

Contribution of Sabalan Geothermal Power Plant to Climate Change Mitigation

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ABSTRACT

The Sabalan geothermal power plant in northwestern Iran is planned to produce 50 MW of electricity by 2011 in a cooperative effort of the Ministry of Energy (MOE) and the Renewable Energy Organization of Iran (SUNA).

Overall, geothermal energy has been shown to be environmentally acceptable with some positive impacts on climate change mitigation, including a relatively small land-use footprint.

EIA process has been already performed (Yousefi et al., 2009). In the evaluation process, the positive and negative environmental impacts of the Sabalan geothermal power plant (GPP) were assessed based on the results of a multi-disciplinary team approach.

In this study, an attempt was made to show the contribution of Sabalan GPP to climate change mitigation by reducing CO₂ emissions in the area compared to conventional power plants.

A network of thirty sampling points and a meteorological station were installed to characterize the air quality and atmospheric transport properties of the area before development. These instruments measured the concentrations of H₂S, CO₂, SO₂, NO, NO₂ and particulates. Wind velocities and directions were also measured to determine atmospheric stability. By using these data, the background dispersion model for each gas was prepared in the GIS environment.

In the current study, a model was used to predict the distribution of CO₂ after utilization of the GPP. To achieve this goal, geothermal steam was analyzed chemically to estimate potential emission rates of air pollutants from the planned 50 MW geothermal power plant.

The Industrial Source Complex Model (ISC3View) was applied to make the predictive CO₂ dispersion model from the 50 MW planned geothermal power plant into the local atmosphere. The prepared background and predictive model were combined in the GIS environment.

The results show that CO₂ concentrations will be well below the standard and Kyoto Protocol limits in 98% of the area, and pollutants will be transferred from the power plant to the northeast and east. A maximum CO₂ concentration of about 325 ppm was predicted to occur in areas close to the powerhouse.

1. INTRODUCTION

Among developing countries, the amount of GHG emissions in Iran is considerable. Recently, global climate change has evolved from a global issue to one of our national

challenges. Although Iran is not included in Annex I, as a signatory to the Kyoto protocol, the country is committed to fulfilling its obligations to reducing Green House Gases (GHGs) emissions into the atmosphere. Of these gasses, carbon dioxide is considered to have the most significant effect on climate change. Recently, the amount of carbon stored in the atmosphere has increased. One of the main causes of accumulation of atmospheric carbon dioxide (CO₂) is the combustion of fossil fuels for power generation. There is an overwhelming consensus that action is needed at the national level to mitigate the risk of high levels of GHG emissions. To achieve this, efficient energy consumption policies must be developed, and at the same time, the use of cleaner energy sources must be increased. The use of geothermal energy can help to reduce energy related CO₂ emissions. In comparison to fossil fuel energy sources, geothermal energy is accepted as being an environmentally benign energy source. Aside from this consensus of experts, the past 40 years of experience in geothermal development have shown that it is not completely free of environmentally adverse effects. The atmospheric effects of geothermal development are chiefly from CO₂ and H₂S emissions. Although these effects are not insignificant compared with conventional fuels (coal, natural gas and oil), investigating them could be beneficial in highlighting the status of contribution of geothermal power generations in climate change mitigation.

1.2 Methodology

There are well-proven computer models used to predict dispersion of gas plumes into the atmosphere. In these studies, the meteorological conditions and potential emissions were used to prepare a predictive dispersion model of CO₂ concentrations and to define the area under risk. Modeling results can be used to assess whether to employ pollution abatement technology and monitoring in the area. The Industrial Source Complex Model ISC3View, (Jesse and Cristiane, 1998) was used for CO₂ dispersion modeling in the Sabalan area. This model is a Gaussian diffusion model designed for two emission categories: continuous (steady-state) and instantaneous (transient). In steady-state modeling, source characteristics do not vary with time, and the release duration is long.

The Sabalan area in northwest Iran has considerable geothermal energy resources that can be used for power generation. The Environmental Impact Assessment Project (GPP-EIA) of the Sabalan Geothermal Power Plant has the goal to evaluate the potential effects of the project. Its aim is to ensure that any development proceeds in an environmentally acceptable manner. An integral part of this project is assessment of the potential impact of the project on the local air quality.

