Evaluation of Ulumbu Geothermal Development Drilling Trough Expected Monetary Value Analysis

M Burhanuddin Aulia Asy'ari[1,2], Suryantini[1], M. Ali Ashat[1] & Yodha Yudhistra Nusiaputra[2]

[1]Geothermal Engineering Master's Program, Institut Teknologi Bandung, Indonesia
[2]Geothermal Division, PT PLN (Persero) Head Office, Jakarta-Indonesia
Email: burhanuddin.aulia@pln.co.id

Abstract. PT PLN (Persero) plans to drill 10 wells for the development of Ulumbu Geothermal Power Plant (Unit 5, 20 MW), consisting of 5 production wells, 2 contingency wells, and 3 reinjection wells. This campaign includes semi-exploratory drilling in the Lungar area, believed to be the main upflow zone, and proven reservoir drilling in the Wewo area. The decision between starting in Lungar or Wewo requires quantitative analysis using Expected Monetary Value (EMV), factoring in Probability of Success (POS). The EMV analysis showed that drilling from the Wewo area, with a higher POS due to proximity to the proven reservoir, is the optimum alternative. Drilling in Lungar will follow to delineate and confirm a larger geothermal prospect, potentially supporting the development of PLTP Unit 6 (20 MW). By balancing the drilling risks and rewards, the strategy aims to maximize the success of the campaign and ensure the completion of Unit 5 planned capacity.

Keywords: *decision tree, expected monetary value, project economics.*

1 Introduction

The Ulumbu geothermal field is a Geothermal Working Area (WKP) owned by PT PLN (Persero) ("PLN") which is located in the southern part of Flores Island (Figure 1) which is administratively located in Satar Mese District, Manggarai Regency, East Nusa Tenggara Province. Currently, the Ulumbu geothermal field has Power Plant Unit 1-4 (4 x 2.5 MW) which has been operating since 2012 and 2014, each with a capacity of 5 MW as stipulated by Triyono, *et al.* in [1]. This Power Plant gets its steam supply from one of the three existing wells located in the Wewo area, namely the ULB-2 well.

In this development phase of the Unit 5, PLN will conduct a drilling campaign, namely drilling development wells for 20 MW power plant with a total of 10 wells, consisting of 5 production wells (5 MW/well), 2 contingency wells (success rate 70%), and 3 reinjection wells. The drilling to be carried out is not purely development/exploitation drilling, but can be categorized as semi-exploration considering that there are Lungar prospect areas where there are no existing wells such as in the Wewo area.

Received ________, Revised _________, Accepted for publication __________
 ISSN: xxxx-xxxx, DOI: 10.5614/xxxx

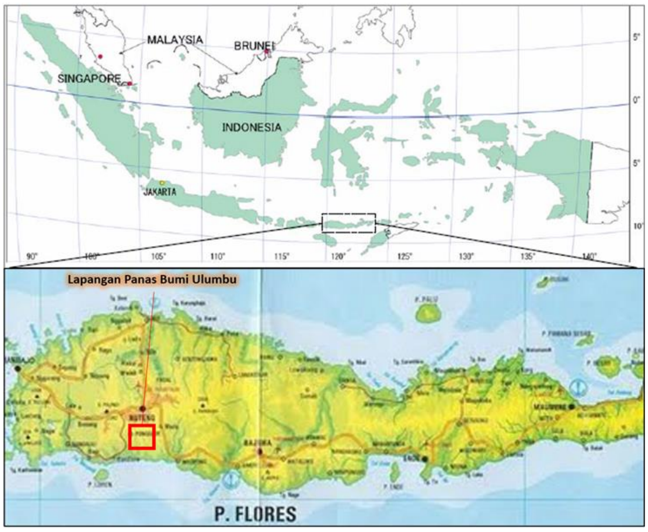

Figure 1 Location of Ulumbu Geothermal Field

In the conceptual model by West JEC and PLN [2], the Lungar area is suspected to be the main upflow area in the Ulumbu geothermal field. According to LAPI ITB and PLN [3], the prospective area of the Lungar area is larger than the Wewo area. However, in the Wewo area there is a proven reservoir from existing wells that have been commercially produced since 2012.

There are two alternative decision trees mentioned by West JEC [4], namely drilling starting from the suspected main upflow area in Lungar or a step out strategy from the proven reservoir area in Wewo first. ISOR-Rigsis and PLN [5] recommend a drilling sequence starting from the Wewo area which is closer to the proven reservoir area. However, to increase the likelihood of success in this drilling campaign, a study is needed to determine the most optimal alternative decision tree for the Ulumbu Unit 5 (20 MW) Geothermal Power Plant. The decision tree selection is expected to be done quantitatively by calculating the expected monetary value for each decision tree alternative that considers the probability of success aspect and the NPV calculation for each branch of the decision tree.

West JEC [4] has tried to calculate the expected monetary value for both decision tree alternatives. However, the expected monetary value figures produced showed negative values, namely -6.618 million USD for the drilling decision tree alternative starting from the Wewo area and -8.852 million USD for the drilling decision tree alternative starting from the Lungar area. Several things that might cause this negative value include:

1. Low electricity price,

2. Low MW capacity per well, and
3. High capital expenditure and/or operational expenditure.

Based on Project Management Institute [6], a negative expected monetary value indicates that the project has a threat or tendency to incur losses. For this reason, it is necessary to recalculate the project's economics for each branch of the decision tree scenario with careful selection of parameters and assumptions so that a new expected monetary value is produced as a comparison to the old negative expected monetary value. This expected monetary value analysis can also determine which decision tree alternative is more recommended.

