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# Life Cycle Based Carbon Footprint Assessment of Indonesia's Geothermal Energy Exploration Project

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Indonesia is committed to increase the contribution of renewable energy to at least 23 % of the total Indonesian energy mix by 2025. The geothermal energy resource of Indonesia could potentially help achieve this target, but there are environmental challenges associated with geothermal energy exploration. This study is aimed to estimate the carbon footprint of the geothermal exploration project using a life cycle assessment (LCA) approach. Literature published to date did not consider the use of LCA to specifically assess the environmental impacts of geothermal energy exploration. A geothermal energy exploration project in West Java, Indonesia, has been taken as a case study to conduct an LCA considering four main activities, namely land clearing, access road improvement, slim-hole well pad, and standard-hole well pad construction. ReCiPe impact assessment analysis was used to convert inputs and outputs of these activities to carbon footprints of 1 $m^2$ of area of geothermal energy exploration. The result showed that the total carbon footprint of geothermal energy exploration stages was 53.2 kg $CO_2$-eq/$m^2$/y. The two most significant contributors to carbon footprints were the construction of a standard-hole well pad (56 %) and a slim-hole well pad (43 %). Diesel fuel and chemicals were two main carbon footprint sources of geothermal energy exploration project. In terms of inputs, the utilization of caustic soda for neutralization during the drilling activity contributed 64.5 % of the total carbon footprint, followed by diesel fuel consumption (27 %), bentonite (4.04 %) and barium sulphate (4.43 %) for the high carbon footprint for standard-hole well pad construction. The effective utilization of caustic soda and diesel by preparing standard operational procedure (SOP) and implementing ISO quality and environmental management systems (ISO 90001 and 14001) could increase the environmental performance of geothermal energy exploration.

## 1. Introduction

Energy consumption is one of the indicators for the increase of the greenhouse gas (GHG) concentration in the atmosphere, which is responsible for climate change. There exists a reasonable correlation between energy consumption and environmental impacts, including resource degradation (Kwakwa et al., 2020), climate change (Akhmat et al., 2014), greenhouse gas emission in copper mine (Adiansyah, 2019), carbon footprint in mine disposal management (Adiansyah, 2020), and correlation of energy consumption and trade (Shahzad et al., 2017). Fossil fuels, including coal, petroleum, and other liquids, account for the major share (44 %-55 %) of global energy consumption (Ismail et al., 2020), while the growth of renewable energy is expected to increase significantly during 2018-2050 (EIA, 2019).

One renewable energy source is geothermal that distributed into more than 30 countries worldwide (Geoenergy, 2020) with the total current installed capacity in 2020 is approximately 15.9 GWe (Huttrer, 2020). Ten countries that recorded as the highest geothermal installed capacity are the United States of America, Indonesia, Philippines, Turkey, Kenya, Mexico, New Zealand, Italy, Japan, and Iceland (Huttrer, 2020).

The Government of Indonesia (GOI) has already committed to increase the share of renewable energy in the energy mix to 23 % and 31 % by 2025 and 2050. The total renewable energy potential recorded by The Indonesian National Energy Council is equivalent to 442 GWe, and geothermal energy is listed as one of the five most significant renewable energy potentials in Indonesia (DEN, 2019). Other studies confirm that

