Proceedings World Geothermal Congress 2023
Beijing, China, October 7-13, 2023

Life Cycle Assessment of Star Energy Geothermal Darajat Unit II and Unit III – Environmental Performance Evaluation and Roadmap to Sustainable Operation

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Keywords: Life Cycle Assessment, Environmental protection, Global Warming Potential, Acidification, Land Use, Water Footprint, Emission reduction, Environmental impact.

ABSTRACT

Star Energy Geothermal Darajat II, Limited (SEGD) is located at Darajat geothermal field, Garut, West Java. SEGD operates steam field and two power plants (Unit II and Unit III) with capacity of 95 and 121 MW, respectively, and supplies 55 MWe steam to Unit I owned by PT. Indonesia Power. Electricity produced is transmitted to Java-Bali-Madura grid managed by the State Electricity Company to fulfill energy demand for 600 thousand homes or equivalent to 1.7 million people. As part of its commitment on environmental protection, SEGD performed environmental performance assessment through Life Cycle Assessment (LCA) study in 2021. The goals of the study are identifying hot spot(s) for further both environment and product improvement and to update Government of Indonesia's National Database. The LCA study applied cradle to grave approach within system boundary from drilling activities (Cradle), processing system (Core) such as steam pipes, turbine, generator, transformer, cooling system, gas removal system and cooling tower, to electricity and steam sales meters (Grave). The study also included supporting facilities i.e., condensate reinjection system, office, water & wastewater treatment, and waste disposal facilities. Basis of Functional Unit used in the study was 1 kWh electricity, or 1-ton steam produced. Life Cycle Impact Assessment (LCIA) was done by using SIMAPRO v.9 software, with 76% of the total processed data was primary data. Impact categories and indicators applied referred to ReCiPe 2016Midpoint (H) V1.04 (for Global Warming Potential, Ozone Depletion, Acidification, Land Use, and Water Footprint), CML-IA baseline method V3.06 (for Abiotic Depletion, Eutrophication, and Human Toxicity), and Cumulative Energy Demand (CED) method for evaluating direct and indirect energy use throughout the life cycle of the facility. Based on the potential environmental impact assessment, hotspots in drilling activities (Cradle) such as CED, Land Use, Water Footprint, and abiotic depletion were found to be lower than similar industry average according to GPPs data compiled by Milousi (2018). As for plants operation (Core), the main hotspot was Global Warming Potential dominated by Non-Condensable Gas (CO_2, H_2S, NH_3) release from Cooling Tower. The calculated GWP value (2.55E-02 kg CO_2 eq/kWh) that is far below the average power plant emission of 122 g CO_2eq / kWh according to data from 85 geothermal power plants in 11 countries compiled in Geothermal Power Generating Plant CO_2 Emission Survey by Enel Green Power in 2001 (IGA, 2012). SEGD consistently performs emission reduction initiatives e.g., continuing Clean Development Mechanism (CDM) program, freshwater substitution to condensate for well work and drilling activity, performing energy efficiency program such as ejector motive steam optimization and house load reductions. Hotspot identification through LCA helps the company in prioritizing projects to improve environmental performance and product quality. There is still room for improvement to further refine the LCA quality by increasing primary data quantity for comprehensive representation. Nevertheless, the study has given a good picture on how we run the facilities in an eco-friendlier manner.

1. INTRODUCTION

Currently Star Energy has three operating areas in Indonesia with a total production of 875 MegaWatt (MW), consisting of; 1) Star Energy Geothermal Wayang Windu located in Bandung, West Java with a capacity of 227 MW; 2) Star Energy Geothermal Salak, Ltd. which is located in Sukabumi, West Java with a capacity of 377 MW and 3) Star Energy Geothermal Darajat II, Ltd. (SEGD II) which is located in Garut, West Java with a capacity of 271 MW.

As one of the advocates in implementing clean production activities, SEGD II is committed to providing full support in achieving Sustainable Development Goals (SDGs) targets, especially in clean water, clean energy, industry innovation, and climate action. One of the efforts that have been made is the application of Life Cycle Management (LCM) as an integrated concept to manage the entire life cycle of a product to create sustainable production and consumption activities. LCM implementation at SEGD II was initiated with the implementation of Life Cycle Assessment (LCA) since 2018.

