothermal System. Int. J. Rock Mech. Min. Sci. 78, 190–206. https://doi.org/10.1016/j.ijrmms.2015.06.003.
Diaz, A.R., Kaya, E., Zarrouk, S.J., 2016. Reinjection in geothermal fields - A worldwide review update. Renewable Sustainable Energy Rev. 53, 105–162. https://doi.org/10.1016/j.rser.2015.07.151.
DiPippo, R., 2016. Geothermal Power Plants. https://doi.org/10.1016/B978-0-08-100879-9.00023-9.
DiPippo, R., Kitz, K., 2015. Geothermal binary power plants at Raft River, San Emidio, and Neal Hot Springs: part 1 — plant descriptions and design performance comparison. GRC Trans. 39, 833–846. pubs.geothermal-library.org/lib/grc/1032225.pdf%0A%0A..
Drouin, V., Sigmundsson, F., Verhagen, S., Ófeigsson, B.G., Spaans, K., Hreinsdóttir, S., 2017. Deformation at Krafla and bjarnarflag geothermal areas, northern volcanic zone of Iceland, 1993–2015. J. Volcanol. Geotherm. Res. 344, 92–105. https://doi.org/10.1016/j.jvolgeores.2017.06.013.
EGEC, 2019. EGEC Geothermal Market Report. https://www.egec.org/media-publications/egec-geothermal-market-report-2018/%0A%0A.
Elfina, 2017. Updated Conceptual Model of the Patuha Geothermal Field, Indonesia, in: Geotherm. Train. Program. UNU-GTP, Reykjavik, Iceland, pp. 89–112. https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2017-10.pdf%0A%0A.
Enedy, S.L., Ca, S.R., 2016. Update of augmented injection benefit model of the geysers. GRC Trans. 40, 893–900.
Enel, 2015. Enel Revised Plan of Utilization.
Enel Green Power, 2019. Where We Are (accessed January 31, 2019). https://www.enelgreenpower.com/where-we-are?topic=geothermal&plant_name=.
Eneva, M., Barbour, A., Adams, D., Hsiao, V., Blake, K., Falorni, G., Locatelli, R., 2018. Satellite observations of surface deformation at the Coso Geothermal Field, California. GRC Trans. 42. https://pubs.er.usgs.gov/publication/70203285%0A%0A.
ErgonEnergy, 2014. Birdsville Organic Rankine Cycle Geothermal Power Station https://www.ergon.com.au/_data/assets/pdf_file/0008/4967/EGE0425-birdsville-geothermal-brochure-r3.pdf.
Escobar, R., 2018. Geothermal development in el salvador and the importance of the contribution of fellows of the UNU-GTP programme. In: 40th Anniv. Work. UNU-GTP. Reykjavik, Iceland. E.L.S.C. A.https://orkustofnun.is/gogn/unu-gtp-40…/UNU-GTP-40-A-5-PPT-Rosa-Escobar.pdf%0A%0A.
Espartinez, C.M.R., See, F.S.S., 2015. The BacMan geothermal Field, Philippines : geochemical changes and operational challenges after twenty years of production. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24003.pdf.
Evans, K.F., Zappone, A., Kraft, T., Deichmann, N., Moia, F., 2012. A survey of the induced seismic responses to fluid injection in geothermal and CO2 reservoirs in Europe. Geothermics. 41, 30–54. https://doi.org/10.1016/j.geothermics.2011.08.002.
Febriani, R., Nurbiyantoko, S., Wicaksono, T., Harahap, R., Dwikorianto, T., 2015. Reinjection strategy analysis in the Well KMJ-21 against the mass flow rate of production wells in kamojang geothermal Field, Indonesia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Feigl, K.L., Mellors, R.J., Reinisch, E.C., Fu, P., Plummer, M.A., Ali, S.T., Liu, F., Liu, Q., 2018. Inferring geothermal reservoir processes at the Raft River Geothermal Field,

