Proceedings of the 6th ITB International Graduate School Conference
Multidisciplinary Collaboration for Sustainable Energy: Science, Technology, Policy, and Society

Technical Study on The Design of Tangkuban Perahu Geothermal Power Plant

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Abstract. The Tangkuban Parahu Geothermal Working Area (WKP) possesses significant geothermal energy potential with high-temperature (high enthalpy) reservoir characteristics estimated at 240–270°C. This potential makes WKP Tangkuban Parahu one of the most promising areas for geothermal power plant development in Indonesia. This study aims to evaluate geothermal resource potential, design an optimal geothermal power generation system, and estimate the overall project development costs.

The analysis integrates geological, geochemical, and geophysical survey data from previous exploration studies. For power generation design, thermodynamic modeling was conducted using Excel with Coolprop extension, considering technologies single flash. This technology were selected for their advantages in utilizing geothermal resources with relatively high efficiency. This research is mainly focused on recalculation of Single Flash Cycle from Tangkuban Perahu Pre-FS Document that were conducted by PT.PLN and PT. New Quest

Based on Monte Carlo simulation results, the electrical power potential of WKP Tangkuban Parahu is estimated at 22 MW (P90) to 67 MW (P10), with a median value of 43 MW (P50).

The findings of this study are expected to serve as an important reference in designing an efficient and sustainable geothermal power plant at Mount Tangkuban Parahu WKP and support PT PLN in achieving its national renewable energy mix targets.

Keywords: *Aspen Hysys, Modeling, Reservoir, Tangkuban Perahu, Thermodynamics, Geothermal Power Plant, WKP*

1 Introduction

The Tangkuban Parahu Geothermal Working Area (WKP) is one of PT PLN's concessions, granted under Surat Keterangan No. 1893 K/30/MEM/2017 since 2017. This WKP spans an area of 44,710 hectares and covers several regions in West Java, including parts of Subang Regency, West Bandung Regency, Purwakarta Regency, and Karawang Regency. It is located approximately 25 km north of Bandung City.

Initially, a 60 MW geothermal power plant was planned to be developed in this WKP, scheduled to operate between 2024–2025 (PLN RUPTL 2019–2028). However, after conducting a resource study and considering existing constraints, the development plan was scaled down to 40 MW, with operations targeted for 2026 (PLN RUPTL 2021–2030). The development of this geothermal plant is expected to contribute green energy to the Java-Madura-Bali (Jamali) grid system and support Indonesia in achieving its 2030 Net Zero Emission target.

Therefore, a study on geothermal utilization in this WKP is necessary, particularly regarding suitable PLTP (geothermal power plant) design and the economic feasibility of the Tangkuban Parahu geothermal project. The plant design study will be calculated using Excel with Coolprop extension to produce optimal performance results.

2 Data & Methodology

2.1 Geological Condition of Tangkuban Perahu

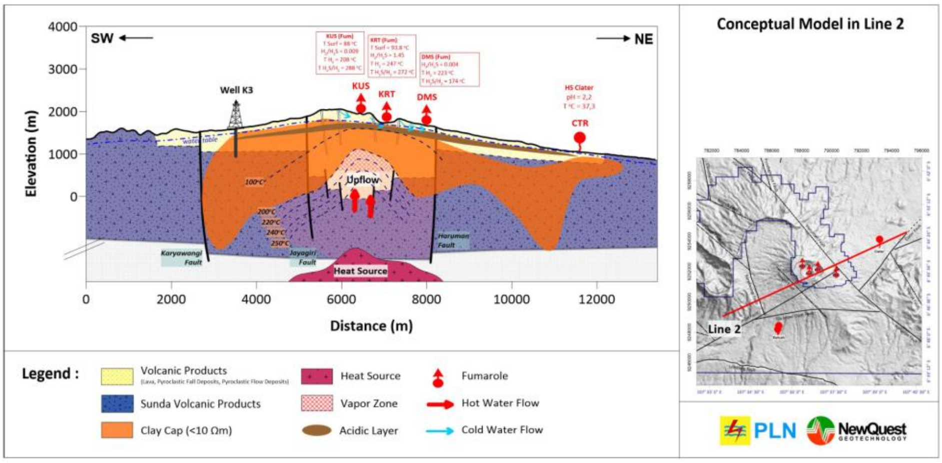


Figure 1 Conceptual Model SW–NE (PLN Unpublished, 2020)