Through the LCA study, SEGD II can identify the environmental impact of its production processes so that the company is able to make and implement the required measures effectively. Apart from that, through the LCA study the company can measure its compliance with the standards set by the government (fulfillment of the environmental document assessment criteria according to the Regulation of the Minister of Environment and Forestry No. 1 2021) and measure how much the company's concern contributes to environmental conditions and quality improvement, so that it is able to compete globally.

The implementation of the LCA study was initiated by SEGD II which was carried out by certified internal resources involving assistance from an external party from one of the universities in Indonesia who has experience and qualification in LCM/LCA study. SEGD II has a production capacity of 271 MWe. The main raw material is steam produced from geothermal wells (cradle) which is then processed at the production units to produce its main products: electricity and steam (gate). The electricity generated is then transmitted to the government grid through a custody metering before being sent to consumers, while the steam goes to Unit I. The products' transmission units are treated as grave. The LCA study has covered 100% of all its main products.

2. STUDY SITE

2.1 Overview

Star Energy Geothermal Darajat II, Limited (SEGD II, Ltd.) is located in Darajat, Padaawas Village, Pasir Wangi District, Garut Regency, West Java, at an altitude of 1884 m asl. SEGDII, Ltd. operates a steam field and two power plants namely Unit II and Unit III with a capacity of 95 and 121 MW respectively and provides 55 MW of steam for Unit I which is operated by PT. Indonesia Power (state owned power plant). The electricity produced by these units is transmitted to the electricity grid of the State Electricity Company (PLN) to be distributed to consumers to meet the electricity needs of 600 thousand homes or equivalent of 1.7 million people.

Figure 1: Location of Darajat Geothermal Power Plant in Garut, West Java, Indonesia

2.1 Facilities Description

The plant design placed emphasis on reliability, flexibility, and ease of maintenance. The Darajat geothermal power plant design is the result of a study that matched the turbine inlet pressure to the resource conditions and then applied the economics of steam cost, generation revenue and capital equipment costs.

Steam for the power plant comes from a dry steam geothermal resource, therefore, no wellpad two-phase separator is needed. There are 40 production wells currently in operation, with a total of more than 20 km pipeline networks in the steamfield transferrring steam to plant’s interfaces and condensate to reinjection well. Once solid particles and moisture droplets are removed from the steam by the scrubber at interface, the steam enters Unit II and Unit III power plants in clean and high-quality condition that match the turbine requirements. The turbines have a maximum rating of 100.706 MW for Unit II and 121 MW for Unit III.

A steam condensing and cooling system is provided for an acceptable plant cycle efficiency. Since there is not a large body of water (such as a river or lake) near the plant, a cooling tower is provided as the source of cooling water for each power plant. The condensed steam is also the source of make-up water for the plant’s cooling water system since some water is lost due to evaporation in the cooling tower. Normal operation of the plant results in a surplus of make-up water. Excess circulating water flows from the cooling basin overflow pipe to the condensate injection well through 5 km of condensate reinjection pipeline.

