PROCEEDINGS, 48th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 6-8, 2023
SGP-TR-224

Recent Soil Carbon Dioxide Flux Measurements at Kızıldere Geothermal Field

Ali Berkay Tokel[1], Serhat Akın[1], Taylan Akın[2], Selçuk Erol[3], Doğuhan Barlas Sevindik[1]

[1]Petroleum and Natural Gas Engineering Department, Middle East Technical University, Ankara, Turkey

[2]Geothermal Application and Research Center, Pamukkale University, Denizli, Turkey

[3]Energy System Engineering Department, İzmir Institute of Technology, İzmir, Turkey

berkayt@metu.edu.tr, serhat@metu.edu.tr, takin@pau.edu.tr, selcukerol@iyte.edu.tr, sevindik.barlas@metu.edu.tr

Keywords: soil carbon dioxide flux, Kızıldere geothermal field, GECO

ABSTRACT

Geothermal fields in the Western part of Turkey are known for their significant carbon dioxide content that results in considerably high amounts of gas emissions from geothermal power plants during electricity production. Geothermal Emission COntrol (GECO) project aims to address this issue and minimize the amount of carbon dioxide emitted on the fields with similar characteristics around Europe. In the framework of the project, the emitted carbon dioxide is reinjected into the reservoir as a method of reducing carbon dioxide emissions to the atmosphere similar to the CarbFix method carried out in Iceland. One of the pilot reinjection fields of carbon dioxide was set up in the Kızıldere geothermal field in Turkey. The objective of this study is to measure the carbon dioxide fluxes on the surface and detect the leakage, thereby, ensuring that the injected carbon dioxide is trapped in the geothermal reservoir. An automated soil carbon dioxide flux system that utilizes accumulation chamber methodology is used. The flux values are measured at more than sixty station points at the Kızıldere field for two years to create a baseline before the carbon-dioxide gas-charged fluid injection. This study will guide for long-term monitoring of the carbon dioxide gas-charged fluid reinjection process. Furthermore, the technique provides a means of assessing the feasibility of the pilot carbon-dioxide injection process in geothermal fields.

1. INTRODUCTION

The utilization of geothermal energy, despite being considered as environmentally friendly, may lead to the emission of substantial amounts of carbon dioxide in fields where the geothermal fluid contains large volume of dissolved carbon dioxide. One of the objectives of the Geothermal Emissions COntrol (GECO) project is to mitigate these emissions by reinjecting the captured carbon dioxide back into the geothermal reservoir, thereby, providing clean and sustainable energy. The Kızıldere geothermal field has been chosen as one of the demonstration sites of the GECO project, due to its naturally high content of carbon dioxide.

The Kızıldere geothermal field, which is located in Denizli at the western region of Turkey, is the largest and most important geothermal field in the country. Geological, geophysical, and geochemical studies, which were supported by United Nations Development Program, showed the existence of two distinct reservoir levels: a shallow medium enthalpy layer and a deep high enthalpy layer (Gokcen et al., 2004). The deeper reservoir, which is composed of metamorphic rocks, typically contains 3% carbon dioxide by weight, while the shallower reservoir section generally contains 1.5% carbon dioxide by weight (Şimşek et al., 2005).

To determine the success of a carbon dioxide sequestration scheme, it is crucial to monitor the movement of the injected carbon dioxide to ensure that it does not escape from the wellbore through leakage or emitted back to the atmosphere through the permeable zone in a reservoir such as faults. The evaluation of the success of a carbon dioxide sequestration program requires continuous monitoring of possible movement of the reinjected carbon dioxide. In order to accomplish this, advanced monitoring techniques such as numerical reactive transport reservoir simulations, tracer tests, and repeated soil carbon dioxide flux surveys are utilized within the framework of the Geothermal Emissions COntrol demonstration campaign at the Kızıldere geothermal field.