Idaho, USA, through modeling InSAR-Measured surface deformation. J. Geophys. Res. Solid Earth 123, 3645–3666. https://doi.org/10.1029/2017jb015223.
Fisch, H., Uhde, J., Bems, C., Lang, P., Bartels, J., 2015. Hydraulic testing and Reservoir characterization of the taufkirchen site in the Bavarian molasse Basin, Germany. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22123.pdf%0A%0A.
Flóvenz, Ó.G., Ágústsson, K., Árni Guðnason, E., Kristjánsdóttir, S., 2015. Reinjection and induced seismicity in geothermal fields in Iceland. In: Proc. World Geotherm. Congr. Melbourne, Australia, 19-25 April, 2015. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/23013.pdf%0A%0A.
Franco, A., Vieira, N., Ponte, C., 2017. Geothermal developments in Pico Alto, Terceira Island, Portugal. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033706.pdf%0A%0A.
Fukuda, M., Tosha, T., Sugisaki, M., Shimada, T., Nakashima, H., 2015. Transient electromagnetic survey using HTS-SQUID sensor in the ogiri geothermal Field, Southwestern Japan. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pdfs.semanticscholar.org/6bf8/47e1410a1e46b310f887b2948b377fc65928.pdf%0A%0A.
Fukuda, D., Kuwano, T., Itoi, R., 2018. Estimation of the steam fraction of injected water at the Matsukawa vapor-dominated geothermal field using two-component, two-phase tracers. Geothermics. 71, 167–177. https://doi.org/10.1016/j.geothermics.2017.08.007.
Garg, S.K., Haizlip, J., Bloomfield, K.K., Kindap, A., Haklidir, F.S.T., Guney, A., 2015a. A numerical model of the kizildere geothermal field, Turkey. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/22014.pdf.
Garg, S.K., Goranson, C., Johnson, S., Casteel, J., 2015b. Reservoir testing and modeling of the patua geothermal Field, Nevada, USA. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22042.pdf%0A%0A.
Geothermal ERA-NET, 2016. Operational Issues in Geothermal Energy in Europe, Geothermal ERA NET. www.geothermaleranet.is/media/publications/OpERA_AnnexII_reduced.pdf.
Geotis, 2018a. Geothermal Electricity Generation in Germany (accessed December 12, 2018). https://www.geotis.de/geotisapp/templates/summationpower.php.
Geotis, 2018b. Geothermal Installation of Grünwald (Laufzorn) (accessed December 20, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=70.
Geotis, 2018c. Geothermal Installation of Dürrnhaar (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=44.
Geotis, 2018d. Geothermal Installation of Kirchstockach (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=60.
Geotis, 2018e. Geothermal Installation of Sauerlach (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=86.
Geotis, 2018f. Geothermal Installation of Taufkirchen (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=94.
Geotis, 2018g. Geothermal Installation of Traunreut (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=97.
Geotis, 2018h. Geothermal Installation of Unterhaching (accessed December 18, 2018). https://www.geotis.de/geotisapp/templates/locationone.php?ID=103.
Gherardi, F., Droghieri, E., Magro, G., 2014. Hydrothermal processes at Aluto-Langano (Ethiopia): insights from the stable carbon isotope composition of fluid inclusions. GRC Trans. 38, 439–444.
Giriarso, J.P., Puspadianti, A., Hartanto, D.B., Siahaan, E.E., 2015. Initial geochemical monitoring ulubelu geothermal Field. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14006.pdf.
Gitobu, G.G., 2017. Model organic rankine cycle for brine at Olkaria Geothermal Field, Kenya. GRC Trans. 41. https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2016-15.pdf%0A%0A.
González, Z., González, D., Kertzschmar, T., González Acevedo, Z.I., González, D., Acevedo, T.G.Kretzschmar, 2015. First approach of environmental impact assessment of Cerro prieto geothermal power plant, BC Mexico. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://colecciondigital.cemiegeo.org/xmlui/handle/123456789/409?show=full.
Grant, M.A., Hole, H., Melaku, M., PLN, P., 1997. Efficient well testing at ulumbu field, flores, Indonesia. In: in: Proc. Twenty-Second Geotherm. Reserv. Eng. Stanford University, Stanford, California, pp. 83–87. January 27-29. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=420.
Grigoli, F., Cesca, S., Rinaldi, A.P., Manconi, A., Clinton, J.F., Westaway, R., Cauzzi, C., Dahm, T., Wiemer, S., 2018. The November 2017 Mw 5.5 Pohang earthquake: a possible case of induced seismicity in South Korea. Science (80-.) 5, 1003–1006. https://doi.org/10.1126/science.aat2010.
GT'2019, 2019. Turkey Geothermal Congress Public Session, Türkiye Jeotermal Kongresi Açılış Konuşmaları & Kamu oturumu, in: Turkey Geotherm. Congr. 2019, 6-7 Febr. 2019. Bilkent Hotel. Ankara, Turkey. https://geothermalturkey.org/videolar.
Gunnarsson, G., 2013. Temperature dependent injectivity and induced seismicity - managing reinjection in the Hellisheidi Field, SW-Iceland. GRC Trans. 37, 1019–1025. http://www.scopus.com/inward/record.url?eid=2-s2.0-84897617241&partnerID=tZOtx3y1.
Gunnarsson, I., Júlíusson, B.M., Aradóttir, E.S., Sigfússon, B., ûór, M., 2015. Pilot scale geothermal gas separation, hellisheiði power plant, Iceland. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/02001.pdf%0A%0A.
Gunnarsson, G., Mortensen, A.K., Reykjavíkur, O., Reykjavík, I.-, 2016. Dealing with intense production density: challenges in understanding and operating the hellisheidi geothermal Field, SW-Iceland. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24.
Guo, Q., Cao, Y., Li, J., Zhang, X., Wang, Y., 2015. Natural attenuation of geothermal arsenic from Yangbajain power plant discharge in the Zangbo River, Tibet, China. Appl. Geochem. 62, 164–170. https://doi.org/10.1016/j.apgeochem.2015.01.017.
Gutiérrez Negrín, L.C.A., Lippmann, M.J., 2016. Mexico: thirty-three years of production in the Los azufres geothermal field. Geotherm. Power Gener. Dev. Innov. 717–742. https://doi.org/10.1016/B978-0-08-100337-4.00024-3.
Halaçoğlu, U., Fishman, M., Karaağaç, U., Harvey, W., 2018. Four decades of service – kızıldere Reservoir, units and management. GRC Trans. 42.
Hanano, M., 2003. Sustainable steam production in the Matsukawa Geothermal Field, Japan. Geothermics. 32, 311–324. https://doi.org/10.1016/S0375-6505(03)00023-3.
Harwood, K., Koorey, K., Mann, C., 2015. Te mihi steamfield production development design. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/25012.pdf.
Heberle, F., Jahrfeld, T., Brüggemann, D., Thermodynamik, T., Bayreuth, U., 2015. Thermodynamic analysis of double-stage organic rankine cycles for Low-enthalpy sources based on a case study for 5.5 MWe power plant kirchstockach (Germany). In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Heberle, F., Eller, T., Brüggemann, D., 2016. Thermoeconomic evaluation of one- and double-stage ORC for geothermal combined heat and power production. In: in: Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September.
Hendriansyah, T., Wicaksono, T., 2015. Tracing reinjected condensate using microearthquake monitoring at the kamojang geothermal Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pdfs.semanticscholar.org/624a/a27a0cfbf247efaf1f966421b28030326560.pdf%0A%0A.
Hernandez, D., Addison, S., Sewell, S., Barnes, M., 2015. Rotokawa: Reservoir response of 172 MW geothermal operation. In: Proc. 37th New Zeal. Geotherm. Work. Taupo, New Zealand, 18-20 November. http://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2015/36_Hernandez.pdf.
Hernández, A.F., Arellano, V.M., Barragán, R.M., Espinoza, E.C., Reyes, L., Mendoza, A., 2015. A study of reinjection and connectivity between Wells in the Los azufres (Mexico) geothermal Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22063.pdf%0A%0A.
Hirayama, S., Itoi, R., Tanaka, T., Takayama, J., 2015. Reservoir simulation for reinjected Water return in produced fluid of Wells at ogiri geothermal Field, Japan. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22137.pdf.
Hoagland, J., Bodell, J., 1990. The Tiwi geothermal reservoir: geology, geochemistry, and response to production. Am. Assoc. Pet. Geol. Bull. 74, 979.
Hoepfinger, V., Marsh, A., Maginness, R., 2015. Adapting surface facilities to changes in rotokawa reservoir in the first 5 years of nga awa purua. In: Proc. 37th New Zeal. Geotherm. Work. Taupo, New Zealand, 18-20 November.
Huttrer, G.W., 2020. Geothermal power generation in the world 2015-2020 update report. In: IcelandProc. World Geotherm. Congr. Reykjavik, 2020, pp. 1–17. April 26 - May 2.
IEA, 2019. 2019 Iceland Country Report.
Iglesias, E.R., Flores-armenta, M., Torres, R.J., Ramirez-montes, M., Reyes-picaso, N., Cruz-grajales, I., 2015. Tracer testing at Los humeros, Mexico, High-enthalpy geothermal Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22108.pdf%0A%0A.
Ikeda, R., Ueda, A., 2017. Experimental field investigations of inhibitors for controlling silica scale in geothermal brine at the Sumikawa geothermal plant, Akita Prefecture, Japan. Geothermics. 70, 305–313. https://doi.org/10.1016/j.geothermics.2017.06.017.
Ingimundarson, A., Arnarson, M.û., Sighvatsson, H., Gunnarsson, T., 2015. Design of a H2S absorption column at the hellisheiði powerplant. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
IRENA, 2017. Geothermal Power: Technology Brief. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf.
Jalilinasrabady, S., Itoi, R., 2015. Exergetic classification of geothermal resources in Japan. Proc. World Geotherm. Congr. Melbourne, Australia, 19-25 April, 2015. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/16025.pdf%0A%0A.
Juliusson, E., Markusson, S., Sigurdardottir, A., 2015. phase-specific and phase-partitoning tracer experiment in the krafla Reservoir, Iceland. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22038.pdf%0A%0A.
Juncu, D., Árnadóttir, T., Geirsson, H., Guðmundsson, G.B., Lund, B., Gunnarsson, G., Hooper, A., Hreinsdóttir, S., Michalczewska, K., 2018. Injection-induced surface deformation and seismicity at the Hellisheidi geothermal field, Iceland. J. Volcanol. Geotherm. Res. https://doi.org/10.1016/j.jvolgeores.2018.03.019.
Karahan, C., Yildirim, N., Atac, T., 2015. Production and Re-injection strategies at celikler holding first 45 GPP on pamukören- Aydin geothermal Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Kaspereit, D., Rickard, W., Osborn, W., Mann, M., Perez, M., 2016. Field management and expansion potential of the momotombo geothermal Field using numerical simulation and conceptual modeling. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=26455.
Kaven, J.O., Hickman, S.H., Davatzes, N.C., 2014. Micro-seismicity and seismic moment release within the coso geothermal Field, California. In: Proc. Thirty-Ninth Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 24-26.