2 Expected Monetary Value Analysis Method

One method used to determine the feasibility of a project is through the Expected Monetary Value (EMV) analysis. Project Management Institute [6] explained that EMV analysis is a statistical concept that calculates the average result when what happens in the future includes scenarios that may or may not occur. This method can be used to select the most optimal alternative choices in terms of financial impact to manage risk. To calculate EMV, probability and impact are required. The calculation can be done by multiplying the probability by the impact, which will produce the EMV value by by adding up all the multiplication results.

This EMV method can also be used to determine the EMV value in the geothermal well drilling decision tree to determine the most optimal alternative decision tree choices. The probability value can be taken from the results of the Probability of Success (POS) analysis of the well. Meanwhile, the impact value can be taken from the Net Present Value (NPV) value of the results of economic calculations using a financial model that takes into account investment costs, operating and maintenance costs, revenue, and others. Saptadji [7] explains that the calculation of the economics of geothermal prospects can be done by:

1. Calculating revenue, namely revenue from electricity sales.
2. Determining operating costs, depreciation costs, interest costs, and others.
3. Calculating the amount of taxable income or taxable profit, namely (1) minus (2).
4. Calculating the amount of tax that must be paid, namely (3) times the corporate tax rate.
5. Calculating the amount of net profit, namely (3) minus (4).
6. Determining cash flow.
7. Determine economic parameters: NPV, Rate of Return, Pay Out Time.

NPV is the difference between the present value of total revenue and the present value of expenditure throughout the life of the project at a given discount rate.

So, this is the calculated value of expenditure and income during the course of the project whose value is projected to a reference year. An investment or project is said to be feasible if the NPV> 0. The greater the NPV value, the greater the profit from the project.

3 Literature Study

3.1 Conceptual Model

West JEC and PLN [2] conducted a review study of geological, geochemical, and existing well data, as well as processing and analysis of the latest gravity and MT geophysical data acquired in 2021. From this study, a conceptual model of the Ulumbu geothermal field was obtained as in Figure 3. The Lungar reservoir is depicted as connected to the Wewo reservoir. The upflow zone is in Lungar. The upflow fluid in Lungar will then flow laterally towards SW (Wewo), S, SE, and potentially towards NW at depth. At an elevation of around 0 masl, the liquid will become steam, forming a steam cap, and triggering the presence of steam heated waters features, both in Lungar and Wewo. Steam also moves laterally to Wewo and produces steam heated waters and fumaroles. In this model, it is not mentioned that the Ulumbu (Wewo) crater is an upflow.

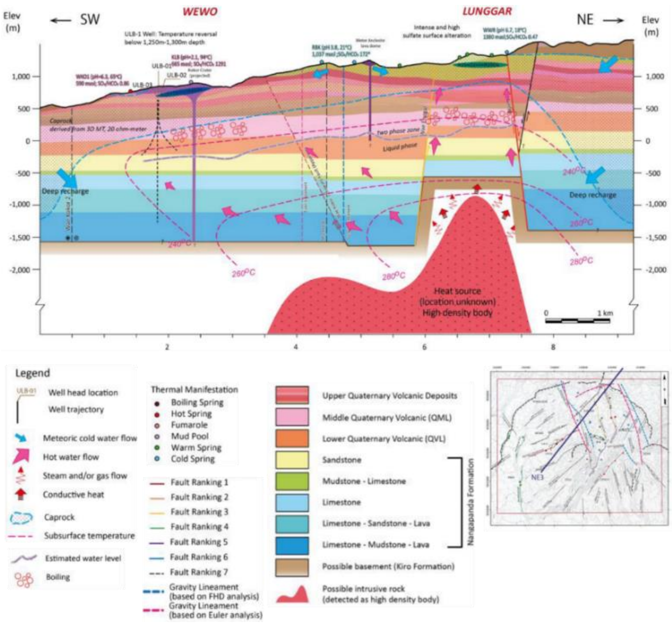

Figure 2 Cross-section of the Ulumbu Geothermal Field Conceptual Model by West JEC and PLN [2]

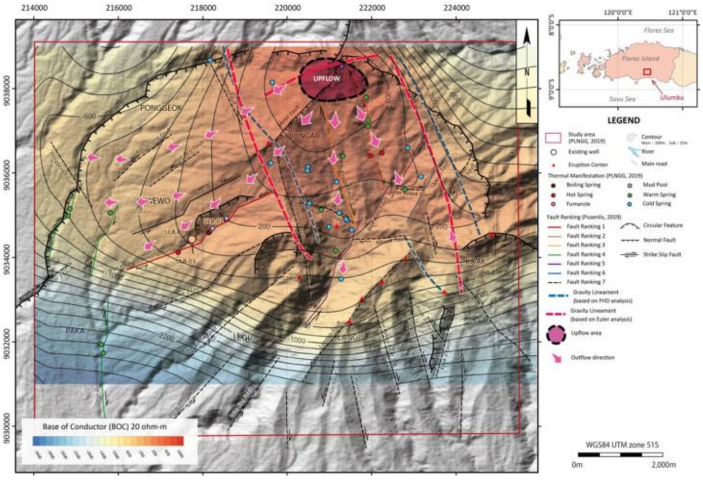

Figure 3 Ulumbu Conceptual Model Map by West JEC and PLN [2]

Figure 4 shows a conceptual model map of the Ulumbu geothermal field. This map is based on the Base of Conductor (BOC) elevation of 20 ohm-m, where the upflow area is indicated by a high BOC elevation in red, namely in the northern part of the Lungar area. West JEC and PLN [2] illustrated the direction of the outflow flowing from the upflow zone to the southeast, south, and southwest to the Wewo area.