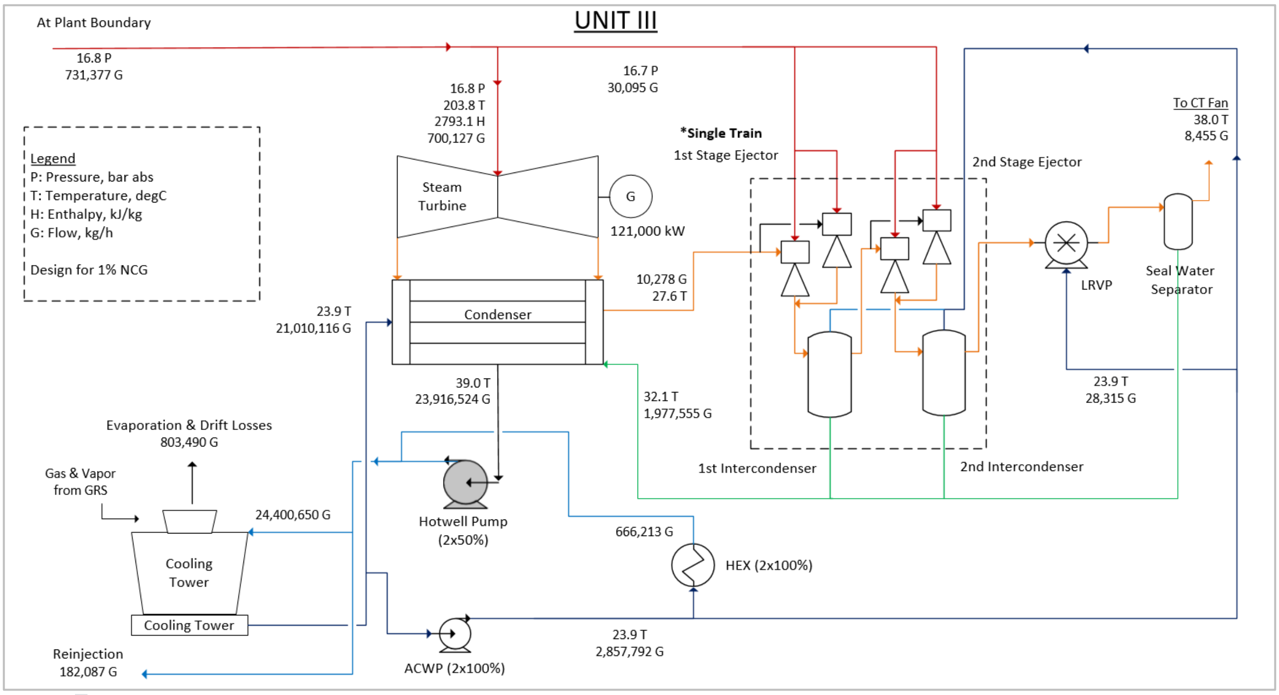

Figure 1: Schematic Diagram of Unit III (Design Parameters).

Steam exhaust from the turbine is cooled in the steam condensing and gas cooling zone in the two shells of the direct contact, spray-jet-type main condensers. Cooling water is drawn in by the condenser vacuum and is directly sprayed into the condenser by vertical columns housing spray nozzles. Condensate from the condenser is pumped by two, 50-percent capacity each, vertical double-suction type, and directly coupled to an electric motor, canned, Hot Well Pumps. Non-condensable gases (NCG) are drawn from the main condenser by Gas Removal System (GRS) using steam jet ejectors and a vacuum pump. A dual train three-stage removal process transitions the gas pressure from a near perfect vacuum to above atmospheric pressure. Each train of the GRS extracts the total non-condensable gas load expected at 100-percent rated capacity of the plant.

The cooling tower serves as both supply and return for the auxiliary cooling water (ACW) System. Cold circulating water from the cooling tower is pumped to the various components in the system. The crossflow induced draft cooling tower has 8 cells for Unit II and 9 cells for unit III and consists of a concrete structure with PVC splash type fill material. The tower is designed to optimize performance under 100-percent plant load conditions at 15.5° C wet bulb. Similar to other geothermal power plants in general, all NCG extracted by GRS is transferred to the top of the cooling tower (fan stacks) to be dispersed to the atmosphere. All gas emissions from the power plant are released into the environment via the cooling tower.

3. METHODOLOGY

Star Energy Geothermal Darajat II, Limited's Life Cycle Analysis methodology refers to ISO 14040:2016 and ISO 14044:2017 and Indonesia Ministry of Environmental and Forestry LCA Guideline. There are 4 steps in the process which are goal and scope definition, inventory analysis, impact assessment and interpretation.

3.1 Procedure

3.1.1 Goal and Scope Definition

3.1.1.1 Goal

The goal of this study is to assess the potential environmental impact of Darajat Geothermal Power Plant Operation, and to seek opportunities to minimize those potential impacts.

3.1.1.2 Scope

SEGD LCA scope covers cradle to grave stages which started from drilling activities up to energy sales metering for both steam and electricity.