https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2013/Kaven.pdf%0A%0A.
Kaya, E., Zarrouk, S.J., O'Sullivan, M.J., 2011. Reinjection in geothermal fields: a review of worldwide experience. Renew. Sustain. Energy Rev. 15, 47–68. https://doi.org/10.1016/j.rser.2010.07.032.
Kaya, E., Zarrouk, S., O'Sullivan, M.J., 2015. Reinjection in geothermal fields, a worldwide review and analysis. Proc. World Geotherm. Congr. 2015 19–25. http://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/23010.pdf.
Kaya, E., Callos, V., Mannington, W., 2018. CO2 –water mixture reinjection into two-phase liquid dominated geothermal reservoirs. Renew. Energy 126, 652–667. https://doi.org/10.1016/j.renene.2018.03.067.
Kirby, S., Simmons, S., Gwynn, M., Allis, R., Moore, J., 2015. Comparisons of geothermal systems in Central Nevada: evidence for deep regional geothermal potential based on heat flow, geology, and fluid chemistry geochemistry of thermal waters. GRC Trans. 39, 25–34. pubs.geothermal-library.org/lib/grc/1032130.pdf%0A%0A..
Kiryukhin, A.V., Rutqvist, J., Maguskin, M.A., 2015. Modeling of the vertical deformations during exploitation of the mutnovsky geothermal Field, kamchatka. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22086.pdf%0A%0A.
Kolar, M., Osgood, S., Echt, W., 2015. Coso case study : 22 years of reliable sulfur removal. GRC Trans. 39, 867–872. pubs.geothermal-library.org/lib/grc/1032229.pdf%0A%0A.
Kolesnikov, D.V., Lyubin, A.A., Shulyupin, A.N., 2015. Geothermal power generation in kamchatka, russia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/26058.pdf%0A%0A.
Kondo, K., Itoi, R., Tanaka, T., Iwasaki, T., 2017. Numerical simulation of the sumikawa geothermal reservoir, Japan, using iTOUGH2. In: in: Proc. 42nd Geotherm. Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15, https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2017/Kondo.pdf.
Kristjansdottir, S., Agustsson, K., Gudmundsson, O., Tryggvason, A., Fehler, M., 2016. Induced seismicity during reinjection of wastewater in hellisheidi geothermal Field, Southwest Iceland. In: Proc. Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September, https://geothermalworkshop.com/wp…/12/ggw-2018-b2-sigridur-kristjansdottir.pdf%0A%0A.
Kristjansson, B., Axelsson, G., Gunnarsson, G., Gunnarsson, I., Oskarsson, F., 2016. Comprehensive tracer testing in the hellisheidi geothermal Field in SW-Iceland 2013-14. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford Univ. Stanford University, Stanford, California. February 22-24. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=26460.
Kudo, K., 1996. 3,000 kW Suginoi Hotel Geothermal Power Plant.
Kuna, I., Zehner, R., 2015. Papua New Guinea Country update. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Kwiatek, G., Bulut, F., Bohnhoff, M., Dresen, G., 2014. High-resolution analysis of seismicity induced at Berlín geothermal field, El Salvador. Geothermics. 52, 98–111. https://doi.org/10.1016/j.geothermics.2013.09.008.
Lawson, R., Gresham, T., Richardson, I., Siega, F., Addison, S., Zealand, N., 2016. Long run polymerization experiments at the kawerau geothermal limited power plant. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November.
Leech, C.N., 2017. Assessing the scaling potential in Hot reinjection Wells in the olkaria geothermal Field, Kenya. In: Proc. 42nd Geotherm. Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15.
Leland, M., Bernie, K., Connie, K., 2015. A working example of small scale geothermal energy sustainability: chena Hot Springs, Alaska. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/38003.pdf%0A%0A.
Lewis, W., Wallace, K., Dunford, T., Harvey, W., 2015. Kizildere II multiple-flash combined cycle : a novel approach for a Turkish Resource. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Li, Y., Zhang, J., Li, Z., Luo, Y., Jiang, W., Tian, Y., 2016. Measurement of subsidence in the Yangbajing geothermal fields, Tibet, from TerraSAR-X InSAR time series analysis. Int. J. Digit. Earth. 9, 697–709. https://doi.org/10.1080/17538947.2015.1116624.
Libert, F.T., 2017. Evaluation of the deepest production well in salak geothermal field, Indonesia. In: Proc.5th Indones. Int. Geotherm. Conv. Exhib. Jakarta. August 2nd - 4th.
Liwei, L., Boheng, L., 2018. Preliminary Study on the Sauerlach Geothermal Power Plant in Germany and an Introduction to the Renewable Energy Market.
Llenos, A.L., Michael, A.J., 2016. Characterizing potentially induced earthquake rate changes in the Brawley Seismic Zone, Southern California. Bull. Seismol. Soc. Am. 106, 2045–2062. https://doi.org/10.1785/0120150053.
Lopez, M.R., Torres-Rodriguez, M.A., 2015. Behavior of the production characteristics of the Wells in the Las Tres virgenes B C S geothermal Field, Mexico. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24018.pdf%0A%0A.
Lovekin, J., Delwiche, B., Spielman, P., 2016. McGinness Hills — case study of a successful expansion. GRC Trans. 40, 67–72. pubs.geothermal-library.org/lib/grc/1032309.pdf%0A%0A.
Lovekin, J., Morrison, M., Champneys, G., Morrow, J., 2017. Temperature recovery after long-term injection: case history from Soda Lake, Nevada. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033904.pdf.
Luviano, M.S., Armenta, M.F., Montes, M.R., 2015. Thermal stimulation to improve the permeability of geothermal Wells in Los humeros geothermal Field, Mexico. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22017.pdf%0A%0A.
Majer, E.L., Freeman, K., Johnson, L., Jarpe, S., Nihei, K., 2017. Monitoring the Effect of Injection of Fluids From the Lake County Pipeline on Seismicity at the Geysers, California, geothermal Field. https://www.energy.gov/sites/prod/files/2014/02/f7/seismic_majer_lake_county.pdf%0A%0A.
Malate, R.C., Prado, L.L., Guidos, J.A., 2016. Modelling of chemical and temperature changes in SJ4-1, San Jacinto-tizate geothermal Field, Nicaragua. In: in: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24.
Mangi, P.M., 2017. Geothermal Exploration in Kenya - Status Report and Updates, in: Short Course II Explor. Geotherm. Resour.. Lake Bogoria and Lake Naivasha, Kenya, Nov 9-29. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-25-0701.pdf%0A%0A.
Markusson, S.H., Hauksson, T., 2015. Utilization of the hottest Well in the world, IDDP-1 in krafla. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. iddp.is/wp-content/uploads/2015/04/1-paper-3-37009-SHM-and-TH.pdf%0A%0A.
Matsuyama, K., Takeda, Y., Shimoda, M., Takamura, K., Ono, T., 2011. Geothermal development and utilization in Hachijojima Island. Japan Soc. Eng. Geol. 51, 273–279.
Matthiasdottir, K.V., Albertsson, A., Sigurðsson, O., Friðleifsson, G.O., 2015. Tracer tests at reykjanes geothermal Field, Iceland. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22092.pdf%0A%0A.
Maturgo, K.M., Fernandez, L.C.D., Olivar, M.V.M., Esberto, M.B., Callos, P.G., Isip, H.L., Llenarizas, L.J., 2015. Challenges in the design and management of a 20-MW geothermal Field : the maibarara geothermal Field (Philippines) experience. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, pp. 1–6, 19-25 April. https://pdfs.semanticscholar.org/5785/f68de964255be44031d06657ca2608e7eba2.pdf%0A%0A.
Mayorga, H., L.S.A.D.C, V., 2012. Geothermal Reinjection Systems in El Salvador, in: Short Course Geotherm. Dev. Geotherm. Wells, Santa Tecla, El Salvador. March 11-17. https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-14-25.pdf%0A%0A.
Mazzoldi, A., Borgia, A., Ripepe, M., Marchetti, E., Ulivieri, G., Della Schiava, M., Allocca, C., 2015. Faults strengthening and seismicity induced by geothermal exploitation on a spreading volcano, Mt. Amiata, Italia. J. Volcanol. Geotherm. Res. 301, 159–168. https://doi.org/10.1016/j.jvolgeores.2015.05.015.
McNamara, D.D., Sewell, S., Buscarlet, E., Wallis, I.C., 2016. A review of the Rotokawa Geothermal Field, New Zealand. Geothermics. 59, 281–293. https://doi.org/10.1016/j.geothermics.2015.07.007.
Mertoglu, O., Basarir, N., 2018. Jeotermal merkezi isitma Ve jeotermal elektrik santralleri yatimlarinin tesvik ihtiyacinin incelenmesi. In: in: Proc. Turkiye Jeotermal Kongresi. Bilkent Otel, Ankara, 6-7 February,www.maspoenerji.com/…/File/gt2019_orhan_mertoglu_sunum.pdf%0A%0A.
Mertoğlu, O., Basarır, N., Saraçoğlu, B., 2015. First geothermal electricity production project from Non-artesian geothermal Wells in Turkey - aydın -Buharkent geothermal Field. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Mertoglu, O., Simsek, S., Basarir, N., 2016. Geothermal energy use, Country update for Turkey. In: in: Proc. Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September.
Mia, M.B., Fujimitsu, Y., Nishijima, J., 2018. Monitoring of thermal activity at the Hatchobaru-Otake geothermal area in Japan using multi-source satellite images-with comparisons of methods, and solar and seasonal effects. Remote Sens. 10 https://doi.org/10.3390/rs10091430.
Milicich, S.D., Clark, J.P., Wong, C., Askari, M., 2016. A review of the Kawerau Geothermal Field, New Zealand. Geothermics. 59, 252–265. https://doi.org/10.1016/j.geothermics.2015.06.012.
Mink, L.L., Pezzopane, S.K., Culp, E.L., 2015. Small scale geothermal development – an example of cooperation between Land owner and electrical cooperative. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06001.pdf%0A%0A.
Miranda-Herrera, C.A., 2015. Geothermal and solar energy in Cerro prieto. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.
Mohammadzadeh Bina, S., Jalilinasrabady, S., Fujii, H., Pambudi, N.A., 2018. Classification of geothermal resources in Indonesia by applying exergy concept. Renew. Sustain. Energy Rev. 93, 499–506. https://doi.org/10.1016/j.rser.2018.05.018.
Monterrosa, M., Montalvo López, F.E., 2010. Sustainability analysis of the Ahuachapán geothermal field: management and modeling. Geothermics. 39, 370–381. https://doi.org/10.1016/j.geothermics.2010.09.008.
Mortensen, A., et al., 2015. The Krafla Geothermal System. gogn.lv.is/files/2015/2015-098.pdf%0A%0A..
Mubarok, M.H., Zarrouk, S.J., 2016. Steam-field design overview of the ulubelu geothermal project, Indonesia. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November. https://www.geothermal-energy.org/pdf/IGAstandard/NZGW/2016/054_Mubarok_Final.pdf.
Murphy, J., Holt, R., Morrison, M., 2017. A numerical model case study of the patua geothermal field. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033906.pdf%0A%0A.
Naritomi, K., Nishijima, J., Ohsawa, S., Fujimitsu, Y., 2015. Monitoring of a hot spring aquifer using repeated microgravity measurements in the northern part of beppu. In: in: Proc. 37th New Zeal. Geotherm. Work. Taupo, New Zealand, 18-20 November.
Nasution, A., Yunis, Y., Afif, M., 2016. The ulumbu geothermal development West Flores, Eastern Indonesia. In: in: Proc. 11th Asian Geotherm. Symp., Chiangmai. Thailand Wood, 18-20 November.
Nietzen, F., Solis, L., 2019. Production-injection at the Costa Rica geothermal fields 1994 - 2018 Dr. Alfredo mainieri protti (formerly miravalles) and pailas. In: Proc. 44th

Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 11-13. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2019/Nietzen2.pdf.

Nietzen, F., Solís, L., Box, P.O., José, S., Rica, C., 2015. Production-injection at the Costa Rica geothermal fields : miravalles and pailas. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06045.pdf%0A%0A.

Nishijima, J., Umeda, C., Fujimitsu, Y., Takayama, J., Hiraga, N., Higuchi, S., 2016. Repeat absolute and relative gravity measurements for geothermal Reservoir monitoring in the ogiri geothermal Field, Southern kyushu, Japan. IOP Conf. Ser. Earth Environ. Sci. https://doi.org/10.1088/1755-1315/42/1/012004.

Okabe, T., Kato, M., Sato, T., Abe, Y., Asanuma, H., 2016. Current status of the EGS project for water injection in the superheated region at okuaizu geothermal field in Japan. In: in: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November. geothermal.jogmec.go.jp/report/file/session_160602_04.pdf%0A%0A.

Okamoto, K., Yi, L., Asanuma, H., Okabe, T., Abe, Y., Tsuzuki, M., 2018. Triggering processes of microseismic events associated with water injection in Okuaizu Geothermal Field, Japan, Earth. Earth Planets Space 70. https://doi.org/10.1186/s40623-018-0787-7.

Okamoto, K., Asanuma, H., Okabe, T., Abe, Y., Tsuzuki, M., 2019. Flow path of injected Water inferred from microseismic monitoring in the okuaizu geothermal Field, Japan. In: Proc. 44th Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 11-13. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2019/Okamoto.pdf%0A%0A.

Ólafsson, M., Fridriksson, T., Hafstad, T.H., Gylfadóttir, S., Óskarsson, F., Ármannsson, H., 2015. The groundwater in the mývatn Area: influence of geothermal utilization at námfjall and origin of the warm groundwater component. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 Aprilhttps://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14112.pdf%0A%0A.

Omagbon, J., Sullivan, M.O., Sullivan, J.O., Walker, C., 2016. Experiences in developing a dual porosity model of the leyte geothermal production Field. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November, https://www.geothermal-energy.org/pdf/IGAstandard/…/085_Omagbon_Final.pdf%0A%0A.

