

Geothermal Projects in Turkey: Extreme Greenhouse Gas Emission Rates Comparable to or Exceeding Those from Coal-Fired Plants

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ABSTRACT

Geothermal power projects in Turkey are outliers for this technology because of their very high CO₂ emissions rates (800-1600 g/kW-hr) which are comparable to or significantly exceed those from coal-fired power generation (940-980 g/kW-hr). A “typical” 50 MW geothermal project in Turkey producing 1000 g/kW-hr CO₂ emits 1,200 tonnes per day of CO₂ to the atmosphere. CO₂ is discharged to the atmosphere from all geothermal plant types installed to date in Turkey: flash, binary and hybrid flash-binary projects. Turkey lacks pumped binary projects which feature zero CO₂ emissions due to use of downhole pumps installed in wells which deliver pressurized liquid to the binary plant. Produced gas is kept in solution in the pumped, pressurized liquid which is reinjected to the reservoir after exiting the heat exchangers, yielding a closed-loop system. Pumping of production wells is generally not feasible in Turkey due to a combination of: 1) high gas contents which can depress the flash point in wells down to depths below the technical limit of downhole pumps; and 2) reservoir temperatures exceeding the 190°C temperature limitation of the pumps.

Declines in CO₂ emissions rates over time are possible for some geothermal projects in Turkey due to dilution of reservoir gas by “de-gassed” injectate. However, available data from the Kizildere I and Germencik projects indicates that gas levels still remain very high for one or more decades of plant operation despite declines from initial gas levels at plant start-up. Mitigation of produced CO₂ by re-injection to the reservoir is unlikely to be a viable option for Turkey geothermal projects, as there is as yet no precedent for successful sustained re-injection of the massive amounts of CO₂ such as produced by these fields. A short-lived experiment at the Coso field in the USA was abandoned due to recycling of injected gas back to production wells, and the scale of ongoing gas injection operations at Hellisheidi in Iceland is too small to be applicable to Turkey projects. A portion of the CO₂ produced by the initial plants installed at the Kizildere and Salavatli fields has been sold for commercial uses. However, this represents a small proportion of the total CO₂ production by geothermal projects in Turkey and the in-country market for CO₂ appears to be saturated.

Geothermal projects in Turkey are not environmentally friendly due to the adverse climate impacts of these extreme CO₂ emissions rates. Multi-lateral lending agencies such as the European Bank for Reconstruction and Development and World Bank Group are actively providing funding for geothermal development in Turkey, and fueling the recent explosive growth of geothermal capacity in the country. Such financial support is inconsistent with the stated missions of these agencies to reduce greenhouse gas emissions and promote environmentally sustainable projects. Instead, financial support for geothermal development in Turkey should be directed towards facilitating: 1) exploration for and development of other low-gas geothermal systems similar to those already identified at Tuzla and Buharkent; 2) research and development directed towards increasing the pressure and depth limits for downhole pumps so that more gassy geothermal systems in Turkey can be developed as zero-emissions pumped binary projects; and 3) research and development focused on scaling-up of gas reinjection systems such as in operation at Hellisheidi.

1. INTRODUCTION

Geothermal power generation is considered a “climate friendly” technology due to the low emission rates of carbon dioxide (CO₂) and other greenhouse gases. Dry steam and flash geothermal projects do emit CO₂ but at significantly lower rates than fossil-fueled generation. Closed loop binary geothermal projects common in the western U.S. produce essentially zero greenhouse gas emissions. However, the geothermal projects of western Turkey are a prominent exception to the general rule of geothermal as an environmentally friendly technology due to the high CO₂ content in reservoir fluids and high CO₂ emission rates from power plants (Askoy et al, 2015; ESMAP, 2016). Nonetheless, geothermal development in Turkey has accelerated rapidly since the early 2000’s, with over 600 MW of capacity currently on line and 147 MW currently under construction or in advanced planning (**Table 1**). The construction of many of these projects was financed by multilateral lending agencies such as the European Bank for Reconstruction and Development (EBRD) and the World Bank Group (WBG).

Operating geothermal projects in Turkey are concentrated in a series of generally east-west trending structural grabens in western Anatolia (**Figure 1**). The Buyuk-Menderes graben is the most important structure as most of the operating and planned projects are located within this feature. Exploited geothermal systems in western Turkey are fault-controlled, moderate temperature (150-240°C) resources with low to moderate salinity, typically hosted within reservoir rocks dominated by carbonates, marble and calc-schists in addition to quartzites and gneisses (Simsek, 1985; Yilmazer et al, 2010; Ozgur, 2016). The dissolution of calcite (CaCO₃), which is widespread in the carbonate reservoir rocks, due to hydrothermal processes is generally considered the most likely explanation for the high CO₂ content in Turkey geothermal reservoirs (Haizlip et al, 2016). CO₂ may also be formed at deeper levels in geothermal environments by the thermal decomposition of calcite where calcite reacts with quartz to form wollastonite (CaSiO₃) and CO₂ (ESMAP, 2016).

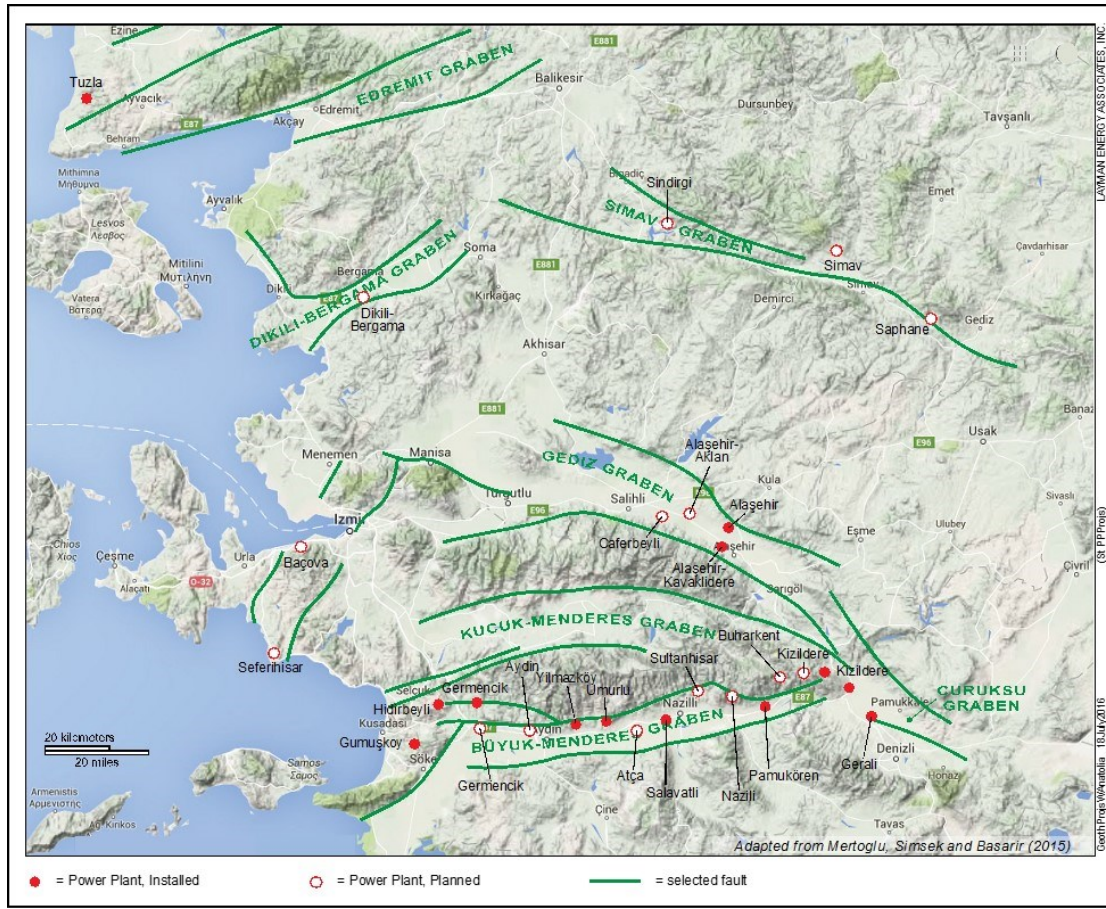


Figure 1: Map of geothermal power projects of Western Anatolia, Turkey, adapted from Mertoglu, Simsek and Basarir (2015)

The main objective of the present study is to raise awareness of the problem of greenhouse gas emissions from Turkey geothermal projects and provide a factual basis for future policy discussions. Some members of the geothermal industry in Turkey have tried to minimize the concerns regarding greenhouse gas emissions from these projects. For example, an executive from Zorlu Enerji publicly stated that greenhouse gas emissions from its geothermal projects are “closer to those of a plant fired by natural gas than coal” and that he does not “see this as a major problem” (Hirtenstein, 2016). The present study intends to focus on these particular areas:

Compile, expand upon and document the existing published database on CO₂ emissions from Turkey geothermal projects;

- 1) Document examples of the mechanisms for atmospheric discharge of CO₂ from various types of geothermal power plants in Turkey;
- 2) Highlight and explain the lack of zero emissions, closed-loop binary geothermal plants in Turkey;
- 3) Show that mitigation of CO₂ emissions by re-injection of produced gases into the subsurface reservoir or commercial sale of CO₂ is at present are not viable options to mitigate the harmful climatic effects of Turkey geothermal projects;
- 4) Prod multilateral lending agencies to re-consider their policy of financing geothermal projects in Turkey with extreme CO₂ emissions due to their harmful effects on global climate.
- 5) Suggest alternative areas to focus funding for research and development to promote construction of low-emissions geothermal projects in Turkey.