As shown in ***Figure 1*** the conceptual cross-section along Line 2 illustrates the geological profile and geothermal fluid flow from the southwest (SW) to the northeast (NE) across the Tangkuban Parahu area. The heat source is located beneath the Jayagiri Fault zone and is presumed to be a magmatic intrusion supporting the geothermal system. The upflow zone is identified beneath Kawah Ratu, with reservoir temperatures estimated between 250°C and 270°C. Geothermal fluids rise through fractures supported by faults such as the Haruman Fault. The clay cap is indicated by a low resistivity zone (<10 Ohm-meter) located above the upflow area and consists of argillic alteration. The outflow zone trends northeast through shallow layers toward acid springs around the Ciater area, with surface temperatures dropping to about 37.3°C. Fumaroles and hot springs are distributed around Kawah Ratu (KRT), Kawah Upas (KUS), and Kawah Domas (DMS), reflecting active geothermal manifestations.

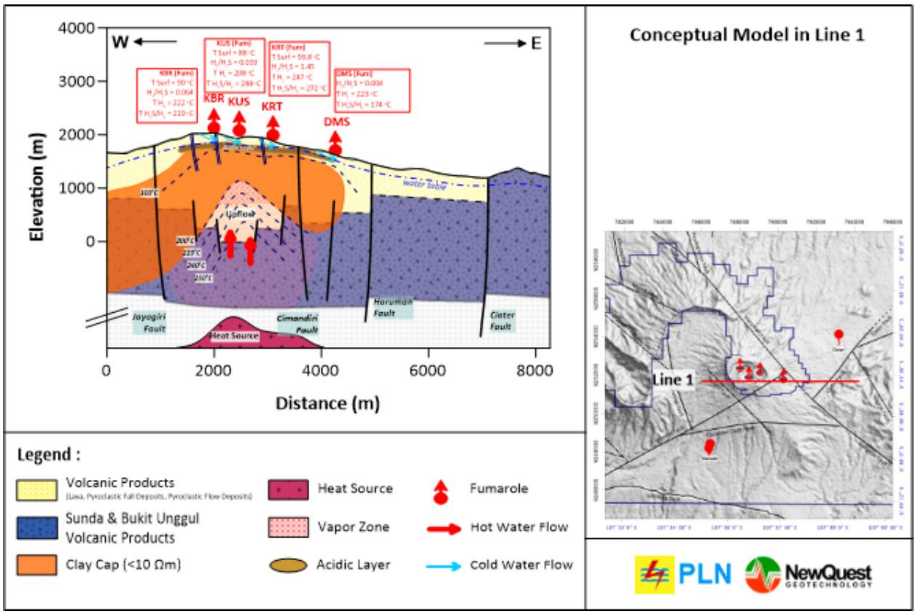


Figure 2 Conceptual Model W–E (PLN Unpublished, 2020)

As shown in ***Figure 2*** the conceptual cross-section along Line 1 presents the geological profile from west (W) to east (E) across the Tangkuban Parahu area. The heat source beneath the Jayagiri Fault, formed by magmatic intrusion, provides thermal energy for the geothermal system. The upflow zone is centered beneath Kawah Ratu (KRT), with high temperatures (250°C–270°C). Geothermal fluids ascend through active faults, including the Cimandiri and Haruman Faults. The caprock (Clay Cap), formed by argillic alteration with low resistivity, overlays the upflow zone. The outflow zone extends eastward along the Ciater Fault, where temperatures decrease toward hot springs in the Ciater area, measuring around 37°C. Fumarolic activity is detected at Kawah Baru (KBR), Kawah Upas (KUS), Kawah Ratu (KRT), and Kawah Domas (DMS).