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Indonesia's geothermal potential is the largest resource worldwide with a total of 29 GWe from more than 300 geothermal sites (Huttrer, 2020). The potential sites are mainly located in Java, Sumatera, Sulawesi, and East Nusa Tenggara. The huge untapped potential of this resource has convinced the GOI to make an ambitous target of expanding the capacity of geothermal power plant to around 6,000 MW by 2020 (ADB and WB, 2015). Whilst this target has been failed, the GOI further made a target of 7,000 MWe by 2025 (Huttrer, 2020). Despite geothermal power could potentially strengthen nation's energy security, it is not entirely environmentally benign as environmental impacts are occuring during the life cycle stages of this plant. The environmental impacts include land disturbance, solid and liquid waste disposal, disturbance of flora and fauna, and the depletion of ecological resources. There are social impacts during exploration, construction, operation, and post-operation stages of geothermal electricity generation (Bošnjaković et al., 2019). Boron contaminated the irrigation water and soil (Yilmaz and Ali Kaptan, 2017), hydrogen sulphide and $CO_2$ emissions can occur (Huang and Tian, 2006). The environmental impact assessment is required to evaluate the potential impact of the geothermal project to device strategies for generating electricity with reduced environment impact.
Life Cycle Assessment (LCA) could be used as a tool for assessing the environmental impact of a project or activity. Various studies associated with LCA in geothermal power sector are found including dry steam geothermal (Buonocore et al., 2015), review on geothermal technologies (Tomasini-Montenegro et al., 2017), low-temperature geothermal (Ruzzenenti et al., 2014), geothermal plant (Martínez-Corona et al., 2017). In addition, one recent study compares the environmental impact of three types of renewable energy sources, namely geothermal, solar, and wind (Basosi et al., 2020). Those studies were focused on the operational stage of a geothermal power plant by evaluating the technology applied. None of the current studies discussed the LCA of geothermal exploration projects in Indonesia. Given the nation has the world's largest reservoir of geothermal energy and the electricity generation from it is expected to increse significantly, it is becomes inevetable to carry out an LCA of Indonesia's geothermal development particulalry including its' exploration stage. On the other hand, Indonesia has a target for reducing the Greenhouse Gas (GHG) emission from energy sector about 14 % by 2030 (DEN, 2019). One of the abvious strategies is by increasing the share of renewable energy in the Indonesia's energy mix. In addition, more than 50 % of the electricity production in Indonesia is supplied by coal-fired power plant where the coal combustion would generate sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$), and particulate matters that contribute to enviromental and health problems (EIA, 2020). This study is important to estimate the contribution of geothermal energy exploration project on Indonesia's carbon footprint. In addition, the environmental hotspots that contribute to the environmental impact would also be presented.

## 2. Methods

The LCA approach was followed to assess the carbon footprint of geothermal exploration project in Indonesia. ReCiPe in SimaPro (Version 9.0) LCA software (Mark et al., 2016) was used for estimating the carbon footprint of geothermal exploration due to absence of local method. The database used ecoinvent database that provided by SimaPro. The LCA consists of four main steps of ISO 14040:2006, namely goal and scope definition, inventory analysis, life cycle impact analysis, and interpretation (ISO, 2006) (ISO, 2006). The first two steps were discussed in Section 2.1 and 2.2, where the impact analysis and interpretation stage were presented in the results and discussion section. A case study of a geothermal exploration project was taken to calculate the carbon footprint generated from the life cycle assessment perspective. The project that is located at Serang Regency, Banten Province, Indonesia. It has a distance of approximately 3.8 km from Palka main road. Geothermal working area of Banten Lake Caldera is located in the North-West of Banten Province with a total concession area of about 104.2 km$^2$. In addition, this project is predicted to be able to generate electric power of 2 x 55 MW.

### 2.1 Goal and scope definitions

The goal of this study was to estimate the carbon footprint of the geothermal exploration project in Indonesia. The scope of this study is presented in Figure 1 that consists of four stages, namely land clearing, access road construction, slim-hole well pad construction, and standard-hole well pad construction. The functional unit was the carbon footprint generated per square meter land utilised per year.

### 2.2 Inventory analysis

A life cycle inventory is a critical step in the life cycle assessment, where each input and output data for the geothermal exploration life cycle are collected. These data, as presented in Table 1 and Table 2, include equipment, fuel consumption, chemical usage, waste generated, and water consumption are used to calculate the carbon footprint associated with the life cycle of the geothermal exploration project where manufacturing process of machineries was excluded.