2. CO₂ CONTENT IN RESERVOIR FLUIDS, TURKEY GEOTHERMAL PROJECTS

High levels of CO₂ dissolved in reservoir fluids in the geothermal systems of Turkey have been previously reported by a number of researchers. Osborn et al (2007) described elevated CO₂ levels in reservoir fluid and produced steam at the Germencik field in the context of inhibition of carbonate scale in production wells. Haizlip and Tut (2011) described the high CO₂ levels in intermediate and deep level reservoir fluids at the Kizildere field and the effects of the high gas levels on the depth of flashing or “gas breakout” and associated calcite scaling in producing wells. Haizlip et al (2013) included data on CO₂ contents in reservoir fluids at the Kizildere, Germencik and Alasehir fields as part of a comparison with other high-gas geothermal systems worldwide. Askoy et al (2015) provided

data on CO₂ contents in reservoir fluids for a number of geothermal projects in Turkey, and also reported that CO₂ comprises 96-99% of the non-condensable gas produced from five geothermal systems in the country. Haizlip et al (2016) describes the general range for CO₂ contents in Turkey geothermal reservoir fluids and the impacts of the high CO₂ levels on calcite scale mitigation and pumping of production wells. Tureyan et al (2016) reported on CO₂ levels in reservoir fluid at the Germencik field.

In the above data sources, calculation of the CO₂ content in reservoir fluids for Turkey geothermal fields was primarily derived from chemical analyses of steam and liquid produced during well discharge tests. The CO₂ levels in the separate steam and liquid phases are recombined into a single CO₂ value for the total well discharge, which is equivalent to the reservoir fluid composition assuming single liquid phase production from the reservoir to the wellbore. Haizlip et al (2016) indicate that there are no reports of vapor phase zones in geothermal reservoirs in Turkey, indicating this single liquid phase assumption is likely correct. CO₂ values for single wells can be averaged across multiple wells with different flow rates to obtain a weighted average for the field as a whole.

Askoy et al (2015) adopted a different approach to determine CO₂ levels in reservoir fluids based on downhole surveys of wellbore pressure and temperature under flowing (dynamic) conditions. This method involves identifying the flash point in a flowing well from an inflection point on the pressure profile, and noting the measured temperature and pressure at the flash point. The pressure at the flash point equals the sum of the partial pressure of gases and the partial steam pressure of water. By comparing the measured pressure at the flash point to the pressure of pure water at the measured temperature, the partial pressure of gas can be determined by Henry's Law. To simplify the calculation, the gas is assumed to be 100% CO₂ which is a reasonable approximation given that 96-99% of the gas in in Turkey geothermal systems is CO₂ as described above.

Available data on CO₂ content in reservoir fluids in Turkey geothermal systems are compiled and presented in in **Table 1** and in **Figure 2**. CO₂ contents are reported in units of weight percent (wt%) gas in the reservoir liquid. The reported values range between 0.2 to 4.4 wt% for 10 different geothermal fields. If the two lower gas fields at Tuzla and Buharkent are excluded, the range is 1.5 to 4.4 wt%. This contrasts with the range of CO₂ contents in reservoir fluids for most geothermal systems worldwide of 0.05 to 1.0 wt% (Henley et al, 1984), clearly highlighting the particularly gassy, CO₂-rich nature of Turkey geothermal resources.

Name of Power Plant / Project Site	Developer	Installed Capacity (MW)	Plant Technology Type	Planned / Under Const. (MW)	Resource temp, deg C	CO ₂ in reservoir fluid, wt %	CO ₂ emissions rate, g/kwh	Sources for CO ₂ data
In Operation or Under Construction								
Kizildere	Zorlu	95	1F, 2F, B		200-245	1.9 - 4.4	900-1300	Askoy et al (2015); Gokcen et al (2004)
Kizildere	Bereket	6.9	B		140			no data available
Salavatli (Dora 1, 2, 3a)	Mederes Geothermal	50.9	B	37	171	1.0-2.2	900-1100	Askoy et al (2015); Di Pippo (2012); Kaplan & Serpen (2010)
Germencik	Gurmat	162.3	2F, B		230-276	1.5 - 2.1	813-1100	Atkins International Ltd (2014); Askoy et al (2015); Tureyan et al (2016)
Germencik	no data	22.5	F					no data available
Tuzla	Enda	7.5	B	7.5	174	0.5	400	Askoy et al (2015)
Hidirbeyli	Maren	92	B	96	180	1.5 - 2.0	1423	Kaypakoglu et al (2015); Askoy et al (2015)
Pamukoren	Celikler	45	B		161-191	1.54	925	Karahan et al (2015); Askoy et al (2015)
Alasehir	Turkeler	24	B		185	3.4	ND	Askoy et al (2015)
Alasehir-Kavaklidere	Zorlu	45	2F, B		287	3.4	1640	ENVY (2013); Askoy et al (2015); Veizades & Associates (2012)
Gumuskoy	BM	6.6	B	6.6	180	1.5 - 2.0	900-1100	Askoy et al (2015)
Yilmazkoy	KenKipas Energy	24	B?		175	2.0	ND	Askoy et al (2015)
Geralti-Sarakoy	Degirmenci / GreenEco Energy	24	B		124	ND	ND	no data available
Umurlu	Karadeniz Elektrik	12	B	12	155	ND	ND	no data available
TOTALS		617.7		147.1				
Planned Project								
Buharkent	Limak Yatirim	15	BP		146	0.2	0	Mertoglu, Basarir & Saracoglu (2015)

1F= single flash; 2F = dual flash; B = artesian binary; BP = pumped binary

Table 1: Turkey geothermal plant capacity, technology and CO₂ emissions data. Plant capacity and technology adapted from Mertoglu, Simsek and Basarir (2015).

As described above, the Buharkent and Tuzla fields are unusual for geothermal fields in Turkey as their gas contents are relatively low at 0.2 and 0.5 wt% respectively. Carbonate reservoir rocks have been reported at both Tuzla (Karamandresi, 2013) and at Buharkent (Mertoglu et al, 2015), so a lack of carbonate host rocks cannot explain the observed low CO₂ content in reservoir fluids at these fields. At Tuzla, the most likely explanation for the low gas content relates to the high salinity of the reservoir fluids which are reported to contain 28,000 – 58,000 ppm chloride (Baba et al, 2008). Experimental data indicates that CO₂ is less soluble in highly saline fluids (Ellis, 1963). Buharkent reservoir fluids have been described as “diluted Kizildere brine” by Mertoglu et al (ibid), suggesting that Buharkent fluids could represent an outflow zone from the higher-temperature Kizildere field. Thus a possible explanation is that lower

gas content at Buharkent is the result of dilution of Kizildere reservoir fluids in an outflow zone by cooler peripheral waters with low gas content. Further research is warranted to provide more definitive understanding of the relatively low gas content at these two fields as compared to other fields in Turkey.