Soil carbon dioxide flux is the rate at which carbon dioxide moves from soil to the atmosphere. Soil carbon dioxide fluxes encompass the exhalation of carbon dioxide from the Earth's crust and mantle caused by degassing, carbon dioxide created by the respiration of plants and roots, carbon dioxide generated by the decomposition of organic compounds and/or the oxidation of organic matter (De Gregorio et al, 2019). Soil carbon dioxide fluxes are useful in monitoring carbon capture and storage (CCS) sites and used commonly at various CCS sites around the world (Carman et al., 2019; Szizybalski et al., 2017). A soil carbon dioxide flux monitoring campaign is also established at the Kızıldere geothermal field to measure and analyze the intensity and variability of soil carbon dioxide fluxes prior and after the carbon dioxide reinjection process. Previous and post injection fluxes will also be investigated to identify potential flux anomalies.

2. METHODOLOGY

2.1 Soil Flux Measurements

The soil carbon dioxide fluxes presented in this study are acquired using a LI-COR Biosciences LI8100A portable single-chamber soil gas flux system (LI-COR, 2015) that utilizes accumulation chamber methodology. The measurement method involves circulating a small amount of air from the chamber to the infrared gas analyzer (IRGA) and subsequently returning it to the chamber (Madsen et al., 2009). A material balance for the carbon dioxide in the closed chamber is then used to derive the flux equation (Equation 1). A linear, or exponential fit of the field measurements is used to determine the initial $\partial C'/\partial t$, and consequently, the soil fluxes (LI-COR, 2015).

$$F_c = \frac{10VP_0\left(1-\frac{W_0}{1000}\right)}{RS(T_0+273.15)}\frac{\partial C_c'}{\partial t} \quad (1)$$

Where F_c is the soil CO_2 efflux rate (µmol $m^{-2}s^{-1}$), V (cm^3) is the volume, P_0 is the initial pressure (kPa), W_0 is the initial water vapor mole fraction (mmol mol^{-1}), S is soil surface area (cm^2), T_0 is initial air temperature (°C), and $\partial C'/\partial t$ is the initial rate of change in water corrected CO_2 mole fraction (µmol mol^{-1}) (LI-COR, 2015).

The field measurements involve the installation of polyvinylchloride (PVC) soil collars, upon which the accumulation chamber is seated, into the ground as depicted in Figure 1. These collars also create the necessary seal needed between the accumulation chamber and the soil. To ensure minimal disruption to the results, soil collars are installed at least 24 hours prior to conducting measurements as per producer recommendations (LI-COR, 2015). At each sampling location, two consecutive measurements are conducted. Each measurement is taken for 90 seconds.

Figure 1: Soil collar installed into the ground for measurement (left), and soil flux measurement at Kızıldere (right).

For the analysis of the field measurements, the software SoilFluxPro by LI-COR Biosciences (LI-COR, 2021) is used. The best results are achieved when the mixing of the air inside the chamber is steady. Dead band refers to the interval of time that starts once the chamber is fully closed and continues until the steady mixing in the chamber is obtained (LI-COR, 2015). Time to reach steady chamber mixing (dead band) is determined to be 20 seconds at the Kızıldere field measurements. Measurements that are not in the dead band are used to calculate soil fluxes. An example exponential fit of the experimental data using SoilFluxPro can be seen in Figure 2.

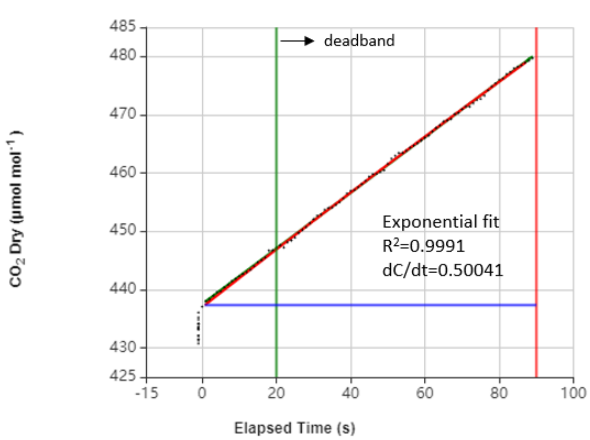

Figure 2: Example exponential fit with SoilFluxPro software.