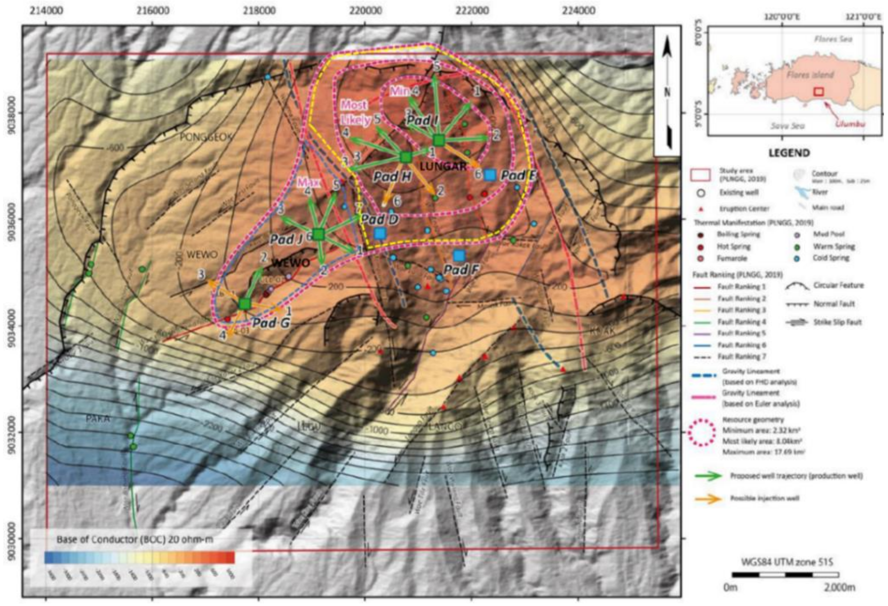

Figure 4 Well Targeting Options in Lungar Area (yellow dashed line) and Wewo Area (blue dashed line) illustrated by West JEC and PLN [2]

3.2 Well Targeting

Based on the study of West JEC and PLN [2] which has been peer reviewed by ISOR-Rigsis and PLN [5], well targeting options were obtained for drilling development wells for Ulumbu PLTP Unit 5 (20 MW) as shown in Figure 5. The Lungar area is represented by well targeting from Wellpad I and H. While the Wewo area is represented by well targeting from Wellpad J and G. Wellpad F is planned to be used for reinjection wells. While Wellpad D and E are potential additional Wellpads for the further development of Unit 6 (20 MW).

3.3 Decision Tree Alternatives

There are two alternatives of decision tree recommended by West JEC [4]. Alternative 1 is to start drilling from the Lungar area, which is the initial recommendation from West JEC which considers the Lungar area as the main upflow area in the conceptual model. Alternative 2 is to start drilling from the Wewo area, which is located near the existing production well (proven reservoir).

West JEC [4] assumes the Probability of Success (POS) of drilling a well near a well that has been proven productive in this case is 80%. While the POS of drilling a well in an area where there is no productive well nearby or targeting a fault that is different from the existing productive well is 50%. If drilling in a new area is successful, the POS of subsequent drilling in that area will increase to 80%. Successful well drilling will produce 5 MW/well.

In the Alternative 1 decision tree (Figure 8), drilling starts from the ULB-I1 well targeting the Wae Wara Fault (2nd rank fault) in the Lungar area. If the ULB-I1 well is successful, the second drilling will be continued on the same wellpad, namely the ULB-I6 well which also targets the Wae Wara Fault. If the ULB-I1 well fails, the second drilling will be continued with the ULB-H1 well targeting the Wae Engal Fault (3rd Rank Fault). And so on. In the Alternative 1 decision tree, there are several yellow branches indicating that drilling will be stopped at a certain number of wells due to more than one failure.

In the Alternative 2 decision tree (Figure 9), drilling starts from the ULB-J1 well targeting the Wae Kokor Fault (1st rank fault) in the Wewo area. If the ULB-J1 well is successful, the second drilling will be continued with the ULB-I1 well targeting the Wae Wara Fault (2nd rank fault) in the Lungar area. If the ULB-J1 well fails, the second drilling will be continued with the ULB-I6 well targeting the Wae Wara Fault (2nd rank fault). And so on. In the Alternative 2 decision tree, there are also several yellow branches indicating that drilling will be stopped at a certain number of wells due to more than one failure.