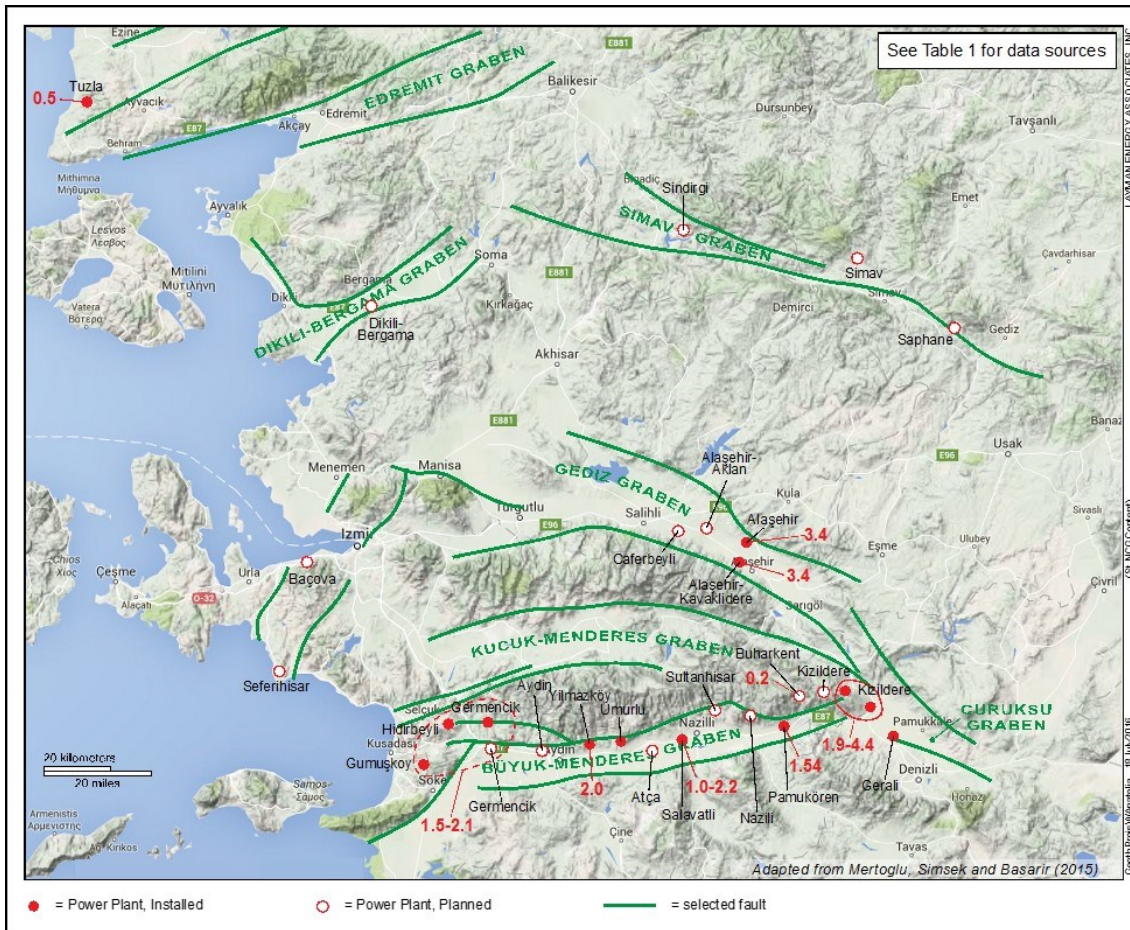


Figure 2: Map of geothermal power projects of Western Anatolia, Turkey with reported content of non-condensable gases in reservoir fluid (in units of weight %). See Table 1 for data sources.

3. CO₂ EMISSIONS RATES, TURKEY GEOTHERMAL PROJECTS

Estimates of the amount of CO₂ discharged to the atmosphere by operating geothermal projects in Turkey are critical to assessment of the environmental and climate impacts of these projects.

3.1 Background on available data and methodology

Askoy et al (2015) provided CO₂ emission rates for a number of projects in Turkey which were calculated based on: 1) the CO₂ content in reservoir fluids determined by analysis of downhole surveys as described above; and 2) the rate of geothermal fluid consumption by the power plant. These previously published results are supplemented here by estimates of CO₂ emissions rates for several projects calculated based on published data. Key data inputs for the calculations are: CO₂ content in reservoir fluids; total non-condensable gas flow rate measured at the plant; plant generation capacity; and plant fluid consumption rates. Such data was available for the following projects: Hidirbeyli (Kaypakoglu et al, 2015); Alasehir-Zorlu project (ENVY,2013; Veizades & Associates, 2012); Germencik (Atkins International Ltd, 2014); Salavatli- Dora I (Di Pippo, 2012); Kizildere Unit I (Gokcen et al, 2004); and Pamukoren (Karahan et al, 2015).

Examples of the simple calculation methodology used here for the Salavatli, Alasehir, Pamukoren plants can be described as follows. The total non-condensable gas flow rate at the 7.35 MW Dora I plant at Salavatli was reported as 7,560 kg/hr, allowing calculation of a total gas emissions rate of 1029 g/kW-hr. For the 45 MW Alasehir project (Zorlu), a CO₂ emissions rate of 1662 g/kW-hr was calculated based on a reported total mass flow to the plant of 2200 tonnes/hour and CO₂ content in the reservoir fluid of 3.4 wt%. At Pamukoren, the flow-weighted average CO₂ content in the total well discharge for each of 7 production wells supplying the plant was used to define a reservoir fluid CO₂ content of 1.54 wt%. This figure was combined with the reported 2700 tonnes / hour total mass flow to the plant to yield a CO₂ emissions rate of 924 g/kW-hr.

The reported CO₂ emissions rates for these projects are considered overall to be reasonably accurate. However, relatively wide ranges of reported CO₂ emissions rates for single projects (see below) highlights some uncertainty regarding this data set. Sources of uncertainty are likely related to one or more of the following factors: 1) accuracy of downhole temperature and pressure surveys when used by Askoy et al to calculate total CO₂ in reservoir fluid; 2) the amount of CO₂ left in the flashed liquid and reinjected to the subsurface reservoir; 3) the presence of other non-condensable gases besides CO₂; and 4) varying times of reported measurements of key parameters relative to plant start up as gas levels may change over time (see below).

Reported CO₂ emissions estimates appear not to take into account the amount of CO₂ left in the flashed liquid and reinjected to the reservoir. However, this effect is not expected to cause overestimation of CO₂ emissions rates by more than about 5-6%. For each project in Turkey the percent of the total gas left in the residual brine will depend upon the particulars of the reservoir temperature and fluid salinity, as well as the plant configuration and final flash pressure before injection. A generic example from Di Pippo (2012) using CO₂ separation coefficient data calculates that for a 200°C reservoir with 1 Molar salinity and 12% flash at the wellhead the residual flashed brine would contain about 1.5% of the original CO₂ in the reservoir liquid. Another example from the 200-230°C Germencik reservoir is based on the output of the WATCH geochemical software program provided to the author by an industry source. The program calculates that flashing of the reservoir fluid to 110°C for injection would yield a 22.7% steam fraction and a residual brine containing about 4.4% of the total CO₂ in the reservoir liquid.

Reported CO₂ emissions rates for some projects may in fact be the total non-condensable gas emissions rate, which includes other gases as well as CO₂. This is particularly the case for projects where the emissions estimates are based on measurements of the total non-condensable gas flow to the plant rather than from chemical analysis of CO₂ in produced steam and liquid, as at Salavatli-Dora I. This will result in an overestimation of CO₂ emission rates. However, the effect is relatively minor because CO₂ comprises 96-99% by weight of the produced gases in Turkey geothermal projects (Askoy et al, 2015).

In terms of global warming effect, the factors described above which promote minor overestimation of the CO₂ emissions rates for Turkey geothermal projects are likely offset by the presence of small amounts of methane (CH₄) in the produced non-condensable gases. Askoy et al reports methane contents in the dry gas ranging from 0.1 to 0.5 wt% for 6 geothermal projects in Turkey. Methane is a very potent greenhouse gas, with a Global Warming Potential (GWP) estimated to be about 30 times higher than CO₂ over a 100 year period (USEPA, 2017). The “CO₂ equivalent” of the reported range of methane contents is thus approximately 3.0 to 6.0 wt% for Turkey geothermal projects. Because the methane emissions are not counted in the CO₂ emissions rates reported here, these tend to offset the factors that promote overestimation of CO₂ emissions rates described above in terms of GWP.