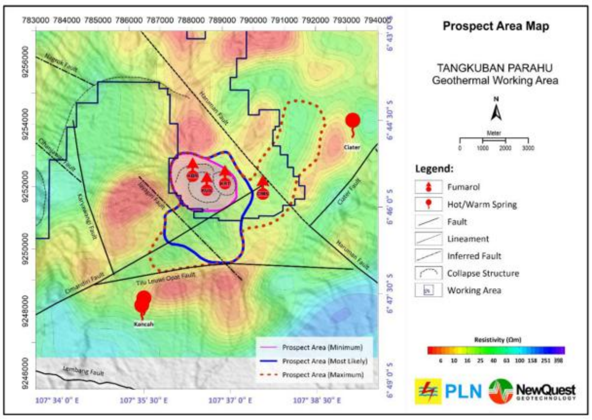


Figure 3 Estimated Resource Map (PLN Unpublished, 2020)

The minimum area focuses on the confirmed core reservoir zone, mainly around Kawah Ratu (KRT), Kawah Upas (KUS), and Kawah Domas (DMS). In ***Figure 3*** is shown that the most likely area includes the main upflow zone with active fumaroles and major faults such as the Tilu Leuwi Opat and Cimandiri Faults. This area is based on integrated geophysical and geochemical survey results and likely contributes significantly to the geothermal system.

The maximum area extends toward the Kancah and Ciater hot springs, including additional faults that may serve as geothermal fluid migration paths.

The input parameters for the Monte Carlo simulation, used to estimate the potential electrical energy reserves, are as shown in ***Tabel 1***:

Table 1 Monte Carlo Input Parameters (PLN Unpublished, 2020)

Input Paramter	Unit	Most Likely	Probability Distribution		Justification	Referencess
			Min	Max		
Area	km²	7.6	3	14	Geology, Geophysics, Geochemistry	Final Report (Prospect Area)
Thickness	km	1.25	1	1.5	Geophysical Data	Final Report (Resistivity Section)
Porosity	fraction	0.1	-	-	Assuming parameter for probable reserve estimation	SNI 13-6482-2000
Specific Heat Capacity	kJ/kg.°C	1	0.9	1.1	Assuming parameter for probable reserve estimation	SNI 13-6482-2000
Rock Density	kg/m³	2000	1800	2700	Geophysical Data	Final Report (Gravity Model)
Initial Water Saturation	fraction	0.9	-	-	Geochemical Data	Final Report (Gas Geochemistry)
Initial Vapor Saturation	fraction	0.1	-	-	Geochemical Data	Final Report (Gas Geochemistry)
Final Water Saturation	fraction	0.1	-	-	Assumption from resource assessment in Kerinci	Hidayat et al, 2007
Final Vapor Saturation	fraction	0.9	-	-	Assumption from resource assessment in Kerinci	Hidayat et al, 2007
Initial Temperature	°C	240	230	260	Geochemical Data	Final Report (Gas Geothermometer)
Cut Off Temperature	°C	180	-	-	Cut-off temperature in high temperature system	SNI 13-6171-1999
Project time	year	30	-	-	Assuming parameter for probable reserve estimation	SNI 13-6482-2000
Electricity Conversion Factor	fraction	0.1	0.05	0.15	Assuming parameter for probable reserve estimation	SNI 13-6482-2000
Recovery Factor	%	25	10	30	Recovery factor assumption for hot-water systems	Muffler, 1978; Hidayat et al, 2007

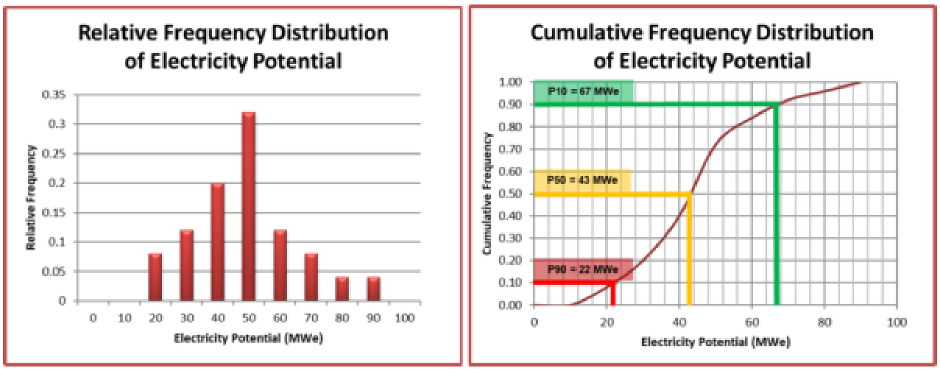


Figure 4 Monte Carlo Calculation Results (PLN Unpublished, 2020)

Figure 4 shows Monte Carlo simulation results with 90%, 50%, and 10% probability estimates indicate geothermal resource potentials of approximately 22 MW, 43 MW, and 67 MW, respectively. The most likely outcome remains aligned with PLN's 2021–2030 RUPTL plan to develop a 40 MW geothermal power plant in Tangkuban Parahu as shown in ***Table 2***.