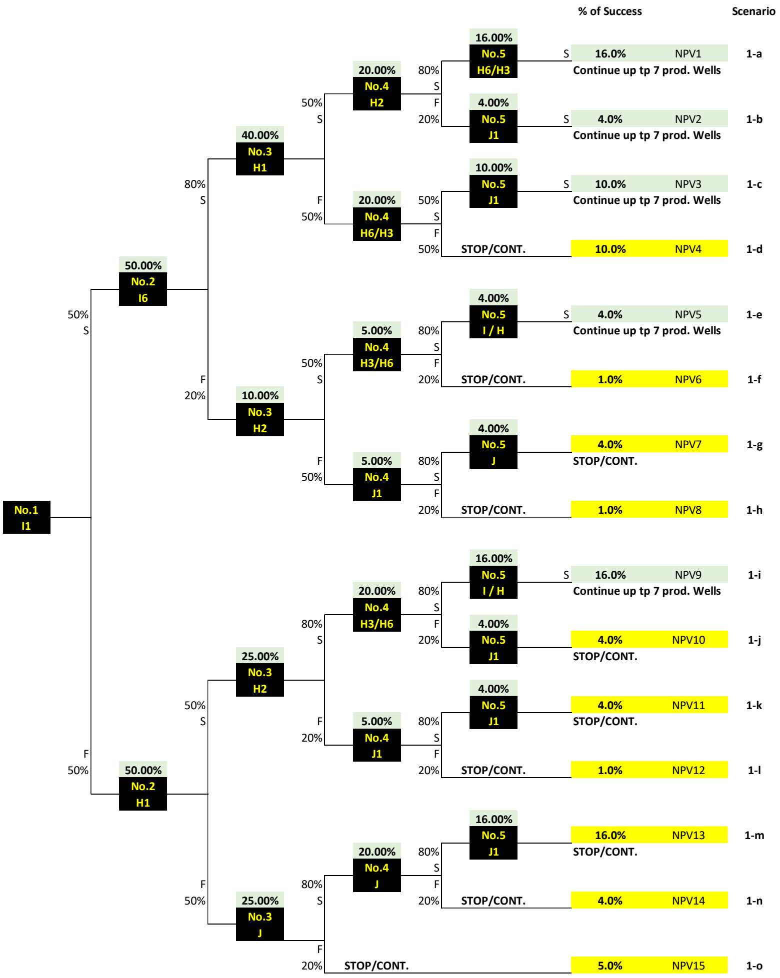

Figure 5 Decision Tree Alternative 1 (Drill Lungar First) by West JEC [4]

4 Pros and Cons Analysis

Several considerations related to the pros and cons of drilling in Lungar and Wewo areas are shown in Table 1. It can be seen that both options (Wewo First and Lungar First) have their own pros. The pros for the Wewo First option are considered more convincing because it has a higher POS and is close to the existing production well. The main upflow in Lungar is heavier as indicated by the MT survey results but has not been proven through well drilling, while we know that the geophysical survey results have uncertainty or ambiguity.

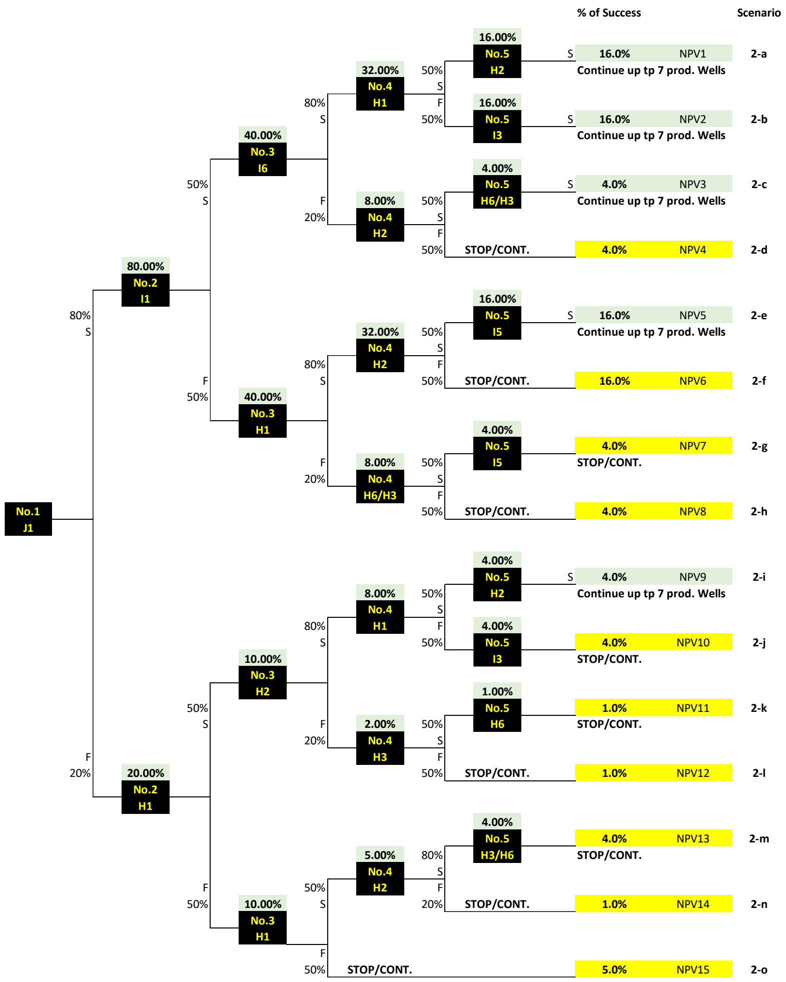

Figure 6 Decision Tree Alternative 2 (Drill Wewo First) by West JEC [4]

The only cons of the Wewo First option is the possibility that the Wewo reservoir is not sufficient for the development of a 20 MW PLTP capacity. However, this can be anticipated by continuing to drill to Lungar, but not in the first well in the drilling campaign. Mwangi [8] stated that appraisal drilling should not be stepped out too far apart from the discovery exploration well and such step-out wells might destroy confidence in the prospect by being unproductive. Therefore, the author is of the view that drilling in Wewo first is a better alternative.

Table 1 Pros and Cons of Drilling in Lungar and Wewo Area.