Basically, GPPs release a variety of gases to the atmosphere. From an environmental perspective, the most significant gaseous contaminants are CO₂, H₂S, NH₃, CH₄, Rn, Hg,

H_3BO_3 and As. The experiences of other GPPs show that the principle gases of concern are CO_2 and H_2S and other constituents are less likely to have a significant adverse effect on the surrounding environment. Contaminant non-condensable gas concentration in the exhausted gas and steam depend on the steam chemistry, power plant technology, and the ambient air quality.

In this study to evaluate the impacts of non-condensable gases on the environment, the Khiavchai river watershed study area and the following tasks were addressed:

- Investigating and modelling of the background air quality prior to utilization.
- Estimating potential contaminant flow rate from the planned GPP and making predicted model.
- Combining background and predicted model to define the impacts and the areas under risk.

To carry out these tasks, a network of 30 sampling point and meteorological air quality monitoring stations were erected in the study area. Each station was used to gather air quality data on the concentration of selected gases, pollutants and airborne particulates.

2. STUDY AREA

The Sabalan geothermal field is located in northwestern part of Iran. The study area is 185 km² including Khiav river watershed located in the east of the field.

It is located between 38° 12' and 38° 22' North and 47° 39' and 47° 49' east. Its population centers are the villages Moil, Valezir and Dizo. Moil is the biggest village with 400 families located approximately 16 km from Meshkinshahr city along a paved road. (Yousefi, 2004).

The remote, grass-covered study area is remote is full of hot and cold springs. The location of the study area is shown in Figure 1.

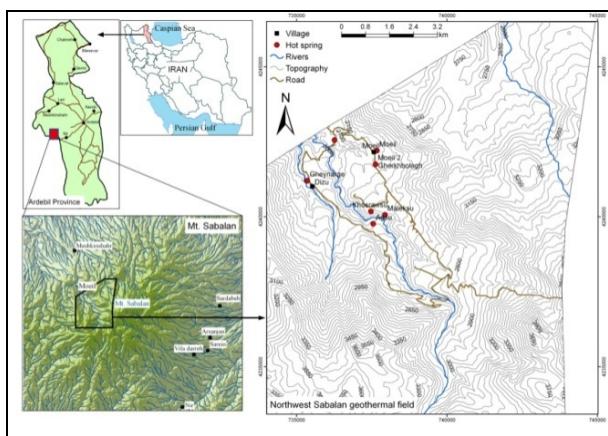


Figure 1: Study area

3. CARBON DIOXIDE (CO_2)

Carbon dioxide is a heavy gas and accumulates in pits and low depressions. It is most common in geothermal steam, at concentrations of 500 ppm to 20,000 ppm. Unlike H_2S , it is not highly toxic, but a large intake can be fatal due to alteration of blood pH. CO_2 is odourless and has a slightly acidic taste (Noorollahi, 1999).

At 5% concentration in air (500,000 ppm), it can produce shortness of breath, dizziness, mental confusion, headache and possible loss of consciousness. At 10 % concentrations, the patient normally loses consciousness and will die unless it is removed. With little or no warning from taste or odour, it is possible to enter a tank or a pit full of CO_2 and be asphyxiated in a very short time. Long term exposure at concentrations of 1-2 % can cause increased calcium deposition in body tissue, and may cause mild stress and behavioural changes. Monitoring is normally accomplished by measuring oxygen levels. Many monitors record H_2S , O_2 and explosive gases simultaneously. The "National Institute for Occupational Safety and Health" (NIOSH) air quality standard for the protection of occupational health sets the limit for CO_2 at 10,000 ppm for 10 hours. The "Occupational Safety and Health Administration" (OSHA) air quality standards for the protection of occupational health sets the limit for CO_2 at 5,000 ppm (Webster, 1995).