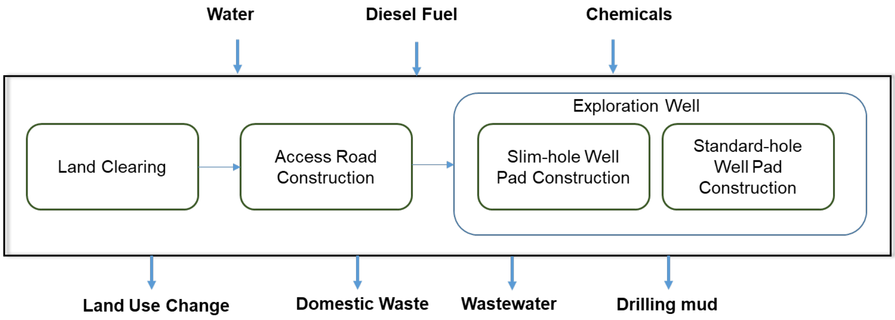


*Figure 1: Geothermal energy exploration boundary*

*Table 1: Data inventory for equipment and fuel consumption*

| Activity | Sub-activity | Equipment | Fuel usage (L/h) | Work hours (h) | Work Days (d) | Total fuel Consumption (L) |
|---|---|---|---|---|---|---|
| Land Clearing | Tree Chipper | Excavator | 33.71 | 8 | 10 | 2,696.8 |
| | Removal of green waste | Dump truck | 27.73 | 8 | 5 | 1,109.2 |
| | Land grading | Excavator | 33.71 | 8 | 20 | 5,393.6 |
| | | Loader | 20.66 | 8 | 20 | 3,305.6 |
| | | Dump truck | 27.73 | 8 | 15 | 3,327.6 |
| | Work supervision | LV 4 x 4 | 41.96 | 8 | 30 | 10,070.4 |
| Access Road | Base course | Dump truck | 27.73 | 8 | 20 | 4,436.8 |
| | Grading | Dozer | 52.61 | 8 | 90 | 37,879.2 |
| | | Excavator | 33.71 | 8 | 90 | 24,271.2 |
| | | Grader | 39.83 | 8 | 90 | 28,677.6 |
| | | Loader | 20.66 | 8 | 40 | 6,611.2 |
| | | Dump truck | 27.73 | 8 | 20 | 4,436.8 |
| | Soil removal | Loader | 20.66 | 8 | 20 | 3,305.6 |
| | | Dump truck | 27.73 | 8 | 20 | 4,436.8 |
| | Work supervision | LV 4 x 4 | 41.96 | 8 | 90 | 30,211.2 |
| Slim-hole well pad | Construction | Crane | 49.20 | 8 | 90 | 35,424 |
| | | Forklift | 18.96 | 8 | 150 | 22,752 |
| | | Electricity Generator | 17.89 | 8 | 150 | 21,468 |
| | | Excavator | 33.71 | 8 | 150 | 40,452 |
| | | Dozer | 52.61 | 8 | 150 | 63,132 |
| | | Drilling truck | 72.80 | 18 | 60 | 78,624 |
| | Grading | Grader | 39.83 | 8 | 150 | 47,796 |
| | | Loader | 20.66 | 8 | 90 | 14,875.2 |
| | Work supervision | LV 4 x 4 | 41.96 | 8 | 150 | 50,352 |
| Standard-hole well pad | Construction | Crane | 49.20 | 8 | 60 | 23,616 |
| | | Forklift | 18.96 | 8 | 90 | 13,651.2 |
| | | Electricity Generator | 17.89 | 8 | 90 | 12,880.8 |
| | | Excavator | 33.71 | 8 | 90 | 24,271.2 |
| | | Dozer | 52.61 | 8 | 90 | 37,879.2 |
| | | Drilling rig | 170.42 | 18 | 35 | 107,364.6 |
| | Grading | Grader | 39.83 | 8 | 90 | 28,677.6 |
| | | Loader | 20.66 | 8 | 60 | 9,916.8 |
| | Work supervision | LV 4 x 4 | 41.96 | 8 | 90 | 30,211.2 |

Table 2 concludes that three chemical types are required by the standard-hole construction stage, namely bentonite, barium sulphate, and caustic soda with total usage of approximately 380,000 kg. The wastes, both solid and liquid, are mainly generated by employee activities. The total solid waste and wastewater generated during the geothermal exploration project were 12,411 kg and 1,702 $m^3$ (Table 2). Based on the SimaPro guideline, solid/domestic waste and drilling mud were classified as final waste flow, and the wastewater was categorized as emission to water. In addition, the land $CO_2$ sequestration due to land use (24.2 Ha) was sourced from Widhanarto et al. (2016) for use in the carbon footprint analysis.