Analysis	Pros	Cons
Wewo First	• Close to reservoir proven by existing production wells that produce steam to the power plant so far. • Close to Ulumbu fumarole/solfatara steam manifestations. • Geological structure near the ULB-02 well that is permeable (1st Rank Fault). • Larger well drilling POS.	• P90 (low case) in Wewo based on LAPI ITB and PLN [3] is 11.9 MW, which means that there is a possibility that the Wewo reservoir alone is not sufficient for the development of the Ulumbu Unit 5 Geothermal Power Plant (20 MW)
Lungar First	• In the conceptual model, it is suspected to be the main upflow indicated by the updoming Bottom of Conductor (BoC) from the MT survey. • There are geological structures ranked 2 and 3. • If proven productive, it will confirm a larger area. Can be the basis for the development of the next Unit.	• New area, not yet proven by wells. • No fumarole/solfatara manifestations. • No boiling manifestations. • Smaller well drilling POS.

5 Input Parameters

5.1 Electricity Price

Electricity price is a parameter that greatly influences the calculation of NPV on the economics of a project. The negative EMV value calculated by West JEC [4] is very likely due to the low electricity price. The West JEC report [4] does not state the assumption of the electricity price used. The author suspects that the electricity price used by West JEC is Rp1,579/kWh according to the Decree of the Minister of Energy and Mineral Resources concerning the assignment to PLN for geothermal business activities in the Ulumbu Geothermal Working Area. In fact, the electricity price is only for calculating production bonus payments and production fees.

Based on one of the project feasibility studies at PLN, the price of electricity sourced from the Diesel Power Plant is around Rp3,334/kWh. This electricity price can be used to calculate the NPV avoided cost for the economics of the Ulumbu PLTP project which will later replace the PLTD.

5.2 Well Capacity (MW/Well)

West JEC and PLN [2] stated that the monitoring data of mass flow rate and wellhead pressure of production wells after commissioning the existing power plant, showed a stable 5 MW power output during the period from 2012 to 2014. However, when the installed capacity increased to 10 MW from 5 MW in 2014, the power output did not reach 10 MW but retained about 7 MW, showing the possibility that the steam reservoir in Wewo area might not have sufficient sustainability to keep 10 MW. Even though the power output maintained about 7 MW, the wellhead pressure of ULB-2 showed a continuous decline trend over time, showing that ULB-2 might not sustainably maintain 7 MW. Therefore, in order to avoid overestimation of the future wells sustainability, an average power output should be estimated at 5 MW per well for the drilling strategy. In addition, considering that there is no data of the reservoir properties such as temperature and permeability in Lungar, 5 MW per well is assumed conservatively and based on the average well productivity in Indonesia written by Eko-Purwanto et.al. [9] also aiming to avoid over estimation. Therefore, assuming a drilling success of 70%, West JEC and PLN [2] assessed that 7 production wells should be drilled to achieve 20 MW (5 MW/well x 5 successful wells with 25% excess power, and 2 uncommercial wells).

However, based on the net MW capacity estimate by Sanyal, et.al. [10] modified with an ambient temperature of 30°C (Figure 10), in the temperature range of 220-240°C, the possible well capacity produced is 5 MW/well or more, except at a temperature of 220°C with the smallest Productivity Index (PI) of 2 l/s/bar which produces a well capacity of around 4 MW/well. Therefore, the selection of a capacity of 5 MW/well in this case can be considered conservative, but on the other hand it is also quite good for carefulness avoiding over estimation. This 5 MW/well assumption is quite matched with PI of 3.3 l/s/bar and temperature of 230°C. However, if in reality the capacity exceeds 5 MW/well, this capacity can be a reserve for further development, namely Unit 6 (20 MW) and for make up well reserves.

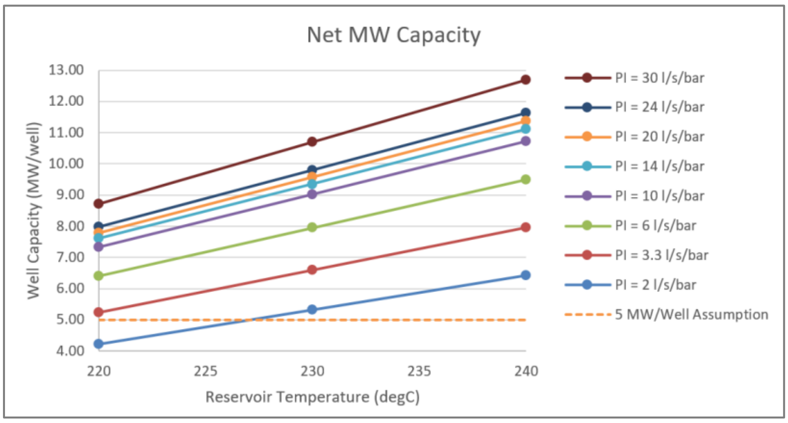

Figure 7 Net MW Capacity at Ambient Temperature of 30°C, modified from Sanyal, et.al. [10]

5.3 Reinjection Wells

In terms of reinjection wells, West JEC and PLN [2] mentioned that 2 injection wells allocation is adequate as long as the deep reservoir is steam dominated or two-phase (mixture of steam and liquid water). In this case, 2 reinjection wells will be enough to dispose steam condensate and a small amount of brine. However, it must be considered the possibility that the deep reservoir may not be a steam-dominated or two-phase but liquid-dominated. In this case, the projected number of reinjection wells may be insufficient, because the mass flow rate of brine produced with steam is roughly estimated to be 4 times of the steam mass flow rate required for a 20 MWe power generation. Assuming the steam consumption rate of a steam turbine is 7.5 t/h/MWe, the steam mass flow rate required for generating 20 MWe is estimated to be 150 t/h (=7.5 t/h/MWe x 20 MWe). Accordingly, the brine mass flow rate for reinjection is roughly estimated to be around 600 t/h (=150 t/h x 4). The mass flow rates of brine can be calculated by assuming the reservoir temperature and separator pressure. For example, Figure 11 shows the steam flow rates, brine flow rates and total mass calculated by assuming the possible temperature range from 240°C to 280°C and separator pressure of 8.0 kscg (7.8 barg) in Ulumbu field. NCG is not assumed in this calculation.