Study Area

The Kızıldere geothermal field, is located in the Western part of Turkey, which is characterized by horst and graben structures between Buldan and Babadağ horsts. The field is situated near the meandering Büyük Menderes River. A representation of the conceptual model of the geothermal system and the general geological setting can be observed in Figure 3.

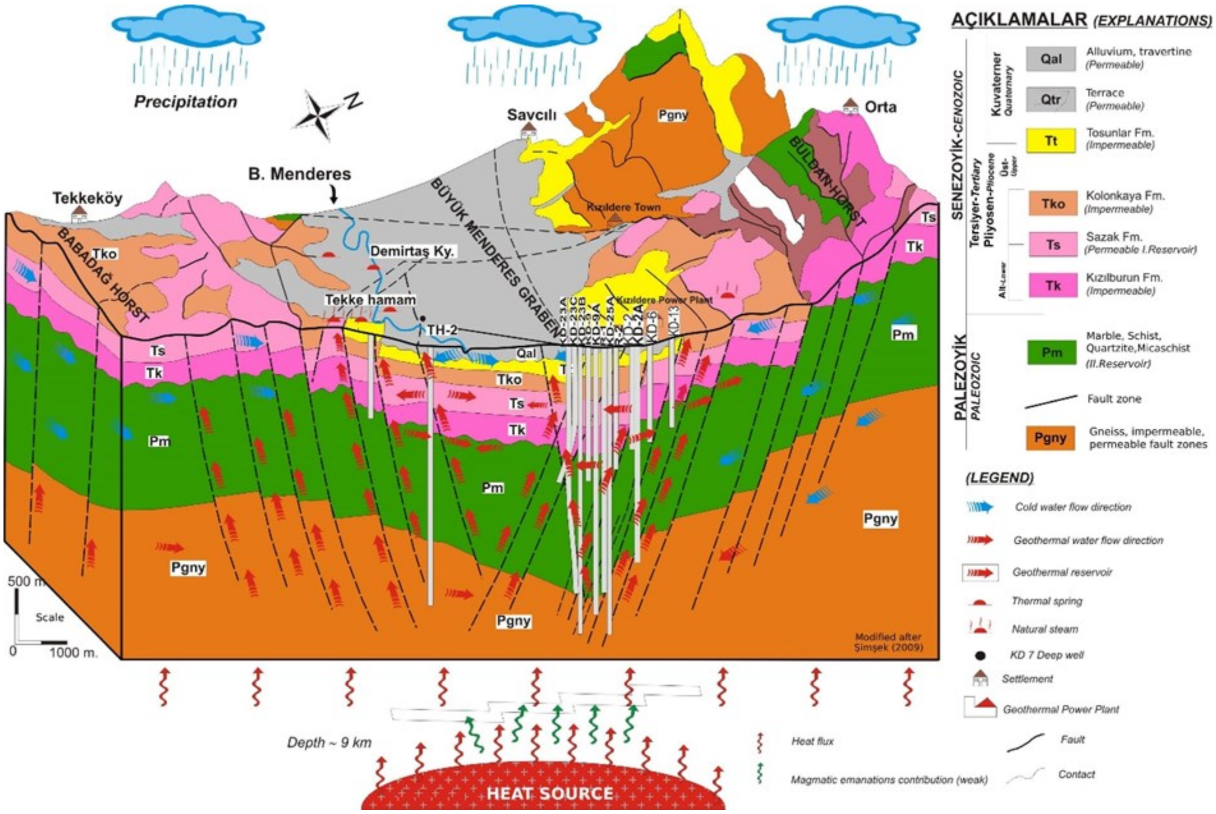

Figure 3: Conceptual model and general geology of the Kızıldere geothermal field (modified after Şimşek et al, 2009).