*Table 2: Data inventory for materials and land use change*

| Material | Activity | Quantity | Unit |
|---|---|---|---|
| Chemical usage | | | |
| Bentonite | Well pad operation in standard-hole | 80,000 | kg |
| Barium sulphate | Well pad operation in standard-hole | 45,000 | kg |
| Caustic soda | Well pad operation in slim-hole | 63,000 | L |
| | Well pad operation in standard-hole | 255,000 | L |
| Waste generated | | | |
| Domestic/solid waste | Land clearing | 399 | kg |
| | Access road | 1,260 | kg |
| | Slim-hole well pad | 6,720 | kg |
| | Standard-hole well pad | 4,032 | kg |
| Wastewater | Land clearing | 54,720 | L |
| | Access road | 172,800 | L |
| | Slim-hole well pad | 921,600 | L |
| | Standard-hole well pad | 552,960 | L |
| Drilling mud | Slim-hole well pad | 125 | $m^3$ |
| | Standard-hole well pad | 840 | $m^3$ |
| Water consumption | | | |
| Water | Land clearing | 68,400 | L |
| | Access road | 216,000 | L |
| | Slim-hole well pad | 1,152,000 | L |
| | Standard-hole well pad | 691,200 | L |
| Land sequestration (Widhanarto et al., 2016) | Land clearing | 362.14 | t $CO_2$/Ha/y |

**2.3 Limitation**

The lack of a local database library for materials such as bentonite, barium sulphate, and caustic soda has created less reliability and accuracy result of the life cycle impact assessment. In addition, the current public availability report of geothermal exploration does not describe the type of equipment usage and mileage. Equipment fuel consumption was estimated based on the equipment horsepower (HP) approach.

## 3. Results and discussion

The results and discussion section presented the carbon footprint analysis and environmental hotspot of the geothermal exploration project. The carbon footprint of each activity was described in Section 3.1, and the hotspot analysis of carbon footprint was discussed in Section 3.2.

**3.1 Carbon footprint analysis**

The carbon footprint of the geothermal exploration project ranged from 0.11 kg CO2-eq/m2/y to 29 kg CO2-eq/m2/y, as presented in Table 3. The highest carbon footprint was recorded by standard-hole well pad construction where total workdays for completing this activity were 90 d. The carbon footprint contribution of standard-hole well pad activity was approximately 56 % of the total carbon footprint. In addition, two main inputs that resulted in the high carbon footprint for standard-hole well pad construction were chemicals usage (73 %), and fuel consumption (27 %). These chemicals usages have a specific function in well pad drilling activity. The specific function of each material is as follows: bentonite is commonly used for increasing mud viscosity, barium sulphate is aimed to increase density, and caustic soda would maintain the pH and alkalinity of drilling mud. The wastes associated with the use of these chemicals during drilling and mud-cutting were considered as a non-hazardous waste by the Indonesian Ministry of Energy and Mineral Resources (ESDM, 2017).

Based on the inventory analysis, as discussed in Section 2.2 showed the slim-hole well pad construction consumed higher amount of diesel fuel (374,875 L) than standard-hole well pad construction (288,469 L). The latter required higher amount of caustic soda (192,000 L) than the former, resulting a higher carbon footprint impact of chemical compared to diesel fuel. In addition, the carbon footprint that generated from carbon sequestration loss due to land clearing was 14.97 t CO2/Ha/y or equivalent with 1.50 kg CO2-eq/m2/y. Total carbon footprint emitted by the geothermal energy exploration were kg CO2-eq/m2/y.

*Table 3: Carbon footprint for geothermal energy exploration*

| Activity | Global Warming (GW) | Unit |
|---|---|---|
| Land clearing | 0.11 | kg $CO_2$-eq/m$^2$/y |
| Access road | 0.28 | kg $CO_2$-eq/m$^2$/y |
| Slim-hole well pad | 22.31 | kg $CO_2$-eq/m$^2$/y |
| Standard-hole well pad | 29.00 | kg $CO_2$-eq/m$^2$/y |