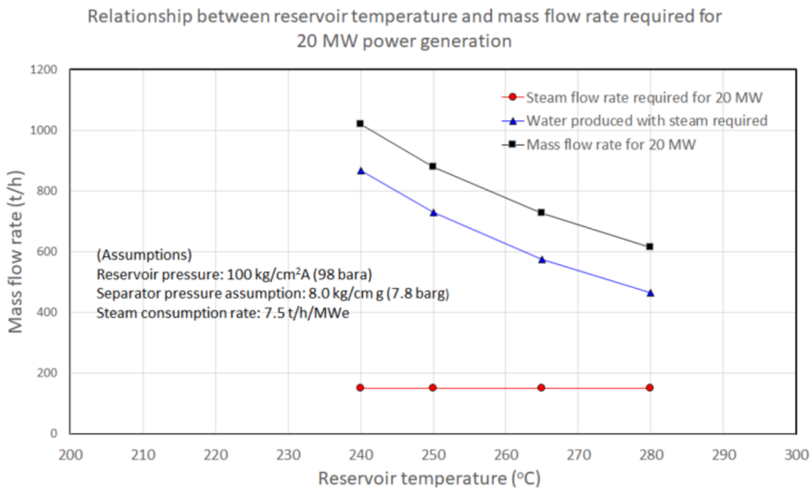

Figure 8 Total steam and brine mass flow rates of wells estimated by assuming the possible reservoir temperature range and separator pressure in the Ulumbu field calculated by West JEC and PLN [2]

If we assume that the average injection capacity of reinjection well is around 300 t/h/well, it is necessary to drill 2 or 3 reinjection wells to dispose the brine of 500 t/h to 900 t/h produced with steam required for generating 20 MWe. Therefore, we plan 3 injection wells to be drilled for the development phase of Unit 5 (20 MW).

5.4 Capital Expenditure

Each scenario shown in Figures 8 and 9 has its Capital Expenditure determined. This Capital Expenditure is calculated considering the number of wells drilled (both successful and failed), as well as the cost of surface facilities for generating and SAGS according to the capacity that can be generated based on the capacity of the wells obtained. Reference of the Capital Expenditure is taken form Wahjosoedibjo and Hasan [11] and average of development well cost based on Drilling Guidance Book by Ministry of Energy and Mineral Resources. Capital Expenditure for all scenarios are shown in Table 2.

For scenarios 1-a and 2-a, all 7 production wells were successfully drilled, resulting in a total capacity of 35 MW. This was followed by the drilling of 3 reinjection wells. The generating capacity developed for Unit 5 remains at 20 MW. Excess capacity will be compensated for by the delay in the need for make-up wells.

Table 2 Capital Expenditure for All Scenarios (in USD).

Scenario	1-a, 2-a, 1-b, 1-c, 1e, 1-i, 2-b, 2-c, 2e and 2-i	1-d, 1-f, 1-g, 1-j, 1-k, 1-m, 2-d, 2-f, 2-g, 2-j, 2-k and 2-m	1-h, 1-l, 1-n, 2-h, 2-l and 2n	1-o and 2-o
Geoscience Study	1,236,570	1,236,570	1,236,570	1,236,570
Drilling Infrastructure, Land, & Permit (Exploration)	6,621,835	6,621,835	6,621,835	6,621,835
Feasibility Study	656,129	656,129	656,129	656,129
Drilling Infrastructure, Land, & Permit (Development)	13,243,670	13,243,670	13,243,670	13,243,670
Rig Mobilization-Demobilization	2,573,056	2,573,056	2,573,056	2,573,056
Production Well Drilling	53,834,458	30,762,547	30,762,547	23,071,910
Injection Well Drilling	23,071,910	15,381,274	15,381,274	0
Gathering & Separation System	21,416,059	12,715,785	6,357,892	0
EPC Power Plant	50,863,140	26,770,074	13,385,037	0
Well Testing	3,859,584	2,315,750	2,315,750	1,157,875
Total Cost	**177,376,411**	**112,276,690**	**92,533,761**	**48,561,046**
Total Cost per MW	**8,868,821**	**11,227,669**	**18,506,752**	-

Scenario 1-b, 1-c, 1e, 1-i, 2-b, 2-c, 2e and 2-i show that 4 out of the first 5 wells drilled are productive. After that, drilling is continued with the success of 2 more production wells and 3 injection wells. The generating capacity developed for

Unit 5 remains at 20 MW. Excess capacity will be compensated by the delay in the need for make up wells.

In scenario 1-d, 1-f, 1-g, 1-j, 1-k, 1-m, 2-d, 2-f, 2-g, 2-j, 2-k and 2-m, from the first 4 wells drilled, only 2 production wells were successful. This means that the capacity obtained is only 10 MW. Next, 2 injection wells are allocated to be drilled with at least 1 successful injection well. The generating capacity developed for Unit 5 is adjusted to 10 MW.

The next scenario is scenario 1-h, 1-l, 1-n, 2-h, 2-l and 2n where from the drilling of the first 4 wells, only 1 production well is successful. This means that the capacity obtained is only 5 MW. Next, 2 injection wells are allocated to be drilled with at least 1 successful injection well. The generating capacity developed for Unit 5 is adjusted to 5 MW.

The last scenario is scenario 1-o and 2-o where the first three wells drilled all fail and it is decided to stop the project.