4. OVERVIEW OF THE DISPERSION MODEL

The pollution mapping section of the ISC3View program allows the user to perform CO_2 dispersion calculations using a simple Gaussian Plume model to predict the level of concentrations downwind from the source. The user can input the following variables: wind speed, direction, atmospheric stability, CO_2 flow rate, and one of two terrain roughness classes. The terrain classes represent a facility surrounded by a flat, open field with crop stubble, or surrounded by elevated barriers. The output of the model is a color-coded map of the CO_2 plume. The map indicates estimates of the plume length.

5. GIS IN AIR QUALITY MANAGEMENT

By modeling air quality in a GIS environment, the output of the pollutant records can be obtained in the form of spatial records.

GIS technology is capable of supporting the development of geospatial air quality models. For modelling in a GIS environment, AQMS (Air Quality Management System) can be considered to include three phases: monitoring, development of DSS (Decision Support System) and execution. The milestone capabilities of GIS for AQMS are as follows (Hussain, 2003):

- a) Location of the monitoring stations
- b) Development of geospatial air quality models
- c) Development of spatial decision support system

6. GAUSSIAN DIFFUSION EQUATIONS

This study is based on the Gaussian diffusion model using the *ISC3view* software. The model for stacks uses the steady-state Gaussian plume equation for a continuous elevated source. For each source and each hour, the origin of the source's coordinate system was placed at ground surface at the base of the stack. The X-axis is positive in the downwind direction; the axis is crosswind (normal) to the Y-axis and the Z-axis extends vertically. The fixed receptor locations are converted to each source's coordinate system for each hourly concentration calculation. The hourly concentration calculated for each source at each receptor is summed to obtain the total concentration produced at each receptor by the combined source emissions.

For the steady-state Gaussian plume, the hourly concentration at downwind distance X (m) and crosswind distance Y (m) was given by:

$$C = \frac{QKVD}{2\pi u_s \sigma_x \sigma_z} \times \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \quad (1)$$

where;

Q =Pollutant emission rate,

K = Scaling coefficient,

(default value for Q of 1×10^6 g/s and concentration in $\mu\text{g}/\text{m}^3$),

V = Vertical term,

D = Decay term,

σ_x, σ_y = Standard deviation of lateral and vertical concentration distribution (m), and

u_s = wind speed at release height (m/s).

Cox and Sheppard (1980) and Cox and Sandalls (1974) have estimated average removal rates of hydrogen sulphide. Using an average reaction rate $5 \times 10^{-12} \text{ cm}^3/\text{s}$ and an average hydroxyl concentration of 3×10^6 molecules/ m^3 , an average removal rate of hydrogen sulphide was estimated to be approximately 5 % per hour. This will give an exponential decay rate of $1.425 \times 10^{-5} \text{ s}^{-1}$ when used in the ISC3View model. In the present study, a similar removal rate of 5% hour was used. (Noorollahi, 1999)

6. METEOROLOGICAL PARAMETERS

In this research, the monitored environmental data from a meteorological station at the site were collected, and the accuracy of the data was assessed using statistical analysis to detect and remove erroneously recorded data. The required meteorological parameters of the model are surface and upper observation data in ASCII meteorological format. The required surface parameters are temperature, cloud cover percent, cloud height, wind speed and wind direction. The upper air data is the mixing layer height. ICS3View can estimate the mixing layer height from the surface data.

There is a meteorological station in Sabalan geothermal field. Modeling was used to predict the conditions of ambient air before and after utilization in a power plant, and data for the year 2001 were compared to the results for analysis.

6.1 Atmospheric Stability

Together with distance from source, the atmospheric stability affected the dispersion parameters (σ_x, σ_y). It is often defined by the Pasquill stability categories, which ran from category A for a stable atmosphere to E for an unstable atmosphere. In the model, the default wind speeds ranging from 1.54 m/s to 10.18 m/s are used in place of the discrete stability categories and are changeable by user. The relationship between the Pasquill stability categories and the wind speed parameters used in the model are shown in Table 1. To define the stability parameter, the model employs one of two methods, using wind speed or the standard deviation of the wind direction to define the stability parameter.