Omenda, P., Mangi, P., 2016. Country update report for Kenya 2016. In: Proc.6th African Rift Geotherm. Conf. Addis Ababa, Ethiopia, 2nd – 4th November.

Openei, 2016. Paisley Oregon Geothermal Plant Operated by Surprise Valley Electrification - 2016 Operational Information (accessed March 16, 2019). https://gdr.openei.org/submissions/912.

Orenstein, R., Delwiche, B., Lovekin, J., 2015. The Don a. Campbell geothermal project – development of a Low-temperature Resource. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06052.pdf%0A%0A.

Orkustofnum, N.E.A., 2017. Pre-Feasibility Study Geothermal District Heating in Oradea, Romania. https://eeagrants.org/project-portal/project/RO06-0008%0A%0A.

Ormat, 2018. Ormat Annual Report, 2018. https://investor.ormat.com/file/4087066/Index?KeyFile=1001250792.

Oskarsson, F., Fridriksson, T., Thorbjornsson, D., 2015. Geochemical monitoring of the reykjanes geothermal reservoir 2003 to 2013. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14085.pdf%0A%0A.

Ouma, P., Koech, V., Mwarania, F., 2016. Olkaria geothermal Field Reservoir response after 35 years of production (1981 - 2016). In: Proc. 6th African Rift Geotherm. Conf. Addis Ababa, Ethiopia, 2nd – 4th November.

Pambudi, N.A., 2018. Geothermal power generation in Indonesia, a country within the ring of fire: current status, future development and policy. Renew. Sustain. Energy Rev. 81, 2893–2901. https://doi.org/10.1016/j.rser.2017.06.096.

Pambudi, N.A., Itoi, R., Jalilinasrabady, S., Sirait, P., Jaelani, K., 2015. Preliminary analysis of single flash combined with binary system using thermodynamic assessment: a case study of Dieng geothermal power plant. Int. J. Sustain. Eng. 8, 258–267. https://doi.org/10.1080/19397038.2014.915895.

Panggabean, P., Yudhistira, A.D., Ramadani, A., 2018. Application of wireline Fishing tools and techniques to restore Well production in salak geothermal Field, Indonesia. In: Proc. 40th New Zeal. Geotherm. Work. Taupo, New Zealand, 14-16 November.

Paramitasari, H.M., Syaffitri, Y., Nelson, C., Adityawan, S.K., Golla, G.U., Energy, S., Darajat, G., Ii, S.S., Asia, J., No, A., 2018. Injection management at darajat Field, Indonesia: impact of moving infield injection to edgefield. In: Proc. 40th New Zeal. Geotherm. Work. Auckland, New Zealand, 14-16 November.

Permana, T., Hartanto, D.B., 2015. Geochemical changes during 12 year exploitation of the Southern Reservoir zone of lahendong geothermal Field, Indonesia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14032.pdf%0A%0A.

Pertamina Geothermal Energy, Annual Report, 2017. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwi1mqm5iozjAhVPFHIKHXZQDXQQFjAAegQIARAC&url=http%3A%2F%2Fpge.pertamina.com%2FUploads%2F6fd3a54e-6324-40b9-bd6c-904e90905201_2017-laporan-tahunan-pge-ar-lowres-web.pdf&usg=AOvVaw396SnAdIu8Aq1vPpnAINTZ.

Portier, S., Vuataz, F.D., Barrios Martinez, A.L., Siddiqi, G., 2010. Preliminary modelling of the permeability reduction in the injection zone at Berlin geothermal Field, El Salvador. In: in: Proc. World Geotherm. Congr. 2010. Bali, Indonesia, 25-29 April. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/2231.pdf%0A%0A.

Power Technology, 2018. The Blue Mountain Geothermal Power Plant. USA, (accessed April 15, 2019). https://www.power-technology.com/projects/bluemountaingeotherm/.

Prabata, W., Berian, H., 2017. 3D natural State model of karaha-talaga bodas geothermal Field, West java, Indonesia. In: Proc. 39th New Zeal. Geotherm. Work. Rotorua, New Zealand, 22-24 November.

Prabowo, T., Yuniar, D.M., Suryanto, S., Silaban, M., 2015. Tracer test implementation and analysis in order to evaluate reinjection effects in lahendong Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22049.pdf%0A%0A.

Prasetyo, F., Sullivan, J.O., Sullivan, M.O., 2016. Inverse modelling of lahendong geothermal Field. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November. https://researchspace.auckland.ac.nz/handle/2292/37822%0A%0A.

PT Geo Dipa Energy, 2017. Laporan Tahunan 2017.

Putri, R.P., Julinawati, T., 2018. Connectivity of wells in the east salak steam cap: resulting of NCG interference testing. In: Proc. 40th New Zeal. Geotherm. Work. Taupo, New Zealand, 14-16 November.

Quinao, J.J., Buscarlet, E., Siega, F., 2017. Early identification and management of calcite deposition in the ngatamariki geothermal Field, New Zealand. In: in: Proc. 42nd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15,.

Raksaskulwong, M., 2015. Update on geothermal utilizations in Thailand. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01004.pdf%0A%0A.

Rangel, G., Guimaraes, T., Hackett, L., Henneberger, R., Pham, M., 2017. Well field optimization and expansion guided by tracer testing and numerical reservoir modeling, Ribeira Grande Geothermal Field, Portugal. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033908.pdf.

Reimus, P.W., Caporuscio, F.A., Marina, O.C., Janney, D., 2018. Field Demonstration of the Combined Use of Thermally-Degrading and Cation-Exchanging Tracers to Predict Thermal Drawdown in a Geothermal Reservoir.

Renewable Energy World, 2015. Popular Hot Springs in Japan Co-exist With Binary Geothermal Power Plants (accessed March 12, 2019). https://www.renewableenergyworld.com/articles/2015/12/popular-hot-springs-in-japan-co-exist-with-binary-geothermal-power-plants.html.

Report, S.I., 2017. Geologic Field-Trip Guide to Long Valley Caldera, California. papers3://publication/uuid/E7B27E12-2A9E-4FDC-B01F-6BE9F5320D03.

Richter, B., 2015. Status quo of the geothermal pilot project in Germany : significance of a professional project management. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://www.geothermal-energy.org/pdf/IGAstandard/EGC/2007/070.pdf%0A%0A.

Romo-jones, J.M., Flores-armenta, M., García, A., Gutiérrez-negrín, L.C., Luis, J., 2016. Mexico Country Report, 2017. iea-gia.org/wp-content/uploads/…/IEA-Geothermal-2016-Mexico-Country-Report.pdf.

Rose, W., 2019. Nevada Geothermal Production for 2018.

Rose, P.E., Moore, J.M., Bradford, J., Mella, M., Ayling, B., McLennan, J., 2017. Tracer testing to characterize hydraulic stimulation experiments at the Raft River EGS Demonstration site. GRC Trans. 41.

Sacerdoti, A., 2015. Cove Fort – binary power plant. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06021.pdf%0A%0A.

Sahin, C., 2016. Dusuk Sicaklikli Jeoterhmal Sahalarda Organik Rankin Cevrimi (ORC) Ile Elektrik Enerjisi Uretiminde Afyon Jeotermal Elektrik Uretim A.S Modellemesi. Dumlupınar Üniversitesi.