Table 2 PLTP Tangkuban Parahu Development Plan (PLN RUPTL 2021–2030)

RUPTL 2021-2030			Keterangan
Nama Proyek	Kap (MW)	COD	
PLTP Tangkuban Perahu (FTP2)	40	2026	Kapasitas sesuai dengan studi pre-FS dan/atau hasil studi *resource* terakhir dan mempertimbangkan kendala-kendala sosial dan lingkungan.
PLTP Cisolok-Cisukarame (FTP2)	20	2030	

2.2 Calculation and Simulation

Well Head and Reservoir data is shown in ***Tabel 3*** is a result from well simulation that conducted by PT. PLN before. This datas are going to used as an input for the Simulation.

Table 3 Estimated Reservoir and Wellhead Parameters (PLN Unpublished, 2020)

Tangkuban Perahu	Parameter	Unit	Slim Hole	Standard Hole	Big Hole
Reservoir	Pressure	Bara	110.00	110.00	110.00
	Temperature	°C	240	240	240
	Enthalpy	kJ/kg	1214.1	1214.1	1214.1
	Non Condensible Gas	%	3.2%	3.2%	3.2%
Well Head	Pressure	Bara	10.00	9.95	10.06
	Temperature	°C	177.4	177.2	177.6
	Max Flow rate (Q_{total})	kg/s	17.8	91.6	141.5
	Dryness	%	25%	25%	25%
	Enthalpy	kJ/kg	1194.9	1194.9	1195.2

To design the geothermal power plant using Excel with Coolprop extension, predictive well output data from previous Pre-FS studies were used. Key data and parameters include:

- Pressure (P): in Bara
- Temperature (T): in °C
- Mass flow rate (ṁ): in kg/s
- Enthalpy (h): in kJ/kg
- Steam quality (x): in %
- Fluid composition: in mass fraction
-

With this data, simulations were conducted using Excel with Coolprop extension cycle simulations that were performed in this study is Single Flash Cycle. Cycle simulations were shown in ***Figure 5.*** The main difference between this new cycle and the old one is this cycle using Non-Mixing Condenser. And also, water cooling for Intercondenser and water supply for LRVP is supplied from Cooling Water from Cooling Tower. After that it came back to Cooling Tower.