6.2 Wind Patterns

Wind data analysis was carried out for the entire year of 2001. It is evident that the dominant wind pattern is one of the important requirements for the model. The dominant wind directions were east and northeast; meaning that transport of CO_2 in the area will possibly be towards east

and northeast. Annual wind rose diagrams of the field are shown in Figure 2.

Table 1: Relations between Pasquill stability categories (SC) and wind speed (m/s) parameters (WS)

SC	A	B	C	D	E
WS	1.54	3.09	5.14	8.23	10.18

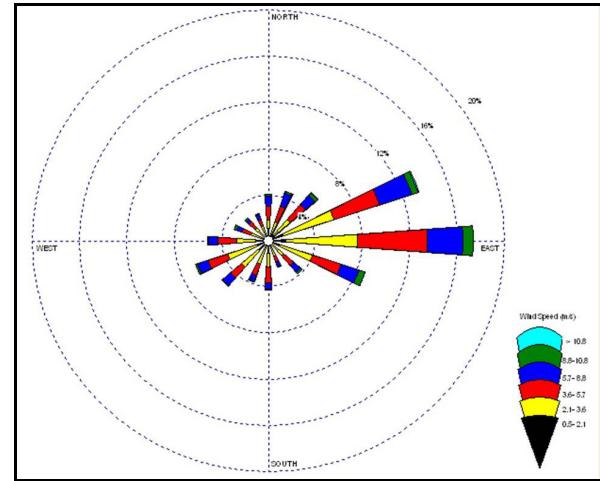


Figure 2: Wind rose diagram of NW Sabalan (2001)

6.3 Temperature

The temperature fluctuations in the study area are large from -35 in January to +30 in June and July. The average temperature variation in the study area from 2000 to 2003 is shown in Figure 3.

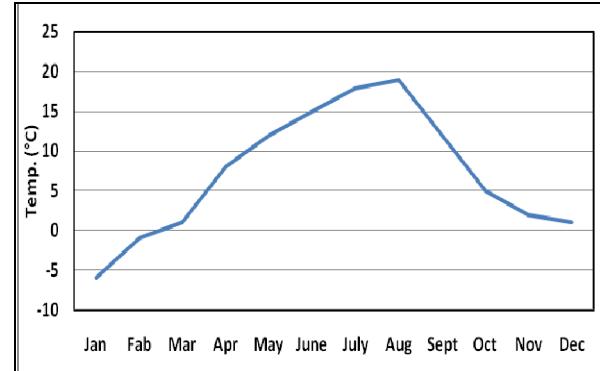


Figure 3. Temperature variation in the study area

6.4 Humidity

The humidity in the area is not very high because of high elevation. Average annual humidity in the study area is 59.5%. The maximum humidity is in May (85 %) and the minimum is in June (13%).

6.5 Precipitation

The measurements from April 2000 to March 2005 show that the average annual precipitation in the area is around 358 mm/year with maximum precipitation in December (89 mm) and the minimum in June and July (0 mm).

7. BACKGROUND AIR QUALITY

A network of thirty sampling points and a meteorological station for air quality monitoring were erected in the study area (Figure 4).

In the meteorological stations, data consisting of temperature, humidity, wind speed, precipitations, wind directions, solar radiation and air pollution such as SO_2 and NO_x were continually recorded in the installed computer every half hour.

In the 30 air quality sampling points, CO_2 , H_2S , No_x , SO_2 and PM (Particulate Matter) were measured once per season from July 2000 to May 2001, and CO_2 was measured once per month from June 2001 to April 2002.