As a part of the demonstration campaign of the GECO project, some portion of the NCG produced from the Kızıldere geothermal field will be reinjected into the reservoir. To generate a baseline of the carbon dioxide fluxes before the start of the pilot reinjection campaign, six different point-based soil carbon dioxide flux measurements were conducted in February, March, April, June, September, and December 2019 (Küçük et al., 2021). In this article, the most recent soil carbon dioxide flux measurements conducted in August 2022 are presented. In total, 79 new soil flux measurements are taken in August 2022. The selection of measurement locations for the previous (2019) and the recent (2022) measurements is carried out based on the following criteria:

1. Finely spaced rectangular sampling locations are selected near the proposed reinjection well to observe possible leaks that may occur in the vicinity of the well by casing and/or cement failure.
2. Locations around the outcrops of the faults that intersect the reservoir are selected, since the faults can act as potential escape routes for the injected carbon dioxide.
3. Locations that are in the vicinity of the projection of the possible flow paths in the reservoir.

The locations of the 2022 August measurements at the Kızıldere geothermal field can be seen in Figure 4.

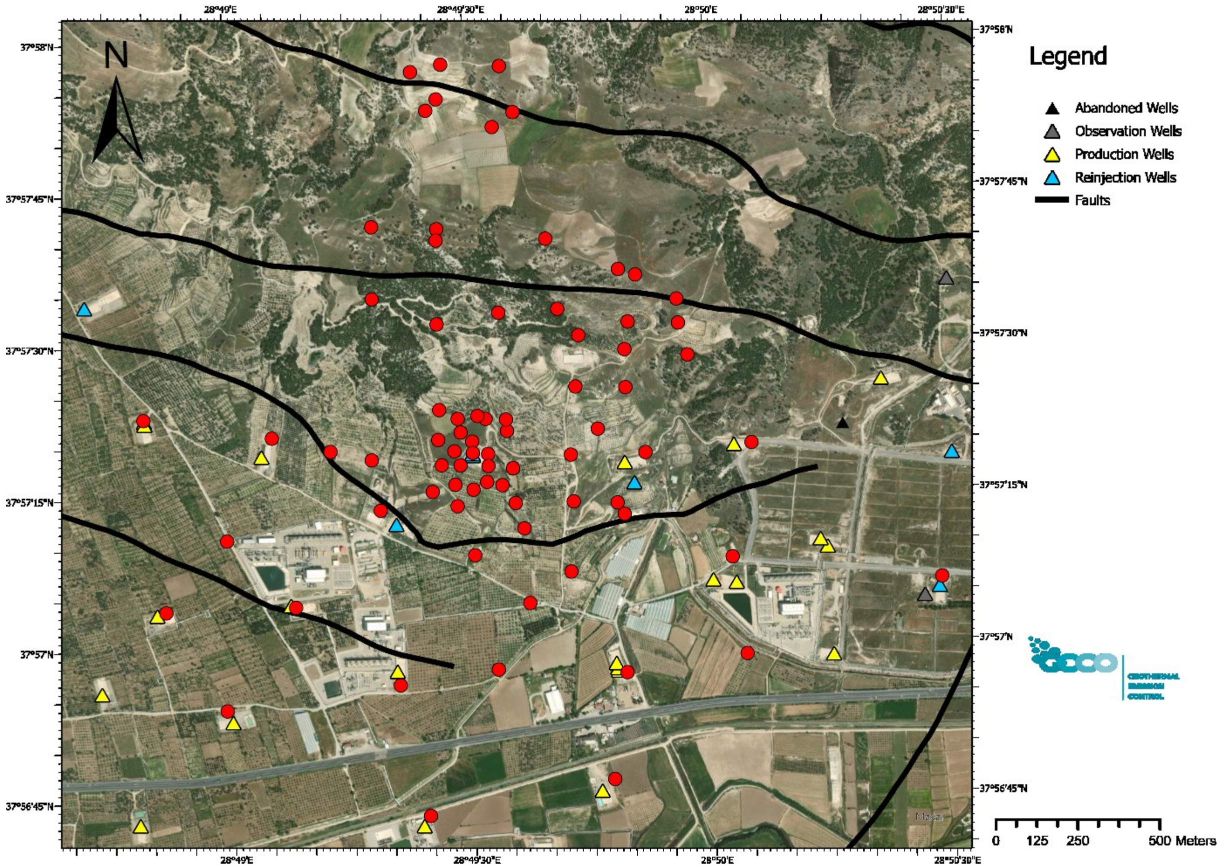

Figure 4: August 2022 measurement locations, wells, and faults.

3.RESULTS