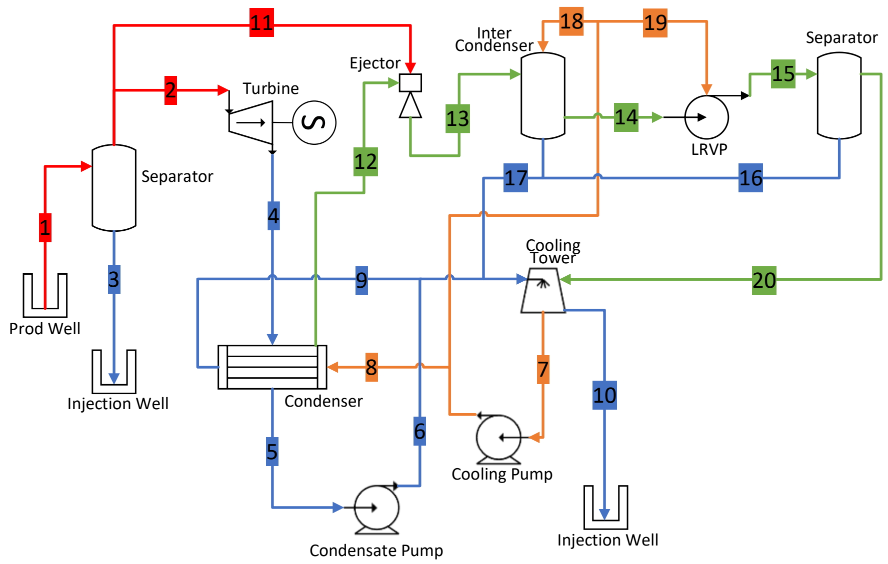


Figure 5 Tangkuban Perahu Power Plant Single Flash Cycle

Table 4 Tangkuban Perahu Power Plant Single Flash Cycle Simulation Result

Parameter	State									
	1	2	3	4	5	6	7	8	9	10
Pressure (bar)	10	6.5	10	0.08	0.08	3	3	4	3	3
Temperature (^{o}C)	180	177	180	41.65877	41.65877	35	24	25	35	24
mass flow total (kg/s)	142.7471	35.68677	107.0603	35.68677	34.54479	1655.984	1621.439	1621.439	1621.439	2.544789
mass flow CO_2 (kg/s)	4.567906	1.141976		1.141976						
Entalphy (kJ/kg)	1407.16	2795.413	762.5151	2131.219	173.8398	146.2716	101.9527	106.2261	146.2716	101.9527

Parameter	State									
	11	12	13	14	15	16	17	18	19	20
Pressure (bar)	6.5	0.08	0.827496	0.827496	3	3	3	4	4	3
Temperature (^{o}C)	177	41.65877	94.54757	94.54757	95	95	94.54757	24	24	95
mass flow total (kg/s)	3.425929	1.176236	4.602165	4.602165	4.602165	5.357411	30	30	2	
mass flow CO_2 (kg/s)	0.102778	1.141976	1.244754	1.244754	1.244754	1.244754				1.244754
Entalphy (kJ/kg)	2730.846	567.6926	2177.98	1753.485	397.6218	397.6218	167.1655	102.0455	102.0455	397.6218

Parameter	Equipment						
	Turbine	Condenser	Condensate Pump	Cooling Tower	Cooling Pump	Inter condenser	LRVP
Power (kW)	21052.63		58.164427	73.391	6929		6443.996
Heat Rejection (kW)		67617.267		73391		1953.5994	

From the result that shown in ***Table 4*** , The number of well that needed to be drilled is known as shown in ***Table 5.***

Table 5 Total Number of Well Needed

Parameter	Value	Unit
Total Steam Needed @ 20 MW	146.1729907	kg/s
Total Steam Needed @ 2x20 MW	292.3459814	kg/s
WKP Tangkuban Production Well Capacity	91.5	kg/s
Number of Production Well Needed	3.195038048	
	4	Well
Number of Production Well Needed to be Drilled (sucsess ratio 50%)	8	Well
Brine Injection Total from Power Plant	141.6050847	kg/s
WKP Tangkuban Injection Well Capacity (Pre-FS)	125	kg/s
Number of Injection Well Needed	1.132840678	
	2	Well
Number of Injection Well Needed to be Drilled (success ratio 50%)	4	Well

Subsequent cost estimations were carried out for all power plant options. The calculations considered the regional Cost of Electricity Production (BPP), PLN's financing structure, and financial ratios. First calculating CAPEX and OPEX as shown in ***Table 6*** and ***Table 7***