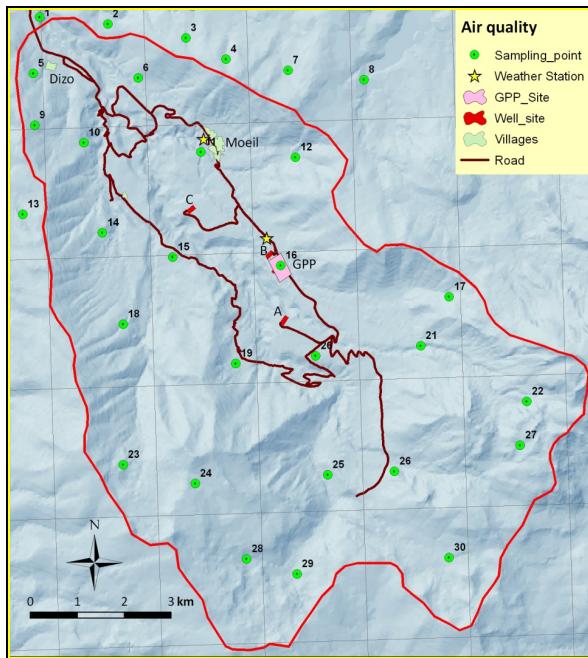


Figure 4: Location of air quality sampling points and meteorological station

Sabalan geothermal field is an unexploited natural area without any industrial or other air polluting activities. Only gases from geothermal manifestations and transportation vehicles escape to the atmosphere. The mentioned air quality parameter concentrations have been monitored in the whole Khiav river watershed, with an area of about 132 km^2 , where most of the geothermal manifestations are located. Comparisons between the world average (358 ppm) and the measurements show that the concentration data are well below the world average, or there is no environmental adverse effect related to CO_2 in the study area.

To make the background dispersion model for CO_2 in the study area pessimistically between the 12 measured values for each station, the maximum concentrations were chosen for the stations (Figure 5).

Table 2 shows the data used to make the background dispersion model in GIS via the Interpolating Gaussian operator.

Figure 6 shows the model that was constructed in GIS environment by using the background data.

The background dispersion model prepared shows that the concentration of CO_2 in the northern part of the field is

greater than the other parts. This part of the study area consists of the biggest and highest geothermal manifestations such as Gheynarge hot spring, which alone can cause such conditions in the model.

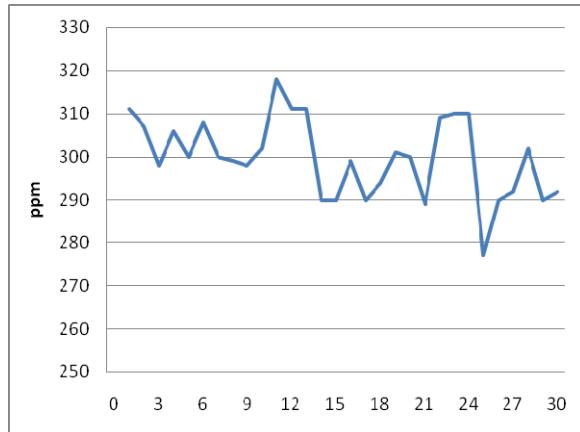


Figure 5: The maximum value for each station were chosen for background CO_2 concentration.

Table 2: Maximum CO_2 value in the stations (ppm)

Sampling Points	CO_2	Sampling Points	CO_2	Sampling Points	CO_2
1	311	11	318	21	289
2	307	12	311	22	309
3	298	13	311	23	310
4	306	14	290	24	310
5	300	15	290	25	277
6	308	16	299	26	290
7	300	17	290	27	292
8	299	18	294	28	302
9	298	19	301	29	290
10	302	20	300	30	292

8. SABALAN GEOTHERMAL POWER PLANT

A schematic flow diagram of 50 MW Sabalan geothermal power plants is presented in Figure 7.

Conventional geothermal power plant development in high temperature water dominated fields would require at least the following main systems with the related equipment:

- Steam piping
- Silencer /Separator
- Steam turbine/Generator
- Condenser
- Cooling towers