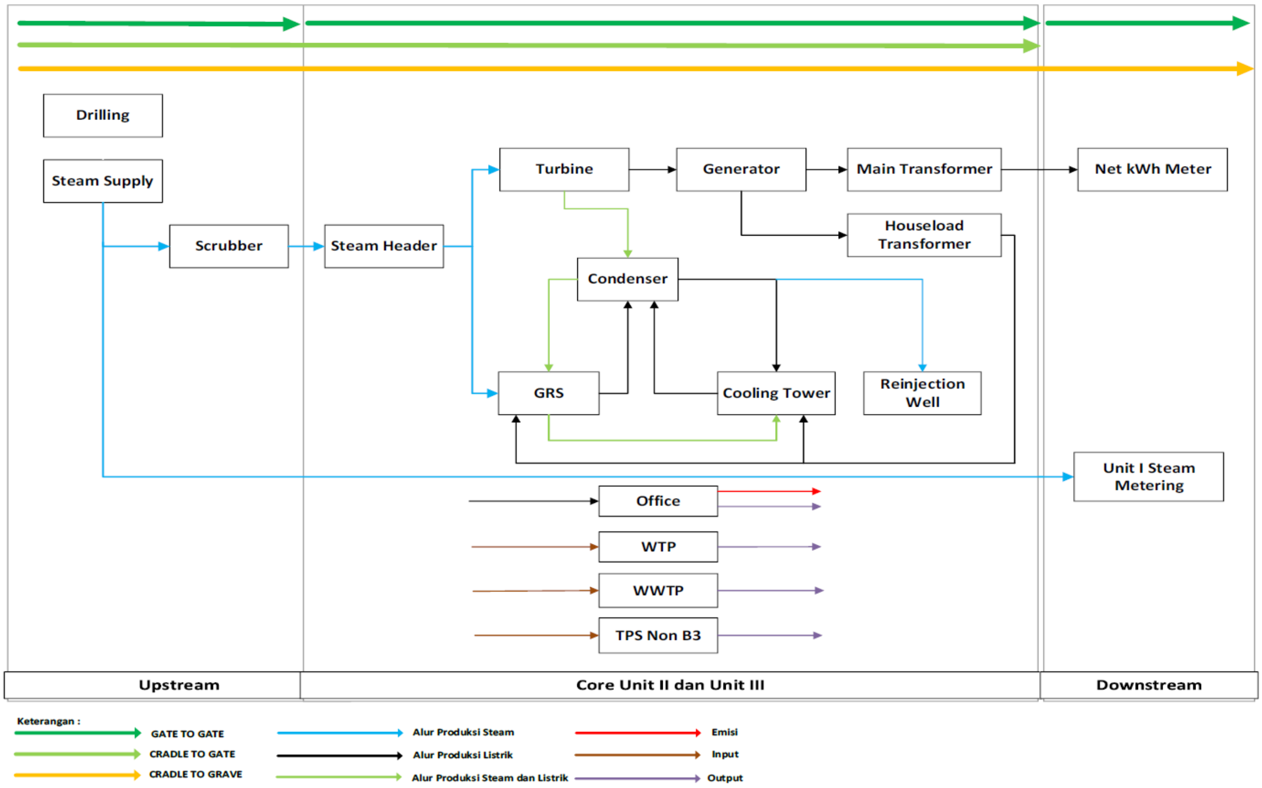

Figure 2: SEGD LCA scope

3.1.2 Inventory Analysis

Life Cycle Inventory (LCI) is one of the critical steps in the LCA. It is the process of quantifying raw material and energy requirements, atmospheric emissions, land emissions, water emissions, resource uses, and other releases over the life cycle of a product or process. The result of the study will be based on the data gathered in this step. The more accurate the data, the more representing the assessment will be.

3.2.3 Impact Assessment

Life Cycle Inventory analysis is followed by a life cycle impact assessment (LCIA). This phase of LCA is aimed at evaluating the potential environmental and human health impacts resulting from the elementary flows determined in the LCI. SEGD utilize SimaPro ver 9.0 software for the calculation and used pre-loaded database including Agrifootpring, Ecoinvent, ELCD, EU & DK Input Output, Industry Data 2.0, Methods, Siwss Input Output and USLCI. Impact characterization was done using models of ReCiPe 2016 Midpoint (H) V1.04, CML-IA Baseline V3.06, IPCC (2019) and Cumulative Energy Demand (CED).