A total of 79 carbon dioxide measurements were performed in August 2022 on dry soil with stable atmospheric conditions to eliminate external effects on the soil flux measurements. The soil carbon dioxide fluxes in 2022 August measurements ranged from 0.7 g $m^{-2}d^{-1}$ to 88.8 g $m^{-2}d^{-1}$ with a standard deviation of 11.8 g $m^{-2}d^{-1}$. Descriptive statistic of the August 2022 measurements can be seen at Table 1 and individual flux results can be observed in Figure 5. It has been observed that there is a substantial degree of variation within the soil flux values. This high standard deviation of the samples can be attributed to the spatial variation of the soil type and its physical properties. The spatial variation of soils may be naturally occurring or may be caused by agricultural activities, which is quite common around the Kızıldere field. Relevant research has demonstrated that application of farmyard manure to the soil can result in elevation of soil carbon dioxide fluxes (Altıkat et al., 2019). Additionally, the spatial variation in geological structures on the surface, such as faults, also contributes to the high standard deviation.

Table 1: Summary of the descriptive statistics of the August 2022 Kızıldere soil CO_2 flux measurements.

Minimum (g $m^{-2}d^{-1}$)	1^{st} quartile(g $m^{-2}d^{-1}$)	Median (g $m^{-2}d^{-1}$)	Mean (g $m^{-2}d^{-1}$)	3^{rd} quartile (g $m^{-2}d^{-1}$)	Max (g $m^{-2}d^{-1}$)
0.70	3.20	5.53	8.86	9.67	88.78

The distribution of the soil flux samples corresponds to an almost bi-modal lognormal distribution (Figure 6), which is common in most geothermal and volcanic areas (Chiodini et al., 1996,1998; Sbrana et al., 2021). This phenomenon can be attributed to the fact that the measurements obtained are a composite of fluxes emanating from biogenic processes and those arising from Earth's degassing (Camarda et al., 2019), consequently, resulting in a combination of lognormal populations.