Sanyal, S.K., Granados, E.E., Menzies, A.J., 1995. Injection - related problems encountered in geothermal projects and their mitigation, the United States experience. Proc. World Geotherm. Congr. 1995. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/1995/3-sanyal.pdf%0A%0A.

Sarychikhina, O., Glowacka, E., Mojarro, J., 2016. Surface deformation associated with geothermal fluids extraction at the Cerro prieto geothermal Field, Baja California, Mexico revealed by dinsar technique. Proc. Living Planet Symp. 2016. adsabs.harvard.edu/abs/2016ESASP.740E.294S.

Satman, A., Tureyen, O.I., Didem, E., Basel, K., Guney, A., Senturk, E., Kindap, A., 2017. Effect of carbon dioxide content on the Well and Reservoir performances in the kizildere geothermal Field. In: Proc. 42nd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 13-15. https://www.geothermal-energy.org/pdf/IGAstandard/SGW/2017/Satman.pdf.

Senturk, E., 2019. Personal Communication, Via Email 25 March.

Serpen, U., Aksoy, N., 2014. Reinjection problems in overpressured geothermal reservoirs. In: Proc. Thirtieth Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. January 31 - February 2. https://www.researchgate.net/publication/237294133%0AREINJECTION.

Serpen, U., Aksoy, N., Öngür, T., 2015. 2015 reinjection update of salavatli geothermal Field in Turkey. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Sewell, S.M., Cumming, W., Bardsley, C.J., Winick, J., Quinao, J., Wallis, S.Sherburn, Bourguignon, S., Bannister, Steven, 2015. Interpretation of microearthquakes at the rotokawa geothermal Field, 2008 to 2012. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/13033.pdf.

Shengtao, L.I., Yanwei, G.U.O., Wenming, L.V., Jun, H.O.U., Fulong, Z., 2015. Status and future of geothermal resources development and utilization along qinghai- Tibet railway in Tibet, China. In: Proc. World Geoterm. Congr. 2015. Melbourne, Australia, 19-25 April.

Sherburn, S., Bromley, C., Bannister, S., Sewell, S., Bourguignon, S., 2015. New Zealand geothermal induced seismicity : an overview. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Siahaan, E.E., Sasradipoera, D.S., Silitonga, T.H., Pelmelay, C., Koestono, H., Mubarok, M.H., Rifki, G., 2015. Success development drilling in ulubelu green field in South sumatra based on geological structure evidence, generate 4X55 MW. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/16014.pdf.

Sicad, J.P., 2015. Tiwi geothermal brine injection surface facility development as response to changing subsurface conditions. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/25000.pdf.

Sifford, A., 2014. Geothermal energy in Oregon 2014. GRC Trans. 38, 99–106.

Sigrún Brá Sverrisdóttir, 2016. Tracer testing in the Svartsengi geothermal field in 2015. GRC Trans. 40, 513–520. https://skemman.is/bitstream/1946/23806/1/MSc-Sverrisdottir-2015.pdf.

Simatupang, C.H., Intani, R.G., Suryanta, M.R., Irfan, R., Golla, G., Cease, C., 2015. Evaluation of Water produced from a steam dominated system, a case study from the darajat Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Simmons, S.F., Kirby, S., Allis, R., Moore, J., Fischer, T., 2018. Update on production chemistry of the roosevelt Hot Springs Reservoir. In: Proc. 43rd Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 12-14. https://www.osti.gov/servlets/purl/1433886%0A%0A.

Simmons, S.F., Kirby, S., Allis, R., Wannamaker, P., Moore, J., 2019. Controls of geothermal resources and hydrothermal activity in the sevier thermal belt based on fluid geochemistry. In: Proc. 44th Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 11-13. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2019/Simmons1.pdf.

Sinaga, R.H.M., Manik, Y., 2018. Optimizing the utility power of a geothermal power plant using variable frequency Drive (VFD) (case study: sibayak geothermal power plant). IOP Conf. Ser. Earth Environ. Sci. https://doi.org/10.1088/1755-1315/124/1/012007.

Sirait, P., Ridwan, R.H., Battistelli, A., 2015. Reservoir modeling for development capacity of dieng geothermal Field, Indonesia. In: Proc. Fortieth Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. January 26-28.

SKM, 2006. Review of Geothermal Production and Reinjection Schemes Worldwide.

Soengkono, S., 2014. 3D imaging of High Resolution airborne magnetic data Over mokai geothermal Field, New Zealand. In: Proc. 36th New Zeal. Geotherm. Work. Auckland, New Zealand, 24-26 November.

Sofyan, Y., Daud, Y., Nishijima, J., Fujimitsu, Y., 2019. Sustainable energy development and Water supply security in kamojang geothermal Field: the energy-Water nexus. In: Proc. 44th Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 11-13. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2019/Sofyan.pdf%0A%0A.

Solis, R.P., Taboco, K.J.G., 2015. Mitigation of reinjection returns in palinpinon-II, Philippines. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24016.pdf.

Someka Excel Solutions, 2019. World Countries Geographic Heat Map Generator (accessed September 22, 2019). https://www.someka.net/excel-template/world-heat-map-generator/.

Sorey, M., Spielman, P., 2017. Rates of thermal water discharge from the hot water geothermal system beneath the Steamboat Hills in Western Nevada, USA. Geothermics. 69, 202–206. https://doi.org/10.1016/j.geothermics.2017.01.009.

Stefánsson, V., 1997. Geothermal reinjection experience. Geothermics. 26, 99–139. https://doi.org/10.1016/S0375-6505(96)00035-1.

Stimac, J., Wilmarth, M., Mandeno, P.E., Dobson, P., 2017. Review of exploitable supercritical geothermal resources to 5 km at Geysers-Clear Lake, Salton Sea, and coso. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033767.pdf.

Sujarmaitanto, W., Mulyanto, H., Wicaksono, H.D.B.T., 2015. Geochemistry monitoring in the kamojang vapor-dominated geothermal Field from 2010 to 2013. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14004.pdf%0A%0A.

Sullivan, J.O., Croucher, A., Sullivan, M.O., Stevens, L., Esberto, M., 2011. Modelling the evolution of a mine pit in a geothermal field at lihir Island, Papua New Guinea. Proc. 33rd New Zeal. Geotherm. Work.

Sunio, E.G., Menzies, A.J., Alvarez, R.R., Lim, W.Q., Stark, M.A., 2015. Downflows in Wells at the mak-Ban geothermal Field, Philippines. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22166.pdf%0A%0A.

Suryadarma, T., Dwikorianto, A., 2010. Zuhro, lessons learned from kamojang geothermal steam Field management: from the beginning until now. In: Proc. World Geotherm. Congr. Bali, Indonesia, 25-29 April, 2010. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0509.pdf%0A%0A.

Suryanta, M.R., Cease, C., Simatupang, C.H., Hadi, D.K., Golla, G., 2015. Production improvement through scale removal by condensate injection in darajat geothermal Field Indonesia. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24013.pdf.

Svalova, V., Povarov, K., 2015. Geothermal energy use in russia. Country update for 2010-2015. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01061.pdf%0A%0A.

Swyer, M.W., Uddenberg, M., Nordin, Y., Cladouhos, T.T., Petty, S., 2016. New injection strategies at Blue Mountain, Nevada through tracer test analysis, injection-production correlation, and an improved conceptual model. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24.