3.2.4 Interpretation

Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study.

4. RESULTS AND DISCUSSIONS

The following table describes the impact assessment from each part of the production system.

Table 1: Impact Assessment Results on the Production Process of Star Energy Geothermal Darajat II.

No	Impact Category	Unit	Method	Total	Cradle	Gate	Grave
Primary							
1	Global warming potential	kg CO2 eq/kWh	ReCiPe 2016 Midpoint (H) V1.03 dan IPCC, 2019	2,68E-02	1,31E-03	**2,55E-02**	0
2	Ozon depletion potential	kg CFC11 eq/kWh	ReCiPe 2016 Midpoint (H) V1.03	2,44E-10	**2,44E-10**	0	0
3	Acid rain potential	kg SO2 eq/kWh	ReCiPe 2016 Midpoint (H) V1.03	4,20E-05	2,99E-06	**3,90E-05**	0
4	Eutrophication	kg PO4--- eq/kWh	CML-IA Baseline V3.05	9,44E-06	2,47E-06	**6,97E-06**	0
Secondary							
5	Photochemical oxidation	kg C2H4 eq/kWh	CML-IA Baseline V3.05	5,71E-07	**5,71E-07**	0	0
Abiotic Depletion Potential (fossil and non fossil)							

No	Impact Category	Unit	Method	Total	Cradle	Gate	Grave
6	a. Abiotic depletion (fossil fuels)	MJ/kWh	CML-IA Baseline V3.05	1,13E-02	**1,13E-02**	0	0
	b. Abiotic depletion	kg Sb eq/kWh	CML-IA Baseline V3.05	5,21E-09	**5,21E-09**	0	0
Biotic Depletion Potential							
7	a. Terrestrial ecotoxicity	kg 1,4-DCB/kWh	ReCiPe 2016 Midpoint (H) V1.03	4,20E-03	**4,20E-03**	0	0
	b. Freshwater ecotoxicity	kg 1,4-DCB/kWh	ReCiPe 2016 Midpoint (H) V1.03	2,51E-05	**2,51E-05**	0	0
	c. Marine ecotoxicity	kg 1,4-DCB/kWh	ReCiPe 2016 Midpoint (H) V1.03	3,56E-05	**3,56E-05**	0	0
8	Carcinogenic	kg 1,4-DCB/kWh	ReCiPe 2016 Midpoint (H) V1.03	1,39E-04	**1,39E-04**	0	0
9	Toxicity	kg 1,4-DB eq/kWh	CML-IA Baseline V3.05	2,44E-03	**2,27E-03**	1,67E-04	0
10	Water Footprint	m3/kWh	ReCiPe 2016 Midpoint (H) V1.03	1,12E-05	**8,17E-06**	3,07E-06	0
11	Land Use Change	m2a crop eq/kWh	ReCiPe 2016 Midpoint (H) V1.03	1,49E-05	**1,49E-05**	0	0
Cumulative Energy Demand							
12	a. Non renewable	MJ/kWh	Cumulative Energy Demand	3,05E-03	**3,05E-03**	0	0
	b. Renewable	MJ/kWh	Cumulative Energy Demand	4,16E-02	0	**4,16E-02**	0

After each impact has been identified and quantified, interpretation of the impact is then carried out. The interpretation process includes correlating between the results of the impact assessment on the inventory and the purpose and scope of the assessment.

4.1 Cradle

The process unit in cradle includes Drilling activities, Steam Supply Unit I, II & III and Scrubber Unit II & III. All the potential impact comes from drilling activities.

4.1.1 Primary Impact

4.1.1.1 Global Warming Potential

Main contributor for global warming potential sourced from diesel fuel engine combustion from drilling activity. This activity releases 90.5% of carbon dioxide to the air

4.1.1.2 Ozon Depletion

Main contributor for potential ozon depletion sourced from diesel fuel engine combustion from drilling activity. This activity releases 80.1 % dinitrogen monoxide and 17.2% of methane to the air.