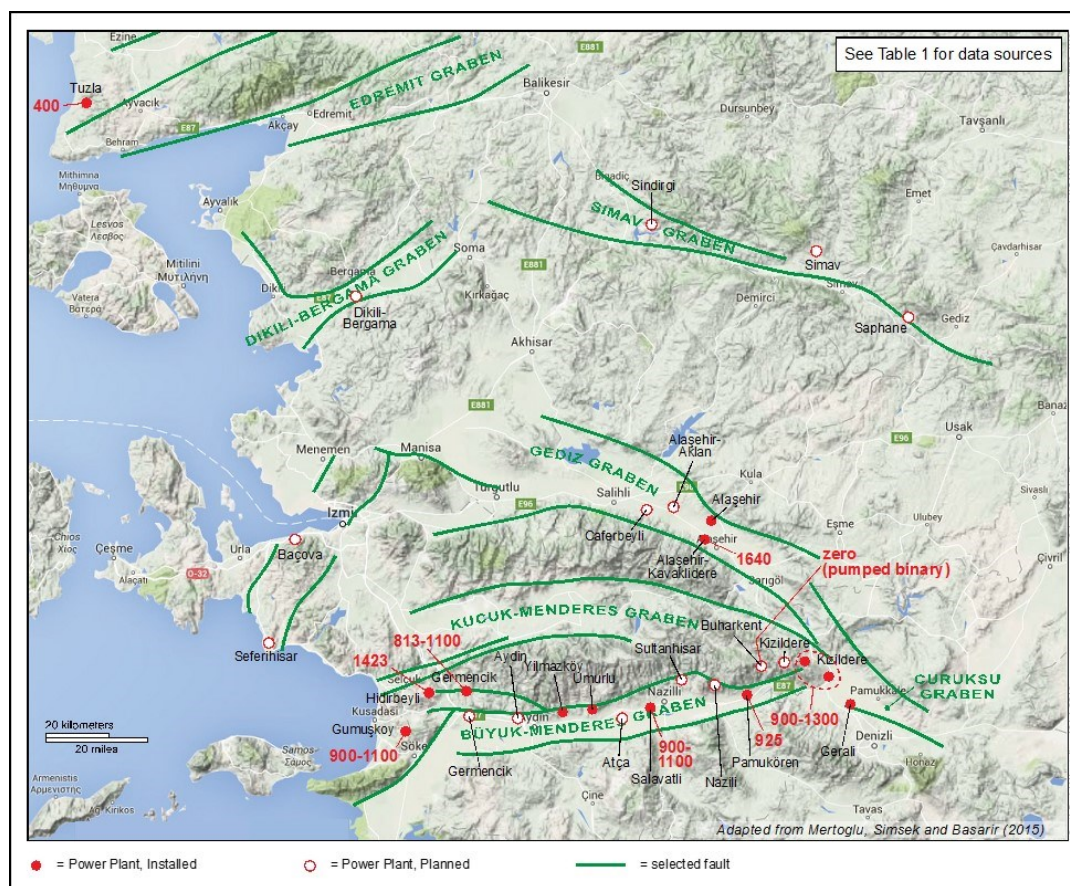


Figure 3: Map of geothermal power projects of Western Anatolia, Turkey with calculated CO₂ emissions rates (in units of grams/kilowatt-hour). See Table 1 for data sources.

3.2 Results and comparison with other projects

Available data on CO₂ emissions rates from Turkey geothermal projects are compiled and presented in **Table 1** and in **Figure 3**. Reported CO₂ emissions rates are in units of grams of CO₂ emitted per kilowatt-hour power generation (g/kW-hr). CO₂ emissions rates and data sources for other geothermal projects worldwide and for fossil fuel generation are listed in **Table 2**. CO₂ emissions rates for Turkey geothermal projects are compared to those from other geothermal projects worldwide and various types of fossil fuel power generation in **Figure 4**.

The reported CO₂ emissions rates for 9 geothermal fields in Turkey range from zero (planned Buharkent pumped binary project; see discussion below) to 1640 g/kW-hr. If Buharkent and the other low gas project at Tuzla are excluded, the range is 900-1640 g/kW-hr for 7 projects in Turkey. The weighted average CO₂ emissions rate for the 8 operating projects in Turkey where data is available is 1121 g/kW-hr for 504.1 MW total installed capacity, based on the mid-range emissions figures from **Table 1**. These are extreme geothermal CO₂ emissions rates which are comparable to or significantly exceed the typical 940-980 g/kW-hr rates for coal-fired generation (U.S. Energy Information Administration website). Coal-fired generation has the highest CO₂ emissions rate of all fossil fuel power generation sources.

	Name of Power Plant / Project Site	CO ₂ emissions rate, g/kwh	Installed Capacity, MW	References for CO ₂ data
WORLDWIDE				
	weighted average	122	6648	<i>Bertani and Thain (2002)</i>
CALIFORNIA, USA				
	Flash steam plants, average	180.4	827	<i>Holm et al (2012)</i>
	Dry steam plants, average	27.3	1585	<i>as above</i>
	Binary plants	0	277	<i>as above</i>
	All fields, weighted average	81.8	2689	<i>as above</i>
ICELAND				
	6 fields, weighted average	50	660	<i>Baldvinsson et al (2011)</i>
	Krafla	152	60	<i>Armannsson et al (2005)</i>
	Svartsengi	181	74.4	<i>as above</i>
	Nesjavellir	26	120	<i>as above</i>
NEW ZEALAND				
	All fields weighted average	104	949	<i>ESMAP (2016)</i>
	Ohaaki	249	105	<i>New Zealand Geoth. Assoc. (2016)</i>
	Wairakei	32	339	<i>as above</i>
	Poihipi	35	55	<i>as above</i>
	Rotokawa	105	174	<i>as above</i>
	Mokai	66	111	<i>as above</i>
	Kawerau	226	140	<i>as above</i>
	Ngawha	597	25	<i>as above</i>
INDONESIA				
	Wayang Windu	73.5	227	<i>Yuniarto et al (2015)</i>
	Kamojang	72.6	200	<i>as above</i>
	Ulubelu	42.6	110	<i>as above</i>
ITALY				
	All fields weighted average	330	876	<i>ESMAP (2016)</i>
MEXICO				
	Cerro Prieto	63.5	570*	<i>Peralta et al (2014)</i>
FOSSIL FUELS				
	Bituminous Coal	937.2	NA	<i>U.S. Energy Information Administration</i>
	Lignite Coal	982.6	NA	<i>as above</i>
	Distillate Fuel Oil (no. 2)	742.6	NA	<i>as above</i>
	Natural Gas	552.4	NA	<i>as above</i>

* estimate made based on measurements at 570 MW out of 720 MW total installed capacity

Table 2: CO₂ emissions rates for geothermal projects worldwide and for fossil fuel-fired generation

The weighted average CO₂ emissions rate for operating projects in Turkey is higher by a factor of 9.2 than the weighted average of 122 g/kW-hr for 6648 MW of worldwide installed geothermal capacity (Bertani and Thain, 2002). Weighted average CO₂ emissions rates are significantly lower for geothermal projects in California (82 g/kW-hr); Iceland (50 g/kW-hr); New Zealand (104 g/kW-hr). Reported CO₂ emissions rates for three large geothermal projects Indonesia (42-74 g/kW-hr) are less than 7% of the weighted averaged for operating geothermal projects in Turkey.

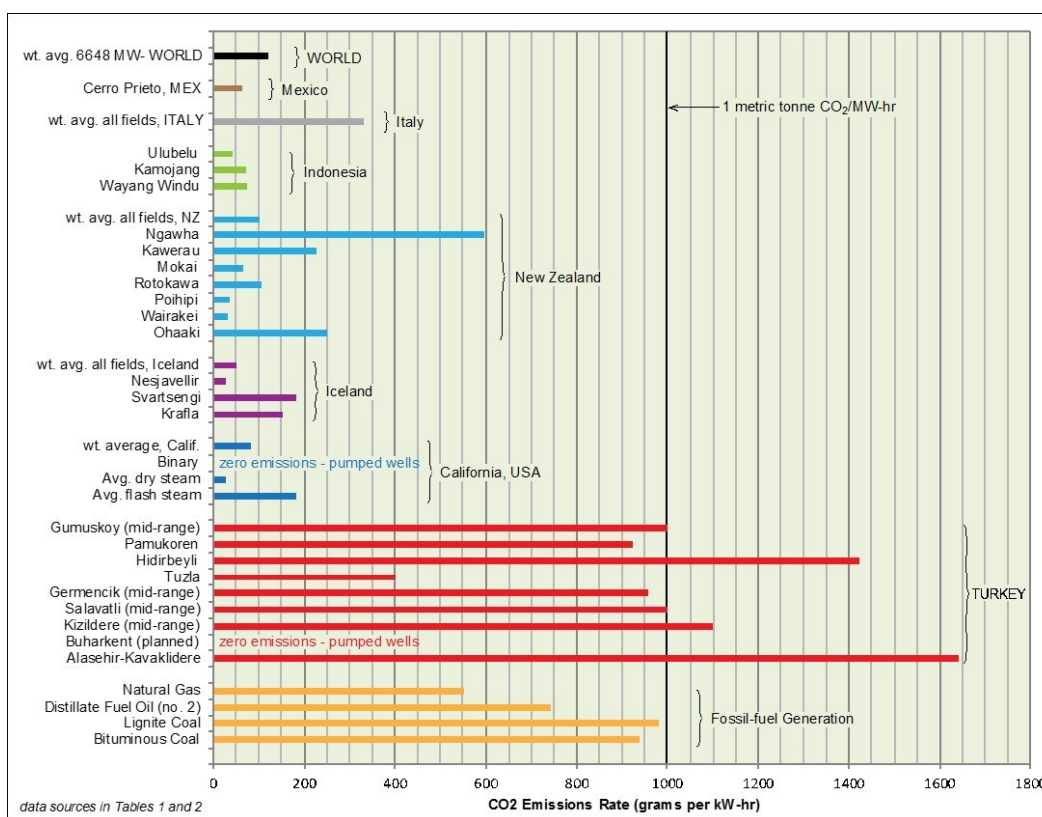


Figure 4: Chart of CO₂ emissions rates for Turkey geothermal projects compared with other geothermal projects worldwide and fossil-fuel power generation

There are several geothermal projects worldwide which are relatively gassy by global standards. However, CO₂ emissions rates from these projects are still well below the 1121 g/kW-hr weighted average figure for operating projects in Turkey. Geothermal projects in Italy exhibit a weighted average CO₂ emissions rate of 330 g/kW-hr for 876 MW of installed capacity. The 25 MW Ngawha project in New Zealand emits 597 g/kW-hr CO₂ which exceeds natural gas-fired generation. However, Ngawha is a relatively small plant that represents just 2.8% of the total of 906 MW installed geothermal capacity in New Zealand.