### 3.2 Carbon footprint hotspot

The hotspot analysis is aimed to identify the inputs causing the most carbon footprint. SimaPro provides the network analysis option for identifying carbon footprint hotspots (Figure 2). Three main hotspots in the life cycle impact of geothermal exploration projects were caustic soda, diesel fuel, and barium sulphate.
The utilization of caustic soda as a neutralization agent during the drilling activity contributed 64.5 % of the total carbon footprint and followed by diesel fuel consumption with 27 % of the overall carbon footprint. The other two contributors were bentonite (4.04 %) and barium sulfate (4.43 %). These four materials have also identified as the main inputs in the inventory stage (see Table 1 and Table 2). In sum, the life cycles of these materials production have contributed significantly to greenhouse gas emissions that requiring Indonesian companies to source these chemicals from manufacturers producing them with reduced level of GHG emissions.
Indication of environmental hotspots could be used as an initial information on how to reduce the carbon footprint from the geothermal energy exploration project. The effective utilization of diesel fuel and chemicals by preparing standard operational procedure (SOP) should be considered by the project to manage the environmental hotspots. In addition, one possible strategy that might be applied to increase the effectiveness of material utilization could be to implement good management principles of well pad construction by adopting the ISO management system concept (ISO, 2015).

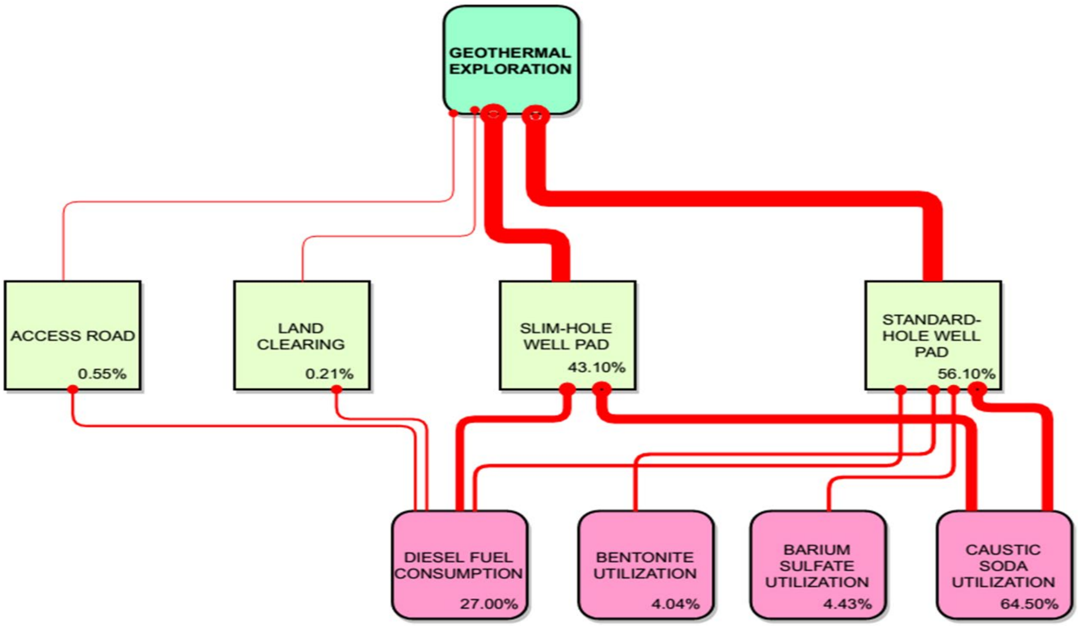


*Figure 2: Environmental hotspot using networking analysis*

## 4. Conclusions

This research paper conducted the life cycle assessment to calculate the carbon footprint of geothermal exploration in Indonesia, which has not been done yet. The carbon footprint of geothermal exploration was estimated to be 53.2 kg$CO_2$-eq/m$^2$/y and diesel fuel and chemical consumption for drilling and mud cutting were identified as the hotspots. The effective management usage of these two input materials by adopting the ISO management system concept (Plan, Do, Check, Act as in ISO 9001 and 14001) might increase the environmental performance of geothermal energy exploration. The life cycle assessment future research on geothermal development and operation in Indonesia is required to provide a complete picture on environmental impact of geothermal energy generation in Indonesia.

## References


ADB, WB, 2015, Unlocking indonesia's geothermal potential. Asian Development Bank and Word Bank, Manila, Philippines and Washington DC, United States.

Adiansyah J.S., 2019, Improving the environmental performance of a copper mine site in Indonesia by implementing potential greenhouse gas emissions reduction activities, Chemical Engineering Transactions, 72, 55–60.

Adiansyah J.S., 2020, Carbon footprint comparison of three different mine tailings management using a life cycle assessment approach, The 2019 International Conference on Mining and Environmental Technology, 16th-17th July, Mataram, Indonesia, 1-5.