4.1.1.3 Acidification

Main contributor for potential acidification sourced from NCG release and diesel fuel engine combustion from drilling activity. This activity releases 82.5% dinitrogen monoxide and 15.3% of methane to the air.

4.1.1.4 Eutrophication

Main contributor for potential eutrophication sourced from NCG release and diesel fuel engine combustion from drilling activity. This activity emitted 23.6% nitrogen oxide to the air and 73.2% phosphate to water body

4.1.2 Secondary Impact

4.1.2.1 Photochemical Oxidation

Main contributor for photochemical oxidation sourced from diesel fuel engine combustion and chemical usage in drilling activity. This activity releases 54.5% carbon monoxide and 33.6% Sulphur dioxide to the air.

4.1.2.2 Abiotic Depletion

Main contributor for abiotic depletion (fossil fuels) sourced from diesel fuel engine combustion in drilling activity, while abiotic depletion (non-fossil fuels) came from diesel fuel engine combustion and construction materials covering 15.4% cadmium, 27.8% copper, 10.2% lead and 14.5% of zinc.

4.1.2.3 Ecotoxicity

Main contributor for ecotoxicity sourced from chemical use and construction materials in drilling activity covering release of copper, mercury, zinc, nickel, chromium to the environment.

4.1.2.4 Carcinogenic

Main contributor for carinogenic potential sourced from construction materials in drilling activity, emmiting 97.5% of chromium to the air

4.1.2.5 Human Toxicity

Main contributor for carinogenic potential sourced from diesel fuel engine combustion and chemical use in drilling activity, emmiting 55.5% nitrogen oxide and 32.8 sulphur dioxide to the air

4.1.2.6 Water Footprint

Main contributor for water footprint sourced from the use of water resources in drilling activity.

4.1.2.6 Land Use Change

Main contributor for the land use change was due to drilling activity use of space, ranging up to 2 hectare per well pad.

4.1.3 Cumulative Energy Demand

The use of non-renewable energy in cradle stage mainly sourced from drilling activity.

4.2 Gate

In the 'Gate' scope, environmental impact calculations from electricity generation activities are performed using the CML-IA Baseline, ReCiPe 2016 Midpoint (H), IPCC (2019), and Cumulative Energy Demand (CED) methods with units of impact generated per 1 kWh of electricity. The analysis was carried out using SimaPro software and manual calculations using the IPCC approach (2019), as well as using monitoring data for all process units studied in the gate scope.

4.2.1 Primary Impact

4.2.1.1 Global Warming Potential

Contributors to the GWP on the power plants come from emissions of used oil in generators and main transformers, and Non-Condensable Gas (NCG) release (containing 90% CO_2) into the atmosphere through Cooling Tower Fans. The biggest contributor is Cooling Tower U-II and U-III amounting 99% of total impact. Hotspots were identified at the U-II & U-III Cooling Tower facilities with an impact of 2.55E-02 kg CO_2 eq/kWh. The results of the percentage of impact contributors can be seen in Table 2.

Table 2. Contributors to the Potential Impact of Global Warming in the Electricity Production Process

Impact Contributor	*Generator* U-II dan U-III	*Main Transformer* U-II dan U-III	*Cooling Tower* U-II dan U-III	Total
Carbon Dioxide	0,8%	0,2%	99%	100%

4.2.1.2 Acidification

Impact calculation result refers to the release of Non Condensable Gas (NCG) containing NH_3 into the atmosphere from the Cooling Tower (100%) which has the potential to cause acid rain. The hotspots were identified at the U-II & U-III Cooling Tower facilities with an impact of 3.90E-05 kg SO_2 eq/kWh. Whereas in other process units, no emissions are produced which have the potential to cause acid rain.

4.2.1.3 Eutrophication

Contributors to the potential impact of eutrophication come from the Cooling Tower U-II and U-III process units, as well as supporting facilities (Office, Water Treatment Plant (WTP), and Waste Water Treatment Plant (WWTP)). The largest contribution to the impact of potential eutrophication was generated from Cooling Tower U-II and U-III of 99.8%. The results of the percentage of impact contributors can be seen in Table 3.