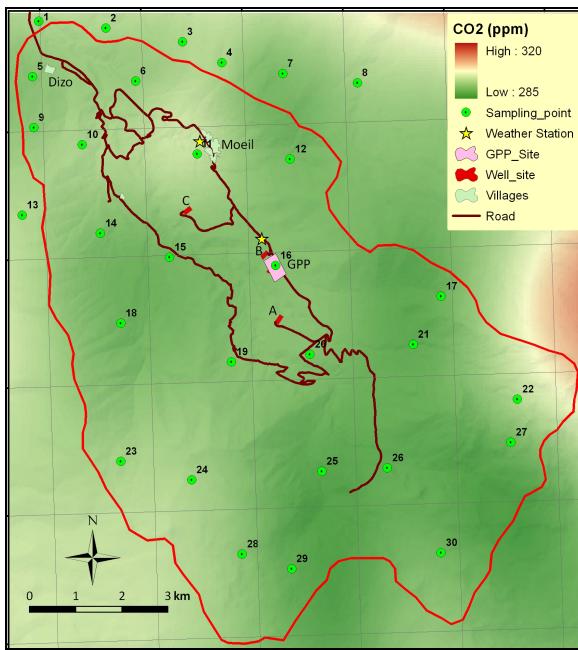


Figure 6: Background dispersion model of CO₂ in the ambient air of study area

CO₂ and other gases may be released to the atmosphere from the separator and condenser.

In the current study, the specifications of these systems were applied in the CO₂ prediction dispersion model as a possible pollutant point source.

Based on the Sabalan reservoir steam specifications and using Engineering Equations Solver (EES) program, steam consumption was calculated for 50 MW of electricity. It will be around 380 ton/hour.

The model was set to predict average annual gas concentrations in the area. In the ISC3View model, which is based on the Gaussian diffusion system, the required emission parameters and power generation specifications were calculated. These parameters are shown in Table 3.

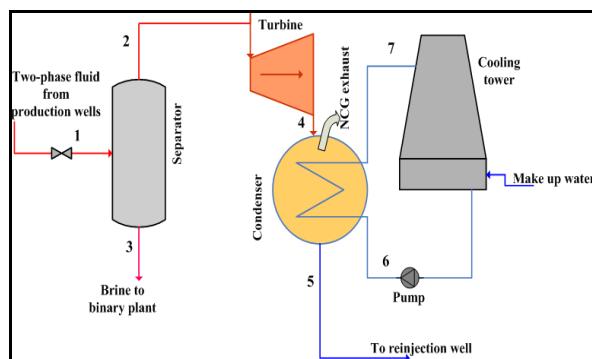


Figure 7: Flow diagram of a geothermal power plant

9. STEAM GEOCHEMISTRY

Estimation of the potential emission rates of specific gases from planned flash-steam power plants must characterize the concentrations in the geothermal steam field of the gases condensed in the condenser after electricity generation.

The steam geochemistry analysis calculations show that almost 2% of the steam which will be used for power

generation (380 ton/h) will be gases (98% CO₂, 1.8% H₂S and 0.2 % others, which are the non condensable gases) (SKM., 2005).

In this study, all non condensable gases included in the required steam for power generation were considered as exhausted gas to be released to the local climate without any abatement controls.

The ISC3View dispersion modeling software was used to make prediction dispersion model of CO₂ gas from the future power generation. The program takes in account the calculated amount of gas (1600 g/s) which most probably will be released to the local atmosphere due to power generation (Table 3).

Table 3: Emission parameters used for modeling

Parameter	Silencer	Condenser
Stack height	25 m	25 m
Stack exit diameter	2 m	0.3 m
Gas exit temperature	192 °C	55 °C
Gas exit velocity	3 m/s	4 m/s
Pressure	2 bar	1.5 bar
CO ₂ flow rate	350 g/s	1600 g/s

10. PREDICTIVE MODEL

The selected source type for geothermal power plants in the current study is point pollutant, which is located at 739480 and 4238380 in Zone 38 of UTM coordinate system.

After running the ISC3View model, the resulting digital data and dispersion map were opened in a GIS environment using AQMS. The data were edited and drawn again to achieve better visualized maps.

Figure 8 shows a map of the prediction dispersion model of CO₂ in the Sabalan geothermal area, considering site B as the location of the power plant which is one of the suitable sites for installation of the power plant (Figure 4).

11. INTEGRATION OF MAPS

The prediction of carbon dioxide concentration imposed by the planned power generation on the atmosphere of Sabalan area required the use of atmospheric transport modeling. To define the area under the risk, the background concentration dispersion model (Figure 6) and prediction calculated dispersion model (Figure 8) of the study area were combined cell by cell in the raster format using GIS map calculation operator. The results of this function are shown in Figure 9.