Takayama, J., Itoi, R., Morita, S., 2014. Eighteen year history of reservoir development in the Ogiri geothermal field, Japan. GRC Trans. 38, 107–111. pubs.geothermal-library.org/lib/grc/1033524.pdf%0A%0A..

Tanase, I.E., 2016. Geothermal reinjection in sedimentary basins. In: Geotherm. Train. Program. UNU-GTP. Reykjavik, Iceland. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24015.pdf%0A%0A.

The Aerospace Corporation, 2011. Clear Creek Associates, Imperial Irrigation District : Geothermal Resource Assessment. https://www.iid.com/home/showdocument?id=4492%0A%0A.

ThinkGeoEnergy, 2014. Groundbreaking Ceremony for 17 MW Dora 4 Extension in Turkey (accessed March 17, 2019). http://www.thinkgeoenergy.com/groundbreaking-ceremony-for-17-mw-dora-4-extension-in-turkey/.

ThinkGeoEnergy, 2016. KenGen Plans 23 MW Expansion of Eburru Geothermal Plant (accessed March 12, 2019). http://www.thinkgeoenergy.com/kengen-plans-23-mw-expansion-of-eburru-geothermal-plant/.

ThinkGeoEnergy, 2017. 18 MW Turcas Kuyucak Geothermal Power Plant Starts Operation in Aydin, Turkey (accessed March 6, 2019). http://www.thinkgeoenergy.com/18-mw-turcas-kuyucak-geothermal-power-plant-starts-operation-in-aydin-turkey/.

ThinkGeoEnergy, 2018a. Turkey Reaches Milestone 1,100 MW of Installed Geothermal Power Generation Capacity (accessed April 4, 2019). http://www.thinkgeoenergy.com/turkey-reaches-milestone-1100-mw-of-installed-geothermal-power-generation-capacity/.

ThinkGeoEnergy, 2018b. Direct Contact Steam Condenser Commissioned for Kubilay Geothermal Plant, Turkey (accessed April 4, 2019). http://www.thinkgeoenergy.com/direct-contact-steam-condenser-commissioned-for-kibilay-geothermal-plant-turkey/.

ThinkGeoEnergy, 2018c. Zorlu Energy's Kizildere 3 Geothermal Power Plant Praised on Efficiency and Impact (accessed February 2, 2019). www.thinkgeoenergy.com/zorlu-energys-kizildare-3-geothermal-power-plant-praised-on-efficiency-and-impact/.

ThinkGeoEnergy, 2018d. Birdsville in Australia Abandons Plans for Renewal of Geothermal Plant (accessed April 7, 2019). http://www.thinkgeoenergy.com/birdsville-in-australia-abandons-plans-for-renewal-of-geothermal-plant/.

ThinkGeoEnergy, 2018e. Equipment of Kalina Geothermal Power Plant of Unterhaching to Be Sold (accessed December 20, 2018). http://www.thinkgeoenergy.com/equipment-of-kalina-geothermal-power-plant-of-unterhaching-to-be-sold/.

ThinkGeoEnergy, 2018f. Two Additional Ormat-supplied Geothermal Plants Successfully Delivered in Turkey (accessed March 6, 2019). http://www.thinkgeoenergy.com/two-additional-ormat-supplied-geothermal-plants-successfully-delivered-in-turkey/.

ThinkGeoEnergy, 2018g. Limgaz Starts Operation of 13.8 MW Buharkent Geothermal Plant Starts Operation in Turkey (accessed April 6, 2019). http://www.thinkgeoenergy.com/limgaz-starts-operation-of-13-8-mw-buharkent-geothermal-plant-starts-operation-in-turkey/.

ThinkGeoEnergy, 2020a. Geo Dipa Energi Increases Power Output of Geothermal Plants Dieng and Patuha in 2017, (2017) (accessed April 4, 2019). http://www.thinkgeoenergy.com/geo-dipa-energi-increases-power-output-of-geothermal-plants-dieng-and-patuha-in-2017/.

ThinkGeoEnergy, 2020b. Field Trip to Wayang Windu Geothermal Plant – 12-13 Aug. 2016, (2016) (accessed April 7, 2019). http://www.thinkgeoenergy.com/iigce-field-trip-to-wayang-windu-geothermal-plant-12-13-aug-2016/.

ûorsteinsdóttir, U., Helgadóttir, H.M., Hersir, G.P., Einarsson, G.M., 2016. Conceptual modelling of the krafla geothermal area, NE-Iceland and lessons on constructing a workflow. In: Proc. Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September.

Torres, M.A., Aqui, A.A., 2015. Experimental fluid-Rock interaction simulating reinjection of cooling Tower condensate in andesitic-hosted Reservoir of Southern negros geothermal Field, Philippines. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April,. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/14016.pdf.

Torres-Mora, Y., Axelsson, G., 2015. Chemical tracer test in Las pailas geothermal Field, Costa Rica. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/14070.pdf%0A%0A.

Traineau, H., Lasne, E., Sanjuan, B., 2015. Main results of a Long-term monitoring of the bouillante geothermal Reservoir during its exploitation. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24024.pdf%0A%0A.

Trianggo, S., Koestono, H., Thamrin, M.H., Kamah, M.Y., 2015. Evaluation of the productive geological structure in ulubelu geothermal system. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Trugman, D.T., Shearer, P.M., Borsa, A.A., Fialko, Y., 2016. A comparison of long-term changes in seismicity at the geysers, Salton Sea, and coso geothermal fields. J. Geophys. Res. Solid Earth 121, 225–247. https://doi.org/10.1002/2015JB012510.

Turboden, 2017. Turboden Report: Smarter Binary Systems Delivered https://www2.ee-ip.org/…/Turboden_srl/20160907_Leaflet_Doppia_Geothermal.pdf.

Tureyen, O.I., Gulgor, A., Erkan, B., Satman, A., 2016. Recent expansions of power plants in guris concession in the Germencik geothermal Field, Turkey. In: Proc. Forty-First Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24. https://pangea.stanford.edu/ERE/db/IGAstandard/record_detail.php?id=26546.

Urban, E., Lermo, J., 2017. Fracture and stress evaluation using well logs and microseismicity, in the exploitation of Los Humeros Geothermal Field, Mexico. GRC Trans. 41. pubs.geothermal-library.org/lib/grc/1033837.pdf%0A%0A.

Uribe, M.H.C., Dacillo, D.B., Dacoag, L.M., Andrino, R.P.J., Alcober, E.H., 2015. 30 years of tongonan-1 (leyte, philippine) sustained production. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/24005.pdf%0A%0A.

Utami, A.G.S.F., Darmanto, P.S., Saptadji, N.M., 2018. Air cooled condenser and Water cooled condenser performance comparison, case study for organic rankine cycle for wayang windu geothermal Field. In: Proc. 12th Asian Geotherm. Symp. Deajeon, Korea, 10-12 November.

Valle, A.D., Prado, L., Matus, I., Guidos, J.A., Malate, R.C.M., 2016. Acid stimulation of injection Wells in San Jacinto geothermal project, Nicaragua. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November.