Table 3. Contributors to the Potential Impact of Eutrophication in the Electricity Production Process

Impact Contributors	*Cooling Tower* U-II dan U-III	*Office*, WTP, dan WWTP	Total
Ammonia	99,8%	0%	99,8%
COD, *Chemical Oxygen Demand*	0%	0,2%	0,2%

Impact calculation result refers to the release of Non-Condensable Gas (NCG) containing NH_3 into the atmosphere from the Cooling Tower which has the potential to cause acid rain. The hotspots were identified at the U-II & U-III Cooling Tower facilities with an impact of 6.97E-06 kg PO_4 eq/kWh.

4.2.1.4 Ozone Depletion Potential

Within the scope of this gate there is no ozone depletion potential impacted from the electricity production process (based on ReCiPe and CML methods the result is 0 kg CFC11 eq).

4.2.2 Secondary Impact

4.2.2.1 Human Toxicity

Impact calculation results refer to the release of Non-Condensable Gas (NCG), which contains 8% H_2S and 0.16% Ammonia, into the atmosphere from the Cooling Tower. Calculated impact from cooling tower is 1,67E-04 kg 1.4-DB eq/kWh which is lower than the hotspots identified in drilling activities with an impact of 2.27E-03 kg 1.4-DB eq/kWh

4.2.2.2 Water Footprint

Contributors to the impact of the water footprint on the electricity production process come from supporting facilities, namely Office, WTP and WWTP. 100% of the impact potential refers to the use of natural resources (water) carried out in these supporting facilities. Meanwhile, in other process units, no fresh water is used, thus no water footprint impacted.

The impact of water footprint on these supporting facilities is 3.07E-06 m3/kWh, this amount is much smaller than impact contributed by drilling process (see section 4.1.2.6).

4.2.2.3 Photochemical Oxidant

Within the scope of this gate there is no photochemical oxidation (PO) impacted from the electricity production process (based on CML methods the result is 0 kg C_2H_4 eq).

4.2.3 Cumulative Energy Demand (CED)

This energy use is related to the houseload needed to operate the hot well pump (U-II & U-III condensers), WTP, WWTP, as well as electricity supply for office buildings. The biggest contributor to the impact of CED was from the Condenser U-II and U-III process units of 75.2%. The results of the percentage of impact contributors can be seen in Table 4.

Table 4. Contributors to the Potential Impact of Cumulative Energy Demand

Impact Contributor	***Condenser* U-II & U-III**	**GRS U-II & U-III**	***Cooling Tower* U-II & U-III**	***Office*, WTP, & WWTP**	**Total**
Energy, renewable	75,2%	5%	19%	0,8%	**100%**

Identified hotspots at U-II & U-III Condenser facilities for operating hotwell pumps resulting in an impact of 3.13E-02.

4.3 Grave

Within the grave stage, there is not any environmental impact identified, as the unit processes are energy sales metering for both electricity and steam sales.

4.4 Hotspots Analysis

After interpreting all the potential impacts resulting from the electricity production process of Star Energy Geothermal Darajat II, Limited, hotspot analysis is carried out. Hotspots can be in the form of process units (process hotspots) or impact categories (impact hotspots) that have the highest value in a series of production processes.

Hotspot analysis is carried out to get a baseline for determining improvement programs for routine production activities. Based on the results of data interpretation, the unit with the highest contribution to each impact can be seen in Table 5.

Table 5. Overall Hotspots Summary in the Production Process of Star Energy Geothermal Darajat II.

No	**Impact Category**	**Unit**	**Methods**	**Total Value**	***Hotspot Process***	**Cause**
Primary Impact						
1	*Global warming potential*	kg CO2 eq/kWh	ReCiPe 2016 *Midpoint* (H) V1.03 dan IPCC, 2019	2,55E-02	*Cooling Tower* U-II & U-III	CO2 emission to atmosphere
2	Ozon depletion potential	kg CFC11 eq/kWh	ReCiPe 2016 *Midpoint* (H) V1.03	0	-	-
3	Acid rain potential	kg SO2 eq/kWh	ReCiPe 2016 *Midpoint* (H) V1.03	3,90E-05	*Cooling Tower* U-II & U-III	NH3 emission to atmosphere
4	Eutrophication	kg PO4--- eq/kWh	CML-IA *Baseline* V3.05	6,97E-06	*Cooling Tower* U-II & U-III	NH3 emission to atmosphere and COD (C*hemical Oxygen Demand*) emission to water
Secondary Impact						
5	*Photochemical oxidation*	kg C2H4 eq/kWh	CML-IA *Baseline* V3.05	0	-	-
Abiotic resources depletion (*fossil* & *non fossil):*						
6	*a. Abiotic depletion (fossil fuels)*	MJ/kWh	CML-IA *Baseline* V3.05	0	-	-