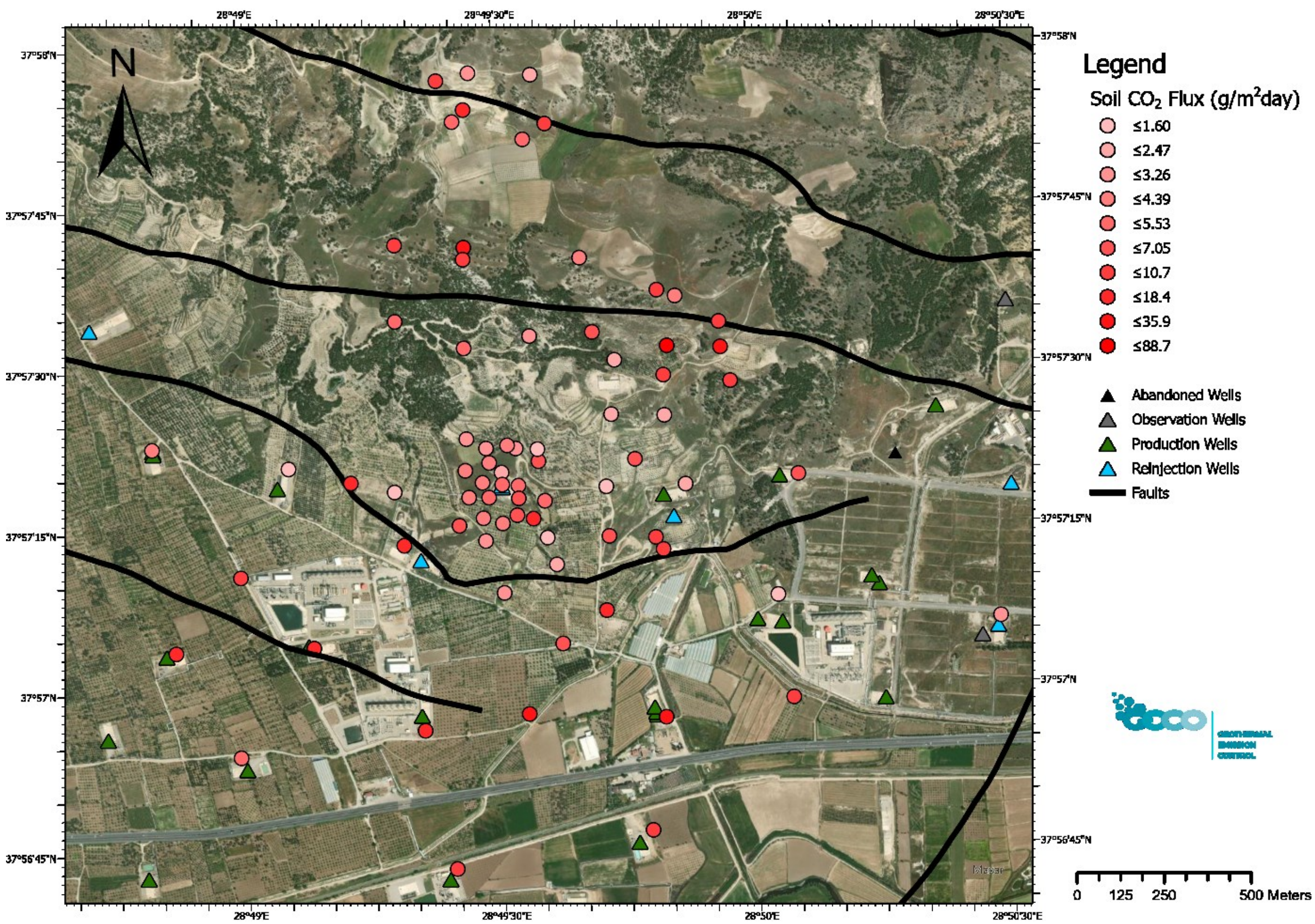

Figure 5: August 2022 point-based soil carbon dioxide flux results.

Mean soil carbon dioxide fluxes from the Kızıldere geothermal field are relatively low compared to other geothermal fields reported in the literature such as: Torre Alfina, with a reported mean flux of 103 g $m^{-2}d^{-1}$ (Carapezza et al., 2015); Larderello, reported mean flux of 197 g $m^{-2}d^{-1}$ with record high flux measurements as high as 2927 g $m^{-2}d^{-1}$ (Taussi et al., 2022). Additionally, it is worth noting that the mean soil carbon dioxide emissions at the Kızıldere field in August 2022 are only slightly higher in comparison to the average global soil carbon dioxide emissions, which have been estimated to be approximately 6 g $m^{-2}d^{-1}$ as reported by Camarda et al. (2019). The anomalously high soil fluxes might be used to identify an active reservoir at depth, whereas the regions with low soil carbon dioxide fluxes may suggest presence of an impervious layer above an active reservoir, or lack of an active reservoir (Carapezza et al., 2015). The relatively low soil carbon dioxide fluxes in the Kızıldere field can be attributed to the high sealing capacity of the caprock over the geothermal reservoir because most of the high flux values are observed near the outcrops of the faults that intersect the reservoir at depth. This high sealing capacity of the caprock makes the Kızıldere field an appropriate candidate for carbon capture and storage (CCS). On the other hand, soil flux measurements alone are not enough to assess the feasibility of a CCS project due uncertainties caused by high temporal and spatial variation of the soil flux data. Moreover, soil flux monitoring solely, may be an inefficient practice of leakage monitoring, because leakages are not likely to cause significant changes on the surface of the soil, making it difficult to detect them using soil fluxes (Carman et al., 2019). Hence, the data obtained from these soil flux studies will be employed in conjunction with other monitoring techniques such as brine sampling and tracer tests, as means of monitoring the reinjection campaign at the Kızıldere field.