3.3 Potential for decline in CO₂ emission rates over time during production

CO₂ emissions rates from some operating geothermal projects in Turkey may decline over time due to a variety of mechanisms. However, available data suggests the declines may not be significant from an environmental standpoint because the initial emission rates are so high, as discussed below. Reinjection of the residual flashed brine with very low gas content back into the reservoir, along with excess steam condensate, may dilute gas concentrations in the reservoir fluids. Invasion of cooler, less gassy peripheral waters into the reservoir in response to production-induced drawdown may also occur and reduce reservoir gas concentrations. Finally, if the rate of CO₂ emissions due to power plant operations exceeds the natural rate of recharge of gas into the subsurface reservoir, the reservoir gas levels may decrease over time.

As part of a global overview, *ESMAP (2016)* concluded that the available data on the effect of reinjection of flashed brine on the gas content of geothermal reservoir fluids is quite limited worldwide, and that such data does not clearly support the beneficial effect of injection on reducing CO₂ emissions over time. Indeed, *ESMAP* concluded that “it cannot be assumed that gas concentrations in geothermal reservoir fluids will decrease with time when future emissions from geothermal projects are assessed”.

A well-documented example of a geothermal plant with declining CO₂ emissions over time is provided by the Dixie Valley project in Nevada, USA. CO₂ emissions declined steeply from 68.4 to 37.9 g/kW-hr over a five-year period, principally the result of dilution of gas in reservoir fluids by injected flashed brine (Benoit and Hirtz, 1994). On the other hand, the Uenotai field in Japan illustrates the uncertainty in projecting future gas emissions from geothermal projects, even where flashed brine is injected back into the reservoir. In this field gas contents in the total flow to the ~30 MW plant gradually increased from an initial value of 0.3 wt% to 0.6 wt% after 8 years of production, in effect a doubling of the gas flow (Butler et al, 2005). The increased gas flow at Uenotai appears to be related to production-induced drying out of the reservoir, with increasing contribution over time of steam from higher-gas fluids in the reservoir rock matrix and lesser contribution from open fractures.

Examples from Turkey: In Turkey, Haizlip et al (2013) report a 15% reduction in gas content within the intermediate depth reservoir at the Kizildere I project after 17 years of production from 1984 to 2000. During this period no spent fluids were injected into reservoir,

as partial injection of 25% of the produced brine only began in 2003 (Serpen & Turkmen, 2005). However, by 2015 the Kizildere I project was still emitting 900 g/kW-hr CO₂ (Askoy et al, 2015), i.e. rates which are comparable to those from coal-fired generation. Thus it is apparent that the magnitude of the decline in reservoir gas content for Kizildere I has not been sufficient, even after over 30 years of operation, to transform this project into a facility with low greenhouse gas emissions.

The 47.4 MW Germencik plant exhibited a clear decline in non-condensable gas production over the first 3 years of operation (Ecofys et al, 2016). Total non-condensable gas flow (>98% CO₂) was regularly measured at the plant site, allowing calculation of changes in CO₂ emissions rates over time. In the first few months of operation the data are erratic but on average indicate a CO₂ emissions rate of about 1100 g/kW-hr. After about 200 days operation this figure had dropped to 1002 g/kW. After 3 years the emissions rate reached 844 g/kW-hr, a reduction of 23% from the initial figure. However, at that point gas levels rose abruptly to 907 g/kW-hr before declining gradually back to 844 g/kW-hr after about 8 months. Thereafter, gas levels remained essentially flat at 844 g/kW-hr for over a year, at which point the record stops at 5 years from plant start-up. This plateau in gas emissions could be extended to the last two years of measurements if the spike in emissions at the end of year 3 is excluded.

Ecofys et al attempted to fit a logarithmic decline curve to the Germencik gas flow data which projects an emissions rate of 790 g/kW-hr after 10 years of plant operation. However, this projection ignores the observed plateau in CO₂ emissions observed during the last 1-2 years of measurement. Nonetheless, it is reasonable to conclude that after 10 years of operation the CO₂ emissions rate for the Germencik plant will likely be in the range of 790-844 g/kW-hr. While this range is less than the 940 to 980 g/kW-hr CO₂ emissions rate for coal-fired plants, it still exceeds the emissions rate for distillate fuel oil-fired generation of 742 g/kW-hr. Thus the projected decline in gas levels after over 10 years of operation at Germencik will not be sufficient to convert this project into a climate-friendly facility.

4. MECHANISMS FOR CO₂ DISCHARGE TO THE ATMOSPHERE

As indicated in **Table 1**, operating geothermal plants in Turkey include both flash and binary facilities. These are installed in a variety of configurations and combinations, primarily depending upon the resource temperature. CO₂ and other produced non-condensable gases are vented to the atmosphere from all of these various types of operating geothermal power plants in Turkey. The entire produced gas stream is vented to the atmosphere in these projects, with the exception of two plants where a portion of the CO₂ produced is sold for commercial use as discussed below. Process flow diagrams were located for several of the Turkey geothermal plants to verify the locations of the exhaust points for emission of CO₂ to the atmosphere.

Germencik 47.4 MW plant: The 47.4 MW Germencik plant (**Figure 5**) is a double-flash plant which came on line in 2009 (Wallace et al, 2009; Di Pippo, 2012). The eight production wells are drilled to depths of 965-2,432 meters and produce reservoir fluid with temperatures up to 232°C under artesian flow conditions without downhole pumps. The plant includes twin high-pressure separators and twin low-pressure flash vessels. Separated brine is returned to the reservoir via injection wells and steam is directed to the condensing turbine. A hybrid non-condensable gas removal system composed of first-stage steam jet ejectors and second-stage liquid ring vacuum pumps draws the gas stream from the condenser unit on the back side of the turbine. The extracted gas, mixed with the steam used by the ejectors, is passed through a second smaller condensing unit and the residual gas stream is directed to the cooling fan stack above the fan blades. The CO₂ and trace gases are diluted and mixed with air in the fan stack and vented to the atmosphere.

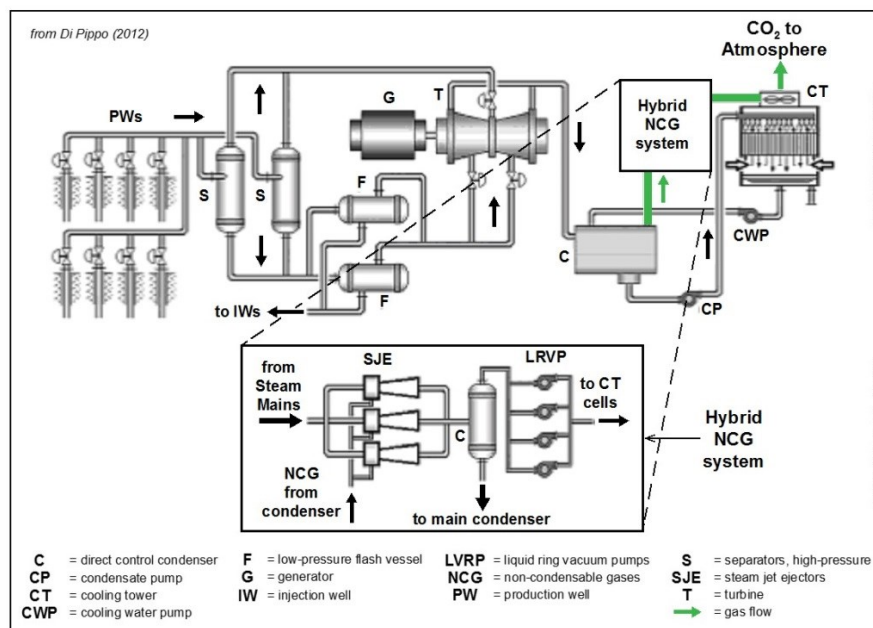


Figure 5: Process flow diagram for Germencik 47.4 MW double-flash geothermal plant, from Di Pippo (2012)

Salavatli Dora II 11.5 MW plant: The 9.5 MW Dora II plant at Salavatli (**Figure 6**) is an Ormat integrated two-level binary (ITL) binary plant that came on line in 2010 (Kaplan & Serpen, 2010; Di Pippo, 2012). The ITL binary plant is an Organic Rankine Cycle (ORC) design in which boiling of the organic working fluid occurs at two pressure levels to achieve higher energy output. Three production wells tap a lower enthalpy subsurface reservoir at about 170°C. The wells flow under artesian conditions without pumping at a wellhead pressure of about 12 bars. The two-phase flow at the wellhead is mainly liquid with just 2.2% steam, and the small steam fraction has very high gas content of over 50%. The separated liquid is directed first to the Level 1 vaporizer then to the Level 2 vaporizer where it flows in a series of tubes separated from the tubes used for the steam flow. Downstream of the vaporizers the brine is directed to the Level 1 and Level 2 preheaters. The separated steam fraction with its high CO₂ content is directed to the Level 2 vaporizer where it gives up its heat to the organic working fluid and the condensate is pumped to the reinjection line. The CO₂ and other trace gases are released to the atmosphere from the rear end of the Level 2 vaporizer, presumably through some type of elevated stack. Because the steam is condensed at above atmospheric pressure, no compressor or vacuum pump is required to discharge the gases.