	b. Abiotic depletion	kg Sb eq/kWh	CML-IA *Baseline* V3.05	0	-	-
Biotic resources depletion*:*						
7	*a. Terrestrial ecotoxicity*	kg 1,4-DCB/kWh	ReCiPe 2016 *Midpoint* (H) V1.03	0	-	-
	b. Freshwater ecotoxicity	kg 1,4-DCB/kWh	ReCiPe 2016 *Midpoint* (H) V1.03	0	-	-

Based on Table 5, it can be seen that the dominant process hotspots are in the Cooling Tower U-II and U-III. This equipment contributes significantly to 4 (four) impact categories. In general, the causes of impacts originating from Cooling Tower U-II and U-III are pollutants released into the air and water. In addition, other process units such as Office, WTP, and WWTP also become hotspots caused by the use of groundwater resources, and Condensers U-II and U-III which are the biggest consumers of houseload electricity (renewable CED for hotwell pumps operation). The improvement plan to reduce the impact of hotspots will then focus on these process units.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the LCA study conducted at Star Energy Geothermal Darajat II, Limited., several conclusions can be drawn based on the impacts that arise in the electricity and steam production process as follows:

a. The potential environmental impacts arising from the electricity and steam production process of Star Energy Geothermal Darajat II, Limited., at each point of its life cycle are as follows:
    - Cradle point: Global warming potential (GWP), ozone depletion potential, acid rain potential, eutrophication potential, photochemical oxidation, abiotic depletion (fossil and non-fossil), biotic depletion, carcinogenic, toxicity, water footprint, land use change, and cumulative energy demands.
    - Gate point: Global warming potential (GWP), acid rain potential, eutrophication potential, toxicity, water footprint, and cumulative energy demand.
    - Grave point: No environmental impact identified at grave scope.

b. The potential for environmental improvement can be carried out in the Generator, Main Transformer, Condenser, GRS, Cooling Tower, and Supporting Facilities (Office, WTP, and WWTP) processing units.

c. The data inventory that has been compiled can be used to create a national LCA database of raw material acquisition, production, and distribution processes which include input (raw materials, water consumption, energy input, chemicals, etc.) and output data (products, by-products, and wastes, including air, water, and soil emissions).

d. This LCA study can be used as an initial stage of a more comprehensive study in accordance with the provisions stipulated for environmental product declarations (Environmental Product Declarations-Share Environmental Metrics of Products to Customer).

In general, there are several program recommendations that can be implemented as an effort to reduce various aspects of the potential impact, including:

a. Carry out energy efficiency activities to reduce the potential impact of GWP, photochemical oxidation, and cumulative energy demand caused by energy use, both fuel and electricity.
b. Carry out activities that support the reduction of air pollutants so as to reduce the potential impact of GWP, potential for ozone depletion, potential for acid rain, potential for eutrophication, photochemical oxidation, reduction of biotic, carcinogenic, and toxicity caused by various emission parameters released into the air.
c. Carry out activities to reduce and/or utilize toxic and hazardous waste so as to reduce the potential impact of GWP and photochemical oxidation from the processing and transportation of the produced toxic and hazardous waste.
d. Carry out 3R (Reuse, Reduce, dan Recycle) program for non-hazardous solid waste activities so as to reduce the potential impact of GWP, photochemical oxidation, and land use change from the processing and transportation of non-hazardous solid waste produced.
e. Carry out water efficiency activities so as to reduce the potential impact of the water footprint.
f. Carry out treatment to reduce the load of water pollutant so as to reduce the potential impact of reducing biotic depletion, carcinogenic, and toxicity caused by various parameters of water pollutant load released into water and soil.

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