Akhmat G., Zaman K., Shukui T., Sajjad F., 2014, Does energy consumption contribute to climate change? Evidence from major regions of the world, Renewable and Sustainable Energy Reviews, 36, 123–134.

Basosi R., Bonciani R., Frosali D., Manfrida G., Parisi M.L., Sansone F., 2020. Life cycle analysis of a geothermal power plant: Comparison of the environmental performance with other renewable energy systems, Sustainability, 12, 1–29.

Bošnjaković M., Stojkov M., Jurjević M., 2019, Environmental impact of geothermal power plants, Tehnički vjesnik, 26, 1515–1522.

Buonocore E., Vanoli L., Carotenuto A., Ulgiati S., 2015, Integrating life cycle assessment and emergy synthesis for the evaluation of a dry steam geothermal power plant in Italy, Energy, 86, 476–487.

DEN, 2019, Indonesia Energy Outlook 2019, Dewan Energi Nasional, Jakarta, Indonesia.

EIA, 2019, International Energy Outlook 2019, U.S Department of Energy, Washington DC, United States.

EIA, 2020, Coal and the environment, U.S. Energy Information Administration < www.eia.gov/energyexplained/coal/coal-and-the-environment.php> accessed 6.15.2020.

ESDM, 2017, Ministry ESDM decree on drilling Mud and cuttings waste management on Geothermal Activities. Ministry of Energy and Mineral Resources, Jakarta, Indonesia.

Geoenergy, 2020, Think geoenergy map <www.thinkgeoenergy.com/map/> accessed 6.6.2020.

Huang S., Tian T., 2006, Study of environmental impact in geothermal development and utilization, Proceedings of the 7th Asian Geothermal Symposium, Qingdao, China, 35–44.

Huttrer G.W., 2020, Geothermal Power Generation in the World 2015-2020 Update Report, World Geothermal Congress 2020, Reykjavik, Iceland, 1–17.

Ismail M.I., Yunus N.A., Hashim H., 2020, The challenges and opportunities of solar thermal for palm oil industry in Malaysia. Chemical Engineering Transaction, 78, 601–606.

ISO, 2006, Environmental Management - Life Cycle Assessment - Principles and Framework ISO 14040, International Standardization Organization, Geneva, Switzerland.

ISO, 2015, ISO 9001: 2015 Quality Management System, International Standardization Organization, Geneva, Switzerland.

Kwakwa P.A., Alhassan H., Adu G., 2020, Effect of natural resources extraction on energy consumption and CO2 emission in Ghana. International Journal of Energy Sector Management,14, 20-39.

Mark G., Oele M., Jorrit L., Tommie P., 2016, Introduction to LCA with SimaPro, Pre consultant, Netherlands.

Martínez-Corona J.I., Gibon T., Hertwich E.G., Parra-Saldívar R., 2017, Hybrid life cycle assessment of a geothermal plant: From physical to monetary inventory accounting, Journal of Cleaner Production, 142, 2509–2523.

Ruzzenenti F., Bravi M., Tempesti D., Salvatici E., Manfrida G., Basosi R., 2014, Evaluation of the environmental sustainability of a micro CHP system fueled by low-temperature geothermal and solar energy, Energy Conversion Management, 78, 611–616.

Shahzad S.J.H., Kumar R.R., Zakaria M., Hurr M., 2017, Carbon emission, energy consumption, trade openness and financial development in Pakistan: A revisit, Renewable and Sustainable Energy Reviews, 70, 185–192.

Tomasini-Montenegro C., Santoyo-Castelazo E., Gujba H., Romero R.J., Santoyo E., 2017, Life cycle assessment of geothermal power generation technologies: An updated review, Applied Thermal Engineering, 114, 1119–1136.

Widhanarto G.O., Purwanto R.H., Maryudi A., Senawi S., 2016, Assessing carbon pool of forest plantation to support REDD+ implementation in Indonesia, International Conference on Science and Technology, 27th - 28th October, Jogjakarta, Indonesia.

Yilmaz E., Ali Kaptan M., 2017, Environmental impact of geothermal power plants in Aydln, Turkey, International Conference Energy, Environment and Material Systems, 13th-15th September, Polanica-Zdrój, Poland.