Table 6 CAPEX of Single Flash Tangkuban Perahu

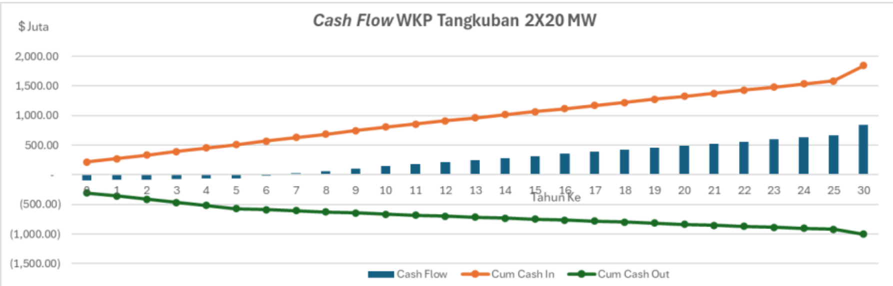
	Estimasi total cost investment 2X20 MW						
	Description	Qty	price	Referensi	Total	VAT	Total CAPEX
Exploration Cost							
	Detail geoscientific survey	1	$ 500,000	PLN	$ 500,000	0%	$ 500,000
	Infracstructure engineering & construction	1	$ 16,300,446	calculation (FS)	$ 16,300,446	0%	$ 16,300,446
	Exploration Drilling						
	Rig Mob+Demobilization	1	$ 3,450,045	EBTKE 2023	$ 3,450,045	0%	$ 3,450,045
	Well drilling	4	$ 6,950,000	Laporan 2019	$ 27,800,000	0%	$ 27,800,000
	Well testing	4	$ 200,000	wahyusoedibjo dkk, 2018	$ 800,000	0%	$ 800,000
	Skidding	3	$ 210,000	EBTKE 2023	$ 630,000	0%	$ 630,000
	Move from pad to pad	1	$ 500,000	PLN	$ 500,000	0%	$ 500,000
	Resources & Engineering Consnultant	1	$ 3,500,000	PLN	$ 3,500,000	0%	$ 3,500,000
	Feasibility Study (+AMDAL)	1	$ 500,000	wahyusoedibjo dkk, 2018	$ 500,000	0%	$ 500,000
	Total Exploration Cost						$ 53,980,491
Development Phase 1 Unit 1							
	Upstream						
	Land acquisition	1	$ 4,321,994	Civil team (FS)	$ 4,321,994	0%	$ 4,321,994
	Well pad construction	2	$ 1,250,000	Civil team (FS)	$ 2,500,000	0%	$ 2,500,000
	Access road construction	1	$ 3,981,299	Civil team (FS)	$ 3,981,299	0%	$ 3,981,299
	Development Drilling						
	Rig Mob+Demobilization	1	$ 3,450,045	EBTKE 2023	$ 3,450,045	0%	$ 3,450,045
	well drilling (8 Prod+ 4 injection well)	12	$ 7,652,996	Laporan 2019	$ 91,835,952	0%	$ 91,835,952
	well testing	5	$ 2,500,000	wahyusoedibjo dkk, 2018 (eskalasi	$ 12,500,000	0%	$ 12,500,000
	Skidding	2	$ 210,000	EBTKE 2023	$ 420,000	0%	$ 420,000
	Move from pad to pad	2	$ 500,000	PLN	$ 1,000,000	0%	$ 1,000,000
	Gathering and Separation system (SAGS)	1	$ 8,000,000	wahyusoedibjo dkk, 2018 (eskalasi	$ 8,000,000	0%	$ 8,000,000
	Overhead	1	$ 800,000	FS	$ 800,000	0%	$ 800,000
	Total Upstream Cost						$ 128,809,290
	Downstream						
	Land acquisition	45000	$ 150	Civil team (FS)	$ 6,750,000	0%	$ 6,750,000
	Access road construction	9798	$ 900	Civil team (FS)	$ 8,818,200	0%	$ 8,818,200
	EPC power plant	40	$ 100,000	wahyusoedibjo dkk, 2018 (eskalasi	$ 4,000,000	0%	$ 4,000,000
	Resources & Engineering Consnultant	20	$ 300,000	FS	$ 6,000,000	0%	$ 6,000,000
	Overhead	1	$ 10,000	10%*EPC power plant	$ 10,000	0%	$ 10,000
	Total Downstream cost						$ 25,578,200
	Total phase 1 cost						**$ 154,387,490**
Development Phase 2 Unit 2							
	Upstream						
	Land acquisition	1	$ 2,297,896	Civil team	$ 2,297,896	0%	$ 2,297,896
	Well pad construction	1	$ 10,408,621	Civil team	$ 10,408,621	0%	$ 10,408,621
	Access road & bridge construction	1	$ 8,925,369	Civil team	$ 8,925,369	0%	$ 8,925,369
	Development Drilling					0%	
	Rig Mob+Demobilization	1	$ 3,450,045	EBTKE 2023	$ 3,450,045	0%	$ 3,450,045
	well drilling (8 Prod+ 4 injection well)	7	$ 7,652,996	Laporan 2019	$ 53,570,972	0%	$ 53,570,972
	well testing	7	$ 500,000	wahyusoedibjo dkk, 2018 (eskalasi	$ 3,500,000	0%	$ 3,500,000
	Skidding	3	$ 210,000	EBTKE 2023	$ 630,000	0%	$ 630,000
	Move from pad to pad	3	$ 500,000	PLN	$ 1,500,000	0%	$ 1,500,000
	Gathering and Separation system (SAGS)	1	$ 8,000,000	wahyusoedibjo dkk, 2018 (eskalasi	$ 8,000,000	0%	$ 8,000,000
	Overhead	1	$ 800,000	FS	$ 800,000	0%	$ 800,000
	Total Upstream Cost						$ 93,082,903
	Downstream						
	Land acquisition	1	$ 2,811,167	FS	$ 2,811,167	0%	$ 2,811,167
	Access road construction	1	$ 641,814	FS	$ 641,814	0%	$ 641,814
	EPC power plant	1	$ 47,121,880	wahyusoedibjo dkk, 2018 (eskalasi	$ 47,121,880	0%	$ 47,121,880
	Resources & Engineering Consnultant	1	$ 3,500,000	FS	$ 3,500,000	0%	$ 3,500,000
	Overhead	1	$ 4,712,188	10%*EPC power plant	$ 4,712,188	0%	$ 4,712,188
	Total Downstream cost						$ 58,787,049
	Total phase 2 cost						**$ 151,869,952**
	TOTAL COST						**$ 306,257,442**
					Biaya Per MW		$ 7,656,436.05