Van Campen, B., Archer, R., 2017. Ohaaki consenting, modelling and resource assessment review: the best place to look for lessons on sustainable geothermal operation and monitoring. In: in: Proc. 39th New Zeal. Geotherm. Work. Rotorua, New Zealand, 22-24 November 2017.

Van den Heuvel, D.B., Benning, L.G., 2016. Passivation of metal surfaces against corrosion by silica scaling. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24.

Vidal, J., Genter, A., 2018. Overview of naturally permeable fractured reservoirs in the central and southern Upper Rhine Graben: insights from geothermal wells. Geothermics. 74, 57–73. https://doi.org/10.1016/j.geothermics.2018.02.003.

Wamalwa, R.N., 2016. Evaluation of factors controlling the concentration of Non condensable gases and their possible impact on the performance of Wells in the olkaria. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24. https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2015-34.pdf%0A%0A.

Wang, S., Yan, J., Li, F., Hu, J., Li, K., 2016. Exploitation and utilization of oilfield geothermal resources in China. Energies. 9, 1–13. https://doi.org/10.3390/en9100798.

Warren, I., 2016. Exploration and development of the neal Hot Springs geothermal Resource, malheur County, Oregon: search and Discovery article #90266. Proc. AAPG Pacific Sect. Rocky Mt. Sect. Jt. Meet. Las Vegas, Nevada, October 2-5 http://www.searchanddiscovery.com/abstracts/html/2016/90266ps_rms/abstracts/500.html.

Warren, I., Gasperikova, E., 2018. Passive seismic emission tomography applied to mapping of geothermal permeability. GRC Trans. 42.

Weber, J., Ganz, B., Sanner, B., Moeck, I., 2016. Geothermal energy use, Country update for Germany. In: in: Proc. Eur. Geotherm. Congr. 2016. Strasbourg, France, 19-24 September.

Wei, S., Avouac, J., Hudnut, K.W., Donnellan, A., Parker, J.W., Graves, R.W., Helmberger, D., Fielding, E., Liu, Z., Cappa, F., Eneva, M., 2015. The 2012 Brawley swarm triggered by injection-induced aseismic slip, Earth Planet. Sci. Lett. 422, 115–125. https://doi.org/10.1016/j.epsl.2015.03.054.

Weijermars, R., Zuo, L., Warren, I., 2017. Modeling reservoir circulation and economic performance of the neal hot springs geothermal power plant (Oregon, U.S.): an integrated case study. Geothermics. 70, 155–172. https://doi.org/10.1016/j.geothermics.2017.04.011.

White, P., Clotworthy, A., 2018. Expanding the boundaries at kawerau: New data from the Te ahi O maui project. In: Proc. 40th New Zeal. Geotherm. Work. Taupo, New Zealand, 14-16 November. www.eastland.nz/eastland-generation/projects/te-ahi-o-maui/%0A%0A.

White, P.J., Lawless, J.V., Terzaghi, S., Okada, W., 2005. Advances in subsidence modelling of exploited geothermal fields. In: Proc. World Geotherm. Congr. 2005. Antalya, Turkey, 24-29 April. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/0222.pdf%0A%0A.

Winick, J.A., Addison, S., Sewell, S., Buscarlet, E., Hernandez, D., Siega, F., 2016. The geochemical response of the rotokawa Reservoir to the first Five years of nga awa purua production. In: Proc. 41st Work. Geotherm. Reserv. Eng. Stanford University, Stanford, California. February 22-24.

Wolf, N., Gabbay, A., 2015. Sarulla 330 MW geothermal project key Success factors in development. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/06003.pdf%0A%0A.

Wood, S.H., Kaewsomwang, P., Singharajwarapan, F.S., 2016. Fang hot springs geothermal area, chiang mai province, northern thailand - geological and geophysical exploration in 2014-2015. In: Proc. 11th Asian Geotherm. Symp. Chiangmai, Thailand Wood, 18-20 November.

Wulaningsih, T., Fujii, Y., Tsutsumi, S., Inagaki, H., Umee, Y., Brien, J.O., 2017. A 3D model of the yamagawa geothermal system: insights into Reservoir structure and future Field management. In: Proc. 39th New Zeal. Geotherm. Work. Rotorua, New Zealand, 22-24 November 2017.

Xu, T., Pruess, K., 2004. Numerical simulation of injectivity effects of mineral scaling and clay swelling in a fractured geothermal reservoir. GRC Trans. 28, 269–276. https://escholarship.org/uc/item/8rz736j9.

Yani, A., 2015. Steam ratio obtained from the mass amount of condensate reinjection by means of monitoring the performance of a groups of production Wells 140 MWe geothermal Field kamojang -Indonesia. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pdfs.semanticscholar.org/dede/f22433d5d7d3e5d79e9cf4ce63875df38125.pdf%0A%0A.

Yasukawa, K., Sasada, M., 2015. Country update of Japan : renewed opportunities. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/01042.pdf%0A%0A.

Yeh, A., 2019. Personal Communication, 10 Mei.

Yoshioka, K., Jermia, J., Pasikki, R., Ashadi, A., 2015. Zonal hydraulic stimulation in the salak geothermal Field. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/23019.pdf%0A%0A.

Yucetas, I., Ergicay, N., Akin, S., 2018. Carbon dioxide injection field pilot in Umurlu Geothermal Field, Turkey. GRC Trans. 42.

Yue-feng, Y., Da, H., Fang-zhi, W., 2015. Applications of the screw expander in geothermal power generation in China. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/26050.pdf%0A%0A.

Yuniar, D.M., Hastuti, P., Silaban, M., 2015. Ulubelu, first year Reservoir monitoring. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/22047.pdf%0A%0A.

Zarrouk, S., McLean, K., 2019. Geothermal Well Test Analysis, Fundamentals, Applications and Advanced Techniques, 1st ed. Academic Press https://www.elsevier.com/books/geothermal-well-test-analysis/zarrouk/978-0-12-814946-1.

Zarrouk, S.J., Moon, H., 2014. Efficiency of geothermal power plants: a worldwide review. Geothermics 51, 142–153. https://doi.org/10.1016/j.geothermics.2013.11.001.

Zatnika, G.G., Wisanto, S., Wityasmoro, A., Kurniadi, D., Zein, A., 2016. Failure analysis and mitigation of corrosion on condensate reinjection pipeline in wayang windu geothermal power plant. In: Proc. 38th New Zeal. Geotherm. Work. Auckland, New Zealand, 23-25 November.

Zheng, K., Wang, M., 2012. Geothermal resources development in tibet, china. New Zeal. Geotherm. Work. 2012 Proc..

Zheng, K., Dong, Y., Chen, Z., Tian, T., Wang, G., 2015. Speeding up industrialized development of geothermal resources in China – Country update report 2010-2014. In: in: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April.

Zhu, J., Hu, K., Lu, X., Huang, X., Liu, K., Wu, X., 2015. A review of geothermal energy resources, development, and applications in China: current status and prospects. Energy 93, 466–483. https://doi.org/10.1016/j.energy.2015.08.098.

Zúñiga, S.C., 2012. Increasing permeability in geothermal wells through hydro-fracturing for the Las pailas and borinquen geothermal fields, Costa Rica. In: Proc. World Geotherm. Congr. 2015. Melbourne, Australia, 19-25 April. http://www.os.is/gogn/unu-gtp-sc/UNU-GTP-SC-14-34.pdf.