Results for distribution predictive model shows the natural transfer of CO₂ will be from the power plant toward north and northeast.

12. CONCLUSIONS

The experiences of other geothermal power plants show that the principle gases of concern in their surrounded

environment are CO_2 and H_2S , and other constituents are less likely to have a significant adverse effect on the local environment.

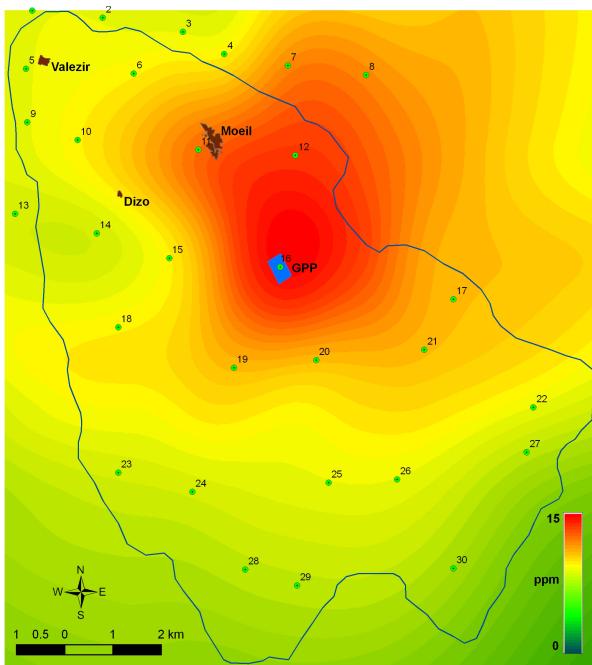


Figure 8: Prediction dispersion model of CO_2 from 50 MW GPP, NW Sabalan

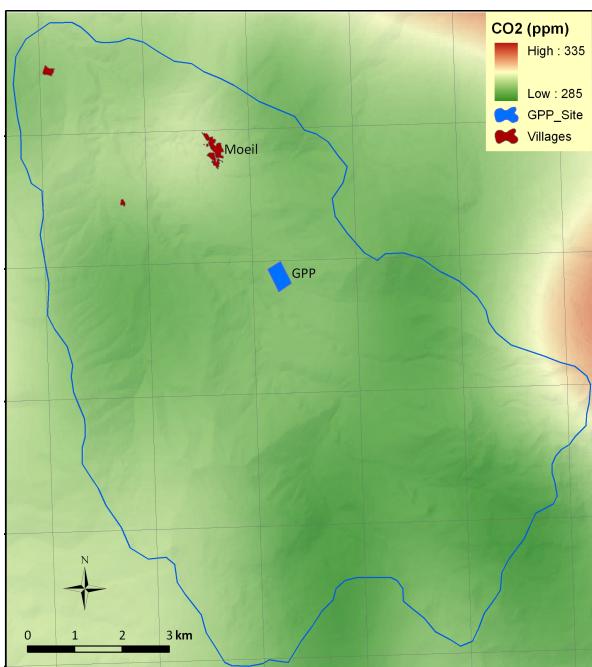


Figure 9: Final prediction dispersion model of CO_2 NW Sabalan

The potential flow rate of these gases depends on the steam chemistry and geothermal power plant technology. The dispersion type of gases and average removal rate depends on the meteorological conditions such as wind directions, wind speed, precipitations, atmospheric stability and surface roughness and topography. Determination of the effects on air quality, the affected area and the area under risk depends on the background concentrations of the gases, national standard and morphology of the ground surface.

CO_2 distribution predictive model was prepared in this study to investigate the concentration trends of CO_2 in the atmosphere of the Sabalan geothermal area.

Overall, in the 185 km² study area, the concentration of CO_2 meets the DOE's standard level for ambient air quality, and there is no need for a health risk assessment project. A comparison between the amount of CO_2 emissions from geothermal power plants and conventional fossil fuel power plants reveals the significant differences between them and identify that geothermal power generation as an approach for mitigating and offsetting future climate change.

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