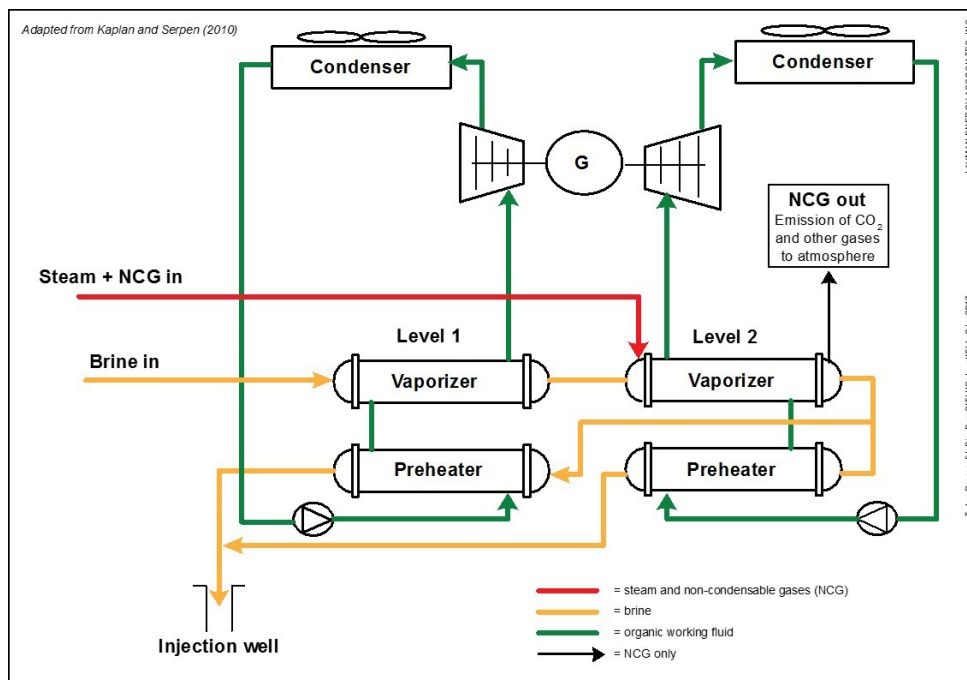


Figure 6: Process flow diagram for 9.5 MW Ormat integrated two-level binary plant at Salavatli (Dora 2 facility), adapted from Kaplan and Serpen (2010)

Alasehir 45 MW plant: The 45 MW Alasehir plant developed by Zorlu Enerji (**Figure 7**) is a hybrid binary and dual-flash plant (ENVY, 2013). The plant came on line in two phases, with a 33.7 MW flash facility commissioned in 2015 followed by an 11.3 MW ORC binary unit in 2016 (Richter, 2015). Based on a total plant fluid requirement of 2200 tonnes/hour and a reservoir fluid CO₂ content of 3.4 wt%, the estimated CO₂ emissions rate from this project is about 1660 g/kW-hr. This is the highest CO₂ emissions rate of all geothermal projects in Turkey. CO₂ is discharged to the atmosphere from both the flash and binary units.

The 33.7 MW Alasehir flash facility includes high-pressure and low-pressure separators. Separated steam from each separator is directed along dedicated lines to the respective high- and low-pressure sections of the turbine. Steam exiting the low pressure section of the turbine is directed to a condenser unit on the back side of the turbine. As at Germencik, a hybrid non-condensable gas system composed of first-stage steam jet ejectors and second-stage liquid ring vacuum pumps draws the gas stream from this condenser unit. The extracted gas, mixed with the steam used by the ejectors, is passed through a second smaller condensing unit, and the residual gas stream is directed to the cooling tower fan stack above the fan blades. The CO₂ is diluted and mixed with air in the fan stack and vented to the atmosphere.

The 11.3 MW Alasehir binary facility uses portions of both the separated steam and brine flows for the project. Steam exiting the high-pressure turbine is directed to the vaporizer unit in the ORC binary facility and boils the organic working fluid. The steam condenses in the vaporizer and the resulting condensate is mixed with separated brine sent from the low pressure separator and directed to a preheater to provide initial heating of the working fluid. This condensate and brine mixture is then pumped to the injection wells. The CO₂ and other trace gases are released to the atmosphere from the top of the vaporizer, presumably through some type of elevated stack. Because the steam is condensed in the vaporizer at above atmospheric pressure, no compressor or vacuum pump is required to discharge the gases.

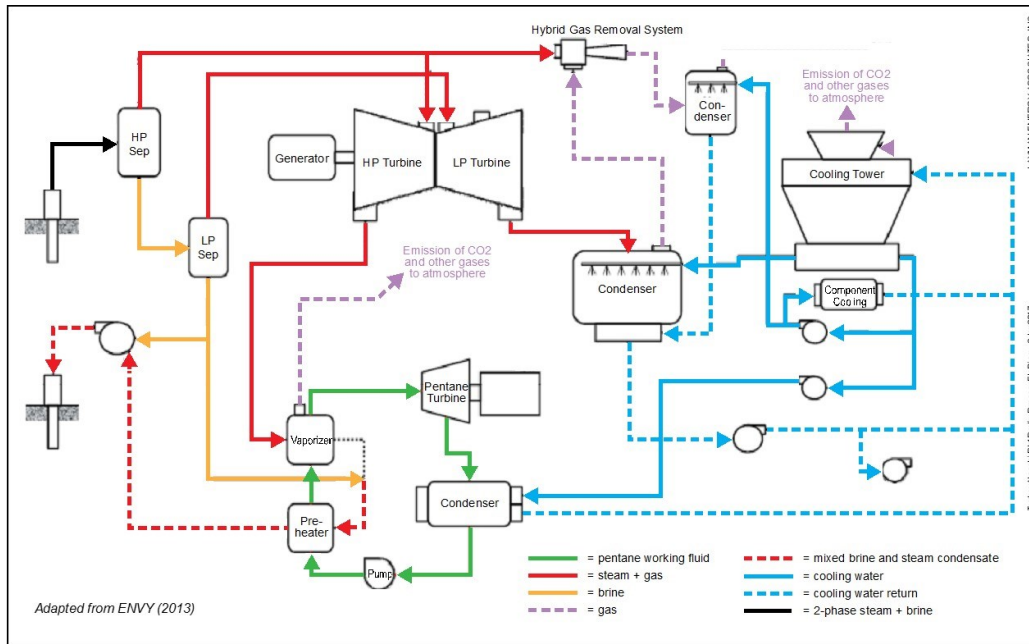


Figure 7: Preliminary process flow diagram for 45 MW Alasehir Phase 1 hybrid flash and binary plant, adapted from ENVI (2013)

4.1 Commercial use of CO₂ from initial plants at Kizildere and Salavatli

Initial geothermal plants installed at Kizildere and Salavatli (and possibly Gumuskoy) supply CO₂ for the beverage industry and other uses. While such CO₂ when consumed is ultimately discharged to the atmosphere, in this case the geothermal CO₂ displaces other sources of CO₂ needed to meet consumer demand. Nonetheless, the market for CO₂ in Turkey is apparently near saturation (EBRD, 2016), implying that commercial sale of CO₂ is unlikely to be a viable alternative for large scale disposal of CO₂ for other geothermal projects in Turkey.

The 17.8 MW Kizildere Unit I plant is a single flash facility which came on line in 1984 and produces about 193,460 tonnes per year (6.13 kg/sec) of CO₂ (Serpén & Turkmen, 2005; Di Pippo, 2012). This equates to a CO₂ emissions rate of 1240 g/kW-hr. About 40,000 tonnes of CO₂ per year were initially sold from 1984 to 1999, thereafter the amount sold increased to 120,000 tonnes/year (Gokcen et al, 2004). By difference, about 38% of the gas produced by this plant is discharged to the atmosphere. Di Pippo reported that as of 2012 this plant supplied about 90% of the CO₂ needs of the local beverage industry and suggested that the market for geothermal CO₂ in Turkey is nearly saturated.

The 7.35 MW Dora-1 binary plant at the Salavatli geothermal field supplies 30,000 tonnes/year of CO₂ for commercial uses (Baba et al, 2014). The CO₂ supplied for commercial use represents approximately 45.4% of the total gas stream of 66,078 tonnes/year produced by the geothermal plant. The total gas flow was calculated based on a reported total steam flow of 22.45 tonnes/hour containing 33.6 wt% gas, and assuming that all of the gas is portioned into the steam phase. Thus 54.6% of the total gas produced for the Dora-1 facility is discharged to the atmosphere and not used commercially. This reinforces the conclusion of Di Pippo and EBRD that the market for CO₂ in Turkey is at or near saturation.