5.5 Operational Expenditure

The Operational Expenditure used refers to Wahjosoedibjo and Hasan [11], namely the total cost of operation and maintenance (steam field and power plant), overhead cost, workover, and plant overhaul. Table 3 shows the Operational Expenditure in 2030 which is escalated per year by 2%.

Table 3 Operational Expenditure

Capacity	**5-10 MW**	**20 MW**
Total O&M: steam field and power plant (US cent/kWh)	2.03	1.9
Overhead cost (US cent/kWh)	0.25	0.25
Workover (Million USD/year)	0.21	0.21
Plant overhaul (Million USD/year)	0.21	0.21

5.6 Make Up Well

In estimating the need for make up wells, the assumption of decline rate ~4% per year is used, taken from the study of Widiatmoro and Nusiaputra [12]. The replacement rate or number of make up wells drilled in one drilling campaign is 3 wells. Considering the condition of steam availability in each scenario, the make up well drilling schedule is shown in Figure 12.

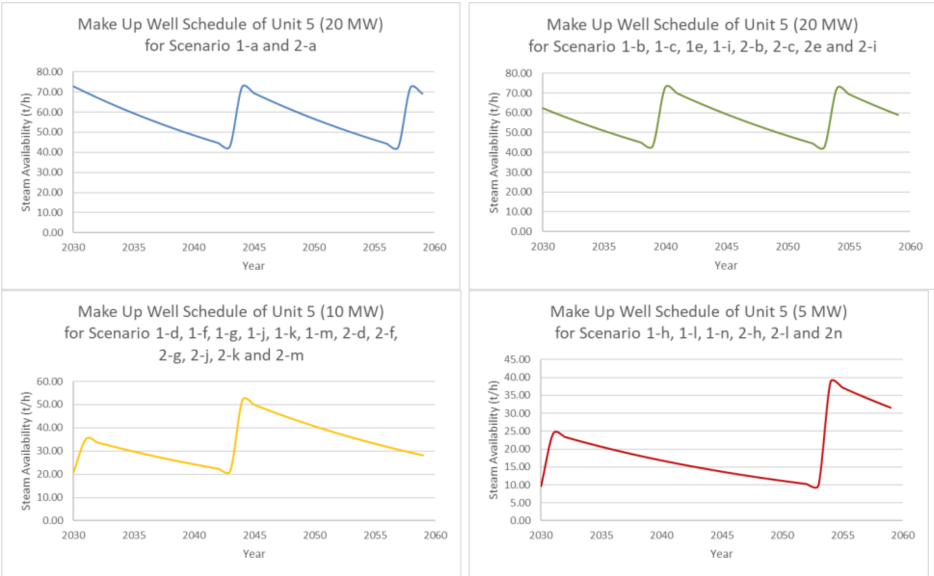

Figure 9 Make Up Well Schedule for All Scenariosa

5.7 Other Assumptions

Other assumptions used can be seen in Table 4.

Table 4 Others Assumptions

Parameter	Value	Unit
Capacity & Availability Factor	95	%
Exchange Rate	15,500	IDR/USD
Equity Financing	30	%
Loan Financing	70	%
Interest Rate	6.4	%
Repayment Schedule	15	Years
VAT	12	%
Depreciation	8	Years
Income Tax Rate	20	%
NJOP Panas Bumi	10.04	x 1 year revenue
NJKP	40%	x NJOP
PBB Panas Bumi	0.5	x NJKP
Production Bonus	0.5	%
Production Fee	2.5	%
Exploitation Fixed Fee	2	USD/ha/year
Inflation	2	%/year

6 Expected Monetary Value (EMV) Results

After the economic calculation for each scenario in the decision tree, then multiplied by the Probability of Success (%) for each branch, the total EMV value is obtained by adding the EMV in each scenario. The results of the EMV calculation for Decision Tree Alternative 1 can be seen in Figure 13. The EMV-1 value is 25.57 million USD. This positive value indicates that this project has an opportunity and a tendency to be profitable or feasible.