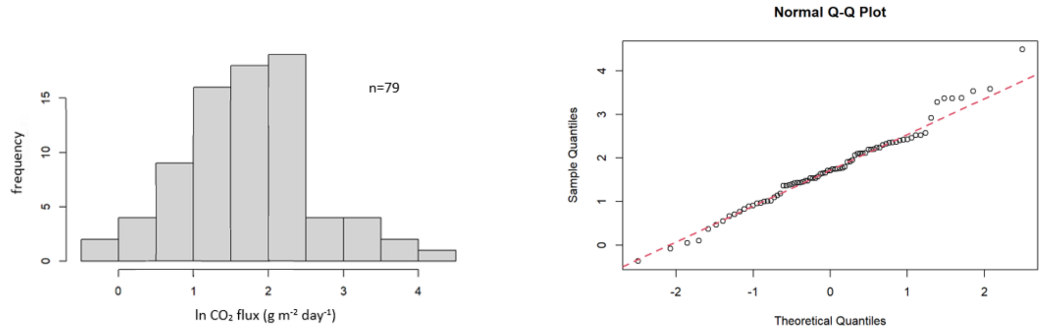

Figure 6: Histogram (left) and quantile-quantile plot (right) of the soil carbon dioxide fluxes, used to identify the distribution of the samples.

3.CONCLUSION

In this study, the latest soil carbon dioxide flux survey results from the Kızıldere Geothermal Field are presented. The latest measurements were used together with the previous seasonal soil flux measurements from Kızıldere to determine the baseline carbon dioxide flux of the field. Determination of baseline carbon dioxide fluxes is important in monitoring the course of the reinjected carbon dioxide. The selection of measurement locations for soil carbon dioxide flux measurements in 2019 and 2022 was based on several criteria. These included selecting finely spaced rectangular sampling locations near the proposed reinjection well to observe potential leaks, selecting locations around outcrops of faults that intersect the reservoir at depth as they may act as escape routes for the injected carbon dioxide, and selecting locations in the vicinity of projected flow paths in the reservoir. The mean flux from the field is found to be 8.86 g $m^{-2}d^{-1}$ ranging from 0.70 g $m^{-2}d^{-1}$ to 88.7 g $m^{-2}d^{-1}$. Compared to other geothermal and volcanic areas and global averages, the Kızıldere field's mean soil carbon dioxide fluxes are comparatively low with higher fluxes generally observed near faults. The established baseline carbon dioxide emissions, together with the other monitoring tools such as brine samples and tracer tests will help assessing the safety and feasibility of the implemented carbon capture and storage scheme. Future measurements of soil carbon dioxide flux will be conducted at Kızıldere in continuation to the monitoring campaign of the carbon dioxide reinjection scheme.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme Grant Agreement No.818169-GECO. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. The authors would like to thank the Zorlu Energy staff for coordinating the field works.

REFERENCES

Altıkat, S., Küçükerdem, H.K., and Altıkat, A.: The response of CO_2 Flux to Soil Warming, Manure Application and Soil Salinity, Journal of the Institute of Science and Technology, 9(3), 2019, 1334-1342.

Camarda, M., De Gregorio, S., Capasso, G., Di Martino, R.M.R., Gurrieri, S., and Prano, V.: The monitoring of natural soil CO_2 emissions: Issues and perspectives, Earth-Science Reviews, 198, 2019, 102928.