5. LACK OF CLOSED-LOOP PUMPED BINARY PROJECTS WITH ZERO EMISSIONS

Pumped or “single-phase” binary plants represent the most environmentally-friendly geothermal power generation technology. These are closed loop systems with essentially zero emission of produced CO₂ or other gases. A key feature of these projects is the installation of downhole pumps in production wells to deliver pressurized, single-phase geothermal liquid to the vaporizer / heat exchangers to boil the organic working fluid. The geothermal fluid remains in liquid phase throughout the power cycle and the CO₂ and other gases remain in solution. The heat-depleted brine with its dissolved gases is pumped to injection wells and returned to the reservoir, thus completing the closed loop with zero greenhouse gas emissions.

Pumped binary projects represent about two-thirds of all binary projects installed worldwide as of 2011 (Di Pippo, 2012). In the U.S., virtually all binary projects installed in California (277 MW capacity) and Nevada (423 MW capacity) are supplied by pumped production wells (GEA, 2012; Boyd et al, 2015). In contrast, none of the many binary geothermal plants installed to date in Turkey (**Table 1**) are pumped, and as a result these projects discharge their produced CO₂ to the atmosphere. There are plans for construction

of a 15 MW pumped binary project at the Buharkent field (see below), and if successful this would be the first such plant in Turkey (Mertoglu et al, 2015).

The absence of pumped binary projects in Turkey relates both to the temperature and gas content of the geothermal fields and the current limitations of downhole pump technology. The temperature limit of the downhole pumps required for pumped binary projects is about 190°C (Sanyal et al, 2007) and reservoir temperatures at many geothermal projects in Turkey exceed 190°C. However, a more significant factor is that even for those geothermal reservoirs in Turkey with temperatures below 190°C, their high gas content has to date precluded the use of downhole pumps.

Haizlip et al (2016) reviewed in detail the effect of the high gas contents in Turkey geothermal reservoirs on the bubble point or depth of first boiling in flowing wells, and noted the difficulty of exploiting these gassy reservoirs with downhole pumps. Higher gas contents increase the bubble point pressure for a given reservoir temperature, which translates to greater depth to first flashing or boiling in a flowing well. Downhole pumps must be installed below the depth of first flashing to maintain flow of single phase liquid through the pump to avoid cavitation and pump failure. Thus pumping gas-rich reservoirs in Turkey would require downhole pumps with very high pressure ratings that can be set deep in the production well. For example, results of wellbore simulations by Haizlip et al for a 175°C reservoir with a range of well flow rates indicate minimum pump set depths as follows: 1) 700-800 meters for 1.5 wt% gas; 2) 1000 meters for 2.0 wt% gas; and 3) 1500-1700 meters for 3.5 wt% gas.

The maximum pump setting depth for the industry standard line-shaft pumps is 457 meters or 1500 feet (Sanyal et al, 2007), therefore line-shaft pumps do not appear to be a viable option for the gas-rich reservoirs in Turkey. Suppliers of electric submersible pumps report that these can potentially be installed as deep as 1,000 meters with fluid temperatures up to 190°C (Vandevier & Gould, 2009). Thus submersible pumps could potentially be applied to Turkey geothermal systems with gas contents less than about 2.0 wt% based on the well simulations of Haizlip et al described above. However, Sanyal et al (2007) note that geothermal industry experience with submersible pumps is quite limited, and this should be especially true for pump setting depths close to the maximum of 1,000 meters recommended by the pump manufacturers.

5.1 Buharkent Exception

As mentioned above, Mertoglu et al report that the developer of the Buharkent field in Turkey plans to construct a pumped binary plant which would discharge no CO₂ to the atmosphere. Results from three wells indicate a reservoir temperature of about 160°C with 0.2 wt% gas in the reservoir fluid, the lowest gas content described for any geothermal field under development in Turkey. The production wells are “non-artesianic” and thus require pumping to sustain flow. Static water level depths range from 220-275 meters and the projected water level under flowing conditions is 300-350 meters. The pump setting depth is planned at 450 meters, presumably to provide a safety factor to allow for future drawdown. The developer plans to install electric submersible pumps in the wells, presumably because the planned pump setting depth is considered too close to the 457 meter depth limit for line-shaft pumps.

6. UNPROVEN MITIGATION STRATEGY OF GAS RE-INJECTION

Some researchers have suggested it may be possible to mitigate the voluminous CO₂ production from geothermal projects in Turkey by re-injection or “sequestration” of the gas back into the subsurface reservoir (Wallace et al, 2009; Askoy et al, 2015; Haizlip et al 2016). However, there is as yet no precedent for successful, sustained re-injection of CO₂ in the massive amounts produced by Turkey geothermal projects. A “typical” Turkey geothermal project with 50 MW plant capacity and a CO₂ emissions rate of about 1000 g/kW-hr would produce 50 tonnes CO₂/hour, or 1,200 tonnes/day. While further research is certainly warranted, the examples below indicate that large scale re-injection of CO₂ at geothermal projects in Turkey is not yet a viable option for mitigation of CO₂ emissions.

6.1 Coso, USA

In 1989, California Energy Co. initiated a program to re-inject CO₂ and other trace gases produced by the 270 MW Coso field in southeastern California, USA but ultimately abandoned this effort due to operational difficulties. The primary goal of the gas injection program was for abatement of hydrogen sulfide (H₂S) gas emissions. Information on CalEnergy’s gas injection program is available from World Environment Center (1994) and Nagl (2009), as well as from the author’s personal experience as an employee of CalEnergy during the period of the gas injection.

The 270 MW Coso facility consists of nine individual 30 MW units installed sequentially as Units 1-9. Gas concentrations in produced steam at Coso ranged from 1-3 wt% with about 97% CO₂ in the dry gas, with more gassy steam produced from Units 7-9 (BLM West and BLM East plants). Assuming an average gas level of 1.9 wt% in steam and a typical steam consumption rate for steam turbines of 7.3 tonnes/hour per MW, the estimated total gas flow reinjected was about 37.4 tonnes/hour (899 tonnes/day) for the 270 MW facility. The associated baseline CO₂ emissions rate for Coso (after gas injection was stopped) is thus about 138 g/kW-hr, or about 14% of the typical 1000 g/kW-hr rate for geothermal projects in Turkey.

CalEnergy started injection of the entire gas stream produced by the Coso project upon start-up of Units 7 and 8 in February 1989, and added injection of gas from Unit 9 upon start-up of that final unit in July 1989. However, injection of gas from Units 7 and 8 was stopped entirely in June 1990 after only 16 months of operation due to gas recycling. Injection of gas from Unit 9 was curtailed in June 1991 after only 12 months of operation for the same reason. As of October 1994, CalEnergy was injecting only a small portion of the produced gases to acidify injected fluids in order to minimize silica scaling in injection wells.

CalEnergy concluded that the gas reinjection program was not successful primarily because of recycling of injected gas back to the production wells and the associated decrease in power plant performance. For example, prior to reinjection the gas content in steam

produced by Units 7 and 8 was 2.2 wt%, but this figure increased to a peak value of about 6.6 wt% prior to ceasing injection of Unit 7 and 8 gases in June 1990. Other operational factors affecting the decision to cease gas injection included corrosion of gas injection pipelines and well casing, and vapor lock at certain reinjection wells due to insufficient liquid flow to maintain gas in solution.

CalEnergy staff concluded that the gas injection program would only work effectively for small facilities with very low gas content and gas injection wells located on the field periphery. The fact that CalEnergy was unable to sustain reinjection of about 37 tonnes/hour of gas for a 270 MW facility suggests that it will be a major technical and economic challenge for the “typical” 50 MW project in Turkey to reinject 50 tonnes/hour of gas flow.

6.2 Hellisheidi, Iceland

A significant gas re-injection effort is currently underway at the 303 MW Hellisheidi geothermal power generation project in Iceland (Gunnarsson et al, 2015; Aradottir et al, 2015; Gunnlaugsson,2016). The Hellisheidi plant emits about 40,000 tonnes of CO₂ per year, which translates into a very low CO₂ emissions rate of about 15.1 g/kW-hr. Hellisheidi is unusual in that CO₂ forms only about 53% by volume of the separated gas, followed by H₂ at 25% and H₂S at 19%. In an experiment in early 2014, about 250 tonnes of CO₂ were injected with condensate via two wells into basaltic bedrock at 400-800 meters depth. Subsequent inspection of drill core indicated significant precipitation of injected CO₂ as calcite in the basaltic rocks near the injectors. In June 2014, larger “industrial-scale” injection of CO₂ and H₂S and condensate was initiated into a different single injection well which receives 14.5 tonnes/day CO₂ and 7.9 tonnes/day H₂S on an ongoing basis. This combined total gas injection rate of 22.4 tonnes/day (0.93 tonnes /hour) represents about 30% of the total gas flow generated by the Hellisheidi power plant. This is presumably the maximum amount of gas flow that the single injection well could accept at a reasonable wellhead pressure. Long-term monitoring of the Hellisheidi gas injection program is needed to insure that injected gas is not recycled back to the producer wells and that corrosion of gas pipelines and well casings is not a problem, as was the case at Coso.