Table 7 OPEX of Single Flash Tangkuban Perahu

OPERATION AND MAINTENANCE COST		
Operation and maintenance - Upstream	US$/kwh	0.007
Operation and maintenance - Downstream	US$/kwh	0.008
Overhead upstream	US$/kwh	0.001
Overhead downstream	US$/kwh	0.001
Sub total	US$/kwh	0.017
40 MW	US$	680
	US$/MWh	17
Major overhaul	US$ Mio	1
- Overhaul schedule	years	3
Workover	US$ Mio	1
- Overhaul schedule	years	3

After that Cashflow is calculated and presented as graph as seen in ***Figure 6***

Figure 6 Cash Flow Graphic of 2x20 Single Flash Tangkuban Perahu



. The project’s feasibility was assessed using the following indicators:

• NPV (Net Present Value): Calculates the net value of a project by discounting future cash flows to assess profitability. The project is viable if NPV is greater than 0 (positive).

• IRR (Internal Rate of Return): Measures the project’s investment return rate. It must exceed 10.01%, which is the Weighted Average Cost of Capital (WACC), to be deemed viable.

• PBP (Payback Period): Measures how long it takes to recover the project's initial investment cost.

IRR on Equity	Cent US$D/kWh		NPV	Payback (year)
	Y1-10	Y11-30		
5.71%	9.41	8.00	-85.8	16
7.62%	11.12	9.45	-50.2	13
8.93%	12.30	10.46	-25.6	11
10.31%	13.53	11.50	0.0	10
10.48%	14.00	11.90	9.8	10
11.13%	14.25	12.11	15.0	10
11.40%	14.49	12.32	20.0	10
11.67%	14.73	12.52	25.0	10
11.99%	15.00	12.75	30.7	10
13.15%	16.00	13.60	51.5	9

3 Result & Discussion

This study was conducted in a greenfield area within the Tangkuban Parahu geothermal working area. Drilling was previously carried out at well K-3 in the Kancah region, but it failed due to the drill bit getting stuck at a depth of 612 meters. As a result, all simulations in this study rely on 3G survey (geological, geophysical, and geochemical). Those data obtained by PT PLN in collaboration with PT New Quest. In the future, exploration drilling is necessary to obtain well data, which will greatly support for both reservoir and power plant analysis and simulations.

This research simulated a geothermal power plant with a capacity of 20 MW. The geothermal fluid supply in this WKP is estimated to have a temperature of 177°C and a pressure of up to 10 bara. The WKP is also estimated to have a mass flow rate of approximately 141 kg/sec.

The results of this study are expected to serve as valuable input for the ongoing development project of the Tangkuban Parahu geothermal power plant.

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