Carapezza, M.L., Ranaldi, M., Gattuso, A., Pagliuca, N.M., and Tarchini, L.: The sealing capacity of the cap rock above the Torre Alfina geothermal reservoir (Central Italy) revealed by soil CO_2 flux investigations, Journal of Volcanology and Geothermal Research, 291, 2015, 25-34.

Carman, C.H., Locke II, R.A., and Blakley, C.S.: Update on Soil CO_2 Flux Monitoring at the Illinois Basin – Decatur Project, USA, Energy Procedia, 63, 2014, 3869-3880.

Carman, C.H., Locke II, R.A., Korose, P.C., and Locke II, R.A.: Illinois Basin – Decatur Project: Soil Carbon Dioxide Flux Monitoring, Illinois State Geological Survey, Circular 599, 2019.

Chiodini, G., Frondini, F., and Raco, B.: Diffuse emission of CO_2 from the Fossa crater, Vulcano Island (Italy), Bullletin of Volcanology, 58, 1996, 41–50.

Chiodini, G., Cioni, R., Guidi, M., Raco, B., and Marini, L.: Soil CO_2 flux measurements in volcanic and geothermal areas, Applied Geochemistry, 13, 1998, 543–552.

Gokcen, G., Ozturk, H.K., and Hepbasli, A.: Overview of Kizildere Geothermal Power Plant in Turkey, Energy Conversion and Management, 45(1), 2004, 83-98.

Küçük, S., Başer, A., Saraçoğlu, Ö., Akın, T., Şentürk E., Tüzen, M.K., and Akın, S.: Soil CO_2 Flux and Temperature Measurements in Kızıldere Geothermal Field, Proceedings, World Geothermal Congress 2020+1, Reykjavik, Iceland, April – October (2021).

LI-COR Biosciences: SoilFluxPro Software Instruction Manual, 2021, 1-92. https://www.licor.com/documents/uh3tbaw1frnwca9tkl7og9uqs27jyjck accessed at 10.01.2023.

LI-COR Biosciences: Using the LI-8100A Soil Gas Flux System and the LI-8150 Multiplexer, 2015, 1-234, https://www.licor.com/documents/jtpq4vg358reu4c8r4id accessed at 10.01.2023.

Madsen, R., Xu, L., Claassen, B., and McDermitt, D.: Surface Monitoring Method for Carbon Capture and Storage Projects, Energy Procedia, 1(1), 2009, 2161–2168.

Sbrana, A., Lenzi, A., Paci, M., Gambini, R., Sbrana, M., Ciani, V., and Marianelli, P.: Analysis of Natural and Power Plant CO_2 Emissions in the Mount Amiata (Italy) Volcanic–Geothermal Area Reveals Sustainable Electricity Production at Zero Emissions, Energies, 14(15), 2021, 4692.

Szizybalski, A., Zimmer, M., Pilz, P., and Liebscher, A.: Results from twelve years of continuous monitoring of the soil CO2 flux at the Ketzin CO_2 storage pilot site, Germany. Energy Procedia, 125, 2017, 543-548.

Şimşek, Ş., Yıldırım, N., and Gülgör, A.: Developmental and environmental effects of the Kızıldere Geothermal Power Project, Turkey, Geothermics, 34(2), 2005, 234–251.

Şimşek, Ş., Parlaktuna M., and Akın S.: Data Gathering and Evaluation of the Kızıldere Geothermal Field, 2009, Unpublished report prepared for Zorlu.

Taussi, M., Brogi, A., Liotta, D., Nisi B., Perrini, M., Vaselli, O., Zambrano, M., and Zucchi, M.: CO2 and heat energy transport by enhanced fracture permeability in the Monterotondo Marittimo-Sasso Pisano transfer fault system (Larderello Geothermal Field, Italy), Geothermics, 105, 2022, 102531.