Significantly, the amount of gas flow being injected into a single well at the 303 MW Hellisheidi project represents just 1.9% of the 1,200 tonnes per day of CO₂ generated by the “typical” 50 MW geothermal project in Turkey described above. Thus the typical geothermal project in Turkey could potentially require over 50 injector wells with properties similar to the injector well used at Hellisheidi to dispose of all the gas produced. A regulatory requirement to drill designated gas injector wells in such numbers would certainly destroy the economics of geothermal projects in Turkey.

6.3 Hijori and Ogachi, Japan

Experiments have been conducted in Japan in which small amounts of CO₂ were injected into the Hijori and Ogachi geothermal reservoirs (Yanagisawa, 2010; Ueda et al, 2010). At Ogachi, only a small slug of water (5 cubic meters) with 1.0 wt% dissolved CO₂ was injected into the reservoir. At Hijori, about 6 tonnes of CO₂ were injected with water into two wells over a 3 month period. Both experiments yielded evidence of partial sequestration of CO₂ in the formation as the mineral calcite (CaCO₃). However, because of the small amounts of CO₂ injected the results have limited applicability to Turkey geothermal fields.

7. FINANCING OF TURKEY GEOTHERMAL PROJECTS BY INTERNATIONAL LENDERS

Multilateral development banks (MDB) have played a critical role in providing financing for geothermal projects in Turkey. These international financial institutions generally promote development projects by providing loans at concessional interest rates and facilitate participation of private sector lenders by sharing financing risk. The MDB may also provide grant funding for certain projects. As described below, the financing of geothermal projects in Turkey with very high greenhouse gas emissions rates is inconsistent with the stated environmental mission of these agencies.

7.1 European Bank for Reconstruction and Development (EBRD)

EBRD has provided over US \$1.3 billion in financing for multiple geothermal projects in Turkey in recent years (*EBRD,2017; EBRD website*). These projects are listed below with the corresponding financing amounts in US dollars:

2010:	7.5 MW Tuzla project, \$22 million
2012:	45 MW Pamukoren project, \$63 million
2012:	13.2 MW Gumuskoy project, \$50 million
2014:	7 MW Babadere project (Tuzla area), \$33 million
2015:	24 MW Alasehir project, \$100 million
2015:	12 MW Umurlu project, \$54 million
2015:	123 MW Germencik project, \$800 million
2015:	PLUTO program for financing early stage development, \$125 million
2017:	70 MW Unit 2 of Kizildere III project, \$70 million

The EBRD website indicates the organization is “committed to promoting environmentally sound and sustainable development in the full range of its investment and technical cooperation activities” and further states that “projects that foster environmental and social sustainability rank among the highest priorities of its activities”.

However, most of the geothermal projects in Turkey financed by EBRD have very high greenhouse gas emissions rates which are on a par with or exceed those from coal-fired generation. From the above financing list high gas projects include Pamukoren; Gumuskoy; Alasehir; Germencik; and Kizildere (**Table 1**). The two projects in the Tuzla area have more modest emissions rates, while there is apparently no publicly available data on CO₂ emissions at Umurlu. For the PLUTO project, it is not yet clear what proportion of the total \$125 million financing amount will be allocated to early stage projects with high CO₂ content in reservoir fluids. However, given the geologic setting and preponderance of high-gas geothermal projects in Turkey, it seems likely that the bulk of the PLUTO funding will promote development of projects with high greenhouse gas emission rates.

7.2 World Bank Group

In November 2016, The World Bank Group (WBG) announced via press release it will be providing \$250 million in loans for development of as yet unspecified geothermal projects in Turkey. The lending agency will be the International Bank for Reconstruction and Development (IBRD) a WBG member organization. IBRD will lend the funds to intermediary banks in Turkey, and these local banks will identify and lend these funds to specific geothermal projects. Although the individual projects to be financed have not yet been identified, it seems likely that the bulk of this funding will promote development of projects with high greenhouse gas emission rates, given the nature of geothermal resources in Turkey.

The World Bank is the Trustee and Administrator of the Clean Technology Fund (CTF) and can also act as an implementing agency for CTF investments, along with other MDB's. On 1 November 2016 the World Bank issued a press release indicating that the CTF would provide \$39.8 million in grant funding to promote an unspecified geothermal development project in Turkey. Furthermore, CTF recently stated its policy is to promote development of over 400 MW of new geothermal generation capacity in Turkey (*CTF, 2015*). As described above, given the dominance of high-gas geothermal resources in Turkey it seems likely that the bulk of the CTF funding will promote development of projects with high greenhouse gas emission rates,

WBG financing of geothermal development in Turkey via IBRD and CTF is not consistent with stated WBG environmental policies to reduce greenhouse gas emissions and mitigate climate change. In April 2016, WBG released a Climate Change Action Plan under which, among other actions, WBG committed to install 30 gigawatts of new renewable energy and mobilize \$25 billion in private financing for clean energy (*WBG, 2016*). The stated mission of the \$5.8 billion CTF is to provide resources to developing and emerging economies to “scale up low carbon technologies with significant potential for long-term greenhouse gas emissions savings” (*CTF website*). However, in a press release dated 1 November 2016, the WBG Country Director for Turkey stated that WBG was pleased to help the Government of Turkey to expand geothermal capacity in the country, and added that geothermal power plants “provide *low-carbon baseload power* to drive economic growth and boost prosperity” (*italics added*). This press release seems to indicate that the WBG, while supporting greenhouse gas reduction in theory, is either unaware of or chooses to ignore the unusually high greenhouse gas emissions rates of Turkey geothermal projects.

8. CONCLUSIONS

Geothermal resources in Turkey typically have very high carbon dioxide (CO₂) content, generally from 1.5 to 3.5% by weight dissolved in the reservoir fluid. As a result, CO₂ emissions rates from most operational geothermal projects in Turkey are the highest in the world by a significant margin. Reported CO₂ emissions rates for projects such as Kizildere, Salavatli, Germencik and Alasehir range from 800-1600 g/kw-hr and thus are comparable to or significantly exceed typical CO₂ emissions rates from coal-fired power plants of about 940-980 g/kw-hr. A “typical” 50 MW geothermal project in Turkey producing 1000 g/kw-hr CO₂ discharges 1,200 tonnes per day of CO₂ to the atmosphere.

In Turkey geothermal projects, CO₂ is vented to the atmosphere not only from flash plants but also from binary plants fed by artesian flow of two-phase fluid supplied by production wells. This contrasts with widespread binary geothermal projects elsewhere fed by pumped wells which typically emit zero CO₂ to the atmosphere. In pumped binary projects the produced gas is kept in solution in the pressurized liquid which is reinjected to the reservoir yielding a closed-loop system. Pumping of production wells is generally not feasible in Turkey due to a combination of: 1) high gas contents which can depress the flash point in wells down to depths below the technical limit of downhole pumps; and 2) reservoir temperatures exceeding the 190°C temperature limitation of the pumps. In these “artesian binary” projects in Turkey, non-condensable gases (>96% CO₂) are discharged to the atmosphere from the back end of the vaporizer units receiving the separated steam plus gas mixture. At flash plants in Turkey (as elsewhere) CO₂ is extracted from the back end of the steam turbine via gas compressor units and/or steam jet ejectors, and directed to the cooling towers for discharge to the atmosphere.

Declines in CO₂ emissions rates over time are possible for some geothermal projects in Turkey due to dilution of reservoir gas by “de-gassed” injectate. However, available data from the Kizildere I and Germencik projects indicates that gas levels can still remain very high for decades despite declines from initial gas levels. Mitigation of produced CO₂ by re-injection to the reservoir is currently not a viable option for Turkey geothermal projects, as there is as yet no precedent for successful sustained re-injection of the massive amounts of CO₂ produced by these fields. A short-lived experiment at the Coso field in the USA was abandoned due to recycling of injected gas back to production wells, and the scale of ongoing gas injection operations at Hellisheidi in Iceland is too small to be applicable to Turkey projects. A portion of the CO₂ produced by several plants is sold for commercial uses but this represents a small portion of the total geothermal CO₂ production in Turkey and the local market for CO₂ appears to be saturated.

Geothermal projects in Turkey are not environmentally friendly due to the adverse climate impacts of these extreme CO₂ emissions rates. EBRD and the World Bank are actively providing funding for geothermal development in Turkey, fueling the recent explosive growth of geothermal capacity in the country. Such financial support is inconsistent with the stated missions of these agencies to reduce greenhouse gas emissions and promote environmentally sustainable projects. Instead, financial support for geothermal development in Turkey should be directed towards facilitating:

- exploration for and development of other low-gas systems such as Tuzla and Buharkent;
- increasing the pressure and depth limits for downhole pumps so more gassy geothermal systems can be developed as zero emissions pumped binary projects; and
- scaling-up of gas reinjection systems such as in operation at Hellisheidi.

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