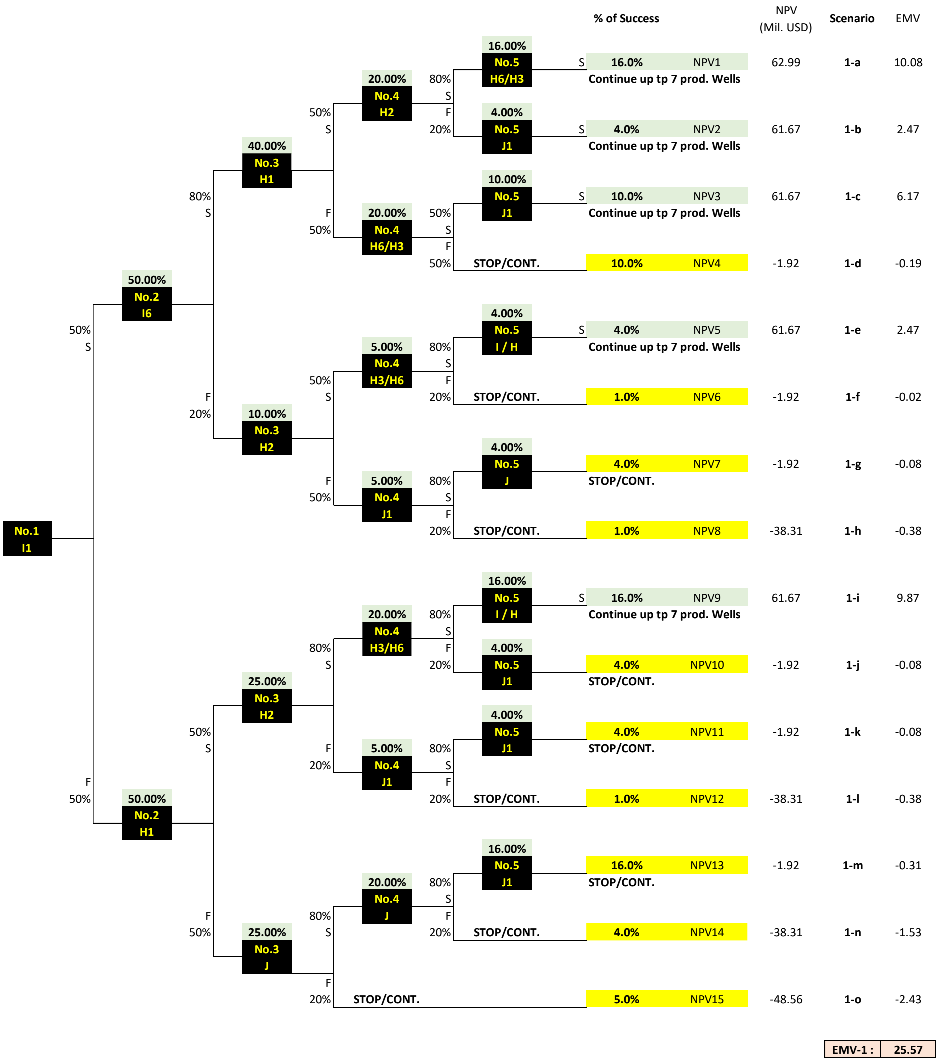

Figure 10 Calculation Result of EMV for Decision Tree Alternative 1

The results of the EMV calculation for Decision Tree Alternative 2 can be seen in Figure 14. A higher EMV-2 value of 29.39 million USD was obtained. This higher value indicates that this project has an opportunity and a tendency to be more profitable or more feasible. For this reason, the decision tree recommendation chosen is the one with a higher EMV value, namely Alternative 2, where drilling begins in the Wewo area first.

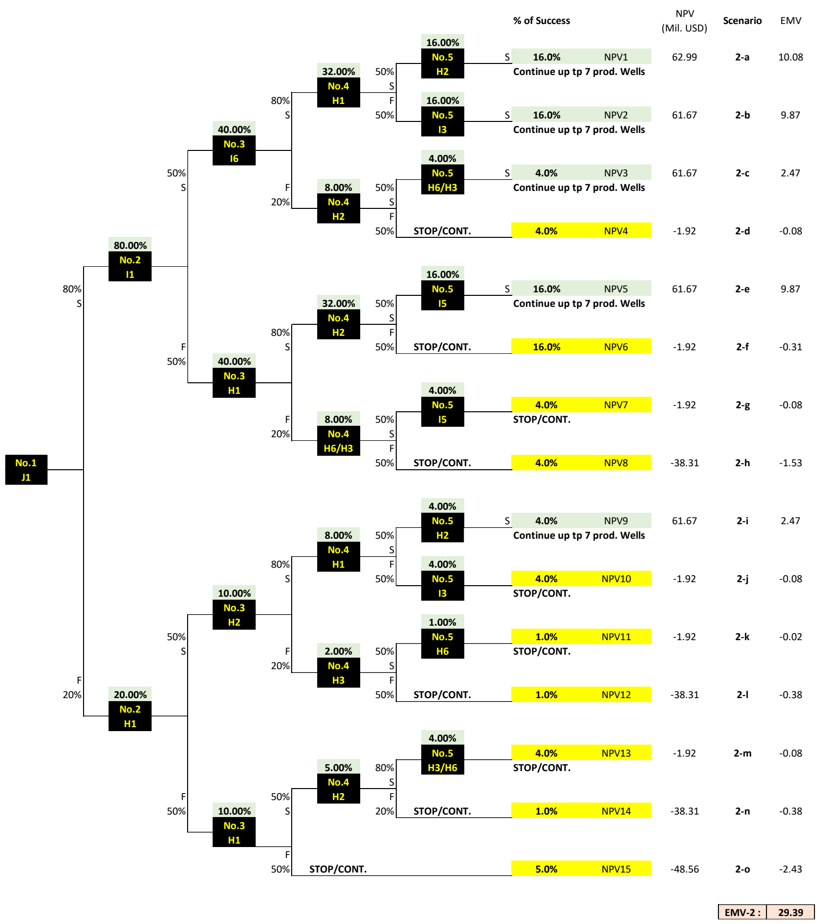

Figure 11 Calculation Result of EMV for Decision Tree Alternative 2

7 Conclusion

Based on the discussion above, the following conclusions can be drawn:

1. Based on the calculations made, the EMV value for both alternative decision trees result a positive number, namely EMV-1 value of 25.57 million USD

and EMV-2 value of 29.39 million USD shows that this project has an opportunity and a tendency to be profitable or feasible.
2. The recommended decision tree is the one with a higher EMV value, namely Alternative 2 where drilling begins in the Wewo area first.
3. The Alternative 2 risk of the possibility that the Wewo reservoir is not sufficient for the development of a 20 MW PLTP capacity is anticipated by continuing to drill to Lungar after Wewo.

8 Recommendation

It is recommended to exercise the EMV results if the well capacity is more than 5 MW/well, i.e. 8 MW/well considering the possibility of obtaining PI of 2 l/s/bar with temperature of 230°C or PI of 3.3 l/s/bar with temperature of 220°C.

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