Selection of Power Plant Management for De-dieselization Program of PLTD Kangean Using Analytical Hierarchy Process (AHP) and Goal Programming

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Abstract

Various challenges have been faced by PLN in carrying out its commitment to providing electricity to all corners of the archipelago and improving the reliability of services at affordable rates. Reduce the cost of supply (BPP) including by continuing to reduce the use of fossil fuel and optimizing cheaper primary energy sources in order to carry out the Government's mandate to maintain electricity prices to stabilize people's purchasing power, industrial competitiveness and target renewable energy (RE) in the energy mix by 2025 of at least 23%, a De-dieselization program was created. Several alternatives are offered in the form of isolated plant management models. Whether later the management of the plant will continue to be carried out by PLN or assignment to subsidiaries with Independent Power Producer (IPP) with Power Purchase Agreement scheme based on the calculation of the optimum Levelized Cost of Energy (LCoE). Decision making uses the AHP method as a quantitative weighting method from qualitative data by PLN management respondents which is integrated with the Goal Programming method. Based on the AHP weighting on the sub-criteria, it was found that the LCOE / BPP had the highest weight of 0.304 and the respondents' preference for alternative PV-Diesel (IPP) was 24.4% compared to other alternatives. Based on the integration of AHP-Goal Programming, the most optimal achievement vector value was obtained in the alternative PV-Diesel (PLN) with Min Z of 873.90 (4 of the 6 Goals achieved), IRR 11.53%, LCOE / BPP Rp 2,860 / kWh and EAF 93.28%.

Keywords
De-dieselization, Independent Power Producer, Levelized Cost of Energy, AHP, Goal Programming

1. Introduction
The availability of adequate electric power is one of the main basic infrastructures that have a major role in supporting the economic growth of a country. For PLN, the spirit to ensure that all areas in the country get an adequate supply of electricity is a form of support for the creation of prosperity. Efforts to reduce the cost of supply (BPP) continue to be carried out, including by continuing to suppress the use of fuel oil (BBM) and optimizing electricity production from cheaper primary energy sources in order to carry out the Government's mandate to maintain electricity prices in order to maintain people's purchasing power and power. industry competitiveness. PLN also continues to improve community access in Front, Outermost and Disadvantaged areas to obtain adequate electrical energy in terms of reliability and tariffs, one of which is the archipelago in Madura which is included in the work area of PT PLN (Persero) Unit Induk Distribusi Jawa Timur. Along with the transformation of PLN, one of the four main themes is GREEN "Leading Indonesia's energy transition through rapid and efficient scale-up of renewables" and in line with the Government program which has set a target for the utilization of New Renewable Energy (EBT) in the energy mix

by 2025. a minimum of 23%, and increased to a minimum of 28% by 2038, a plan was made to reduce fossil fuel power plants to renewable energy through the De-dieselization program.

Researchers want to focus on research on the conversion of fossil energy into New and Renewable Energy (NRE) in the largest off grid system in Madura, namely PLTD Kangean. PLN itself has taken data on the possible sources of NREa in the Kangean Islands that can be used in the Dedieselization program. The measured EBT source is wind potential data at the Kangean PLTD location for the Diesel-Wind hybrid scheme which has a wind speed of 4.89 m/s. The wind speed is declared not to meet the requirements of IEC 61400-1 Wind Classification with a minimum wind speed that can be used as an energy source for power generation is 6 m/s (Bezrukovs et al., 2016). Meanwhile, data on the potential use of solar energy sources is data on solar radiation on Kangean Island at 5.0 kWh/m2/day or 1,831 kWh/m2/year.

In an effort to realize the Dedieselization program, there are several considerations in making the best decision. In general, this program has the objective of obtaining optimal power plant management in terms of cost, reliability (operation & maintenance) and risk criteria. In particular, this program has the objective of minimizing costs, maximizing operation-maintenance-asset management and minimizing delays in completion of project-primary energy intermittent. To obtain an optimal power plant management, 5 alternatives were compiled with 2 main themes, first the type of PV or Hybrid (PV-Diesel) and the manager by PLN, IPP or Hybrid (PLN-IPP). There are also limitations that are owned by the company based on the available resources such as LCoE, EAF and only 1 selected alternative.

In a multi-criteria decision-making process where there is qualitative and quantitative data and has many goals and there are limitations, the suitable methods are Multi Criteria Decision Making (MCDM) using Analytical Hierarchy Process (AHP) and Multi Objective Decision Making (MODM) using Goal Programming. The AHP method helps solve complex problems by structuring a hierarchy of criteria, stakeholders, in order to develop weights or priorities (Saaty, 1994). In general, Goal Programming is a mathematical approach model that provides optimal values for a series of variables where there are many conflicting objectives (Rahmadani & Ciptomulyono, 2011).

2. Literature Review

2.1 Life Cycle Cost (LCC)

The economic price of the PV electricity sales tariff is obtained by taking into account the overall costs required (Life Cycle Cost). There are two methods commonly used in calculating electricity tariffs, namely the Cost of Supply (COS/RoR) method known as backward looking and the Long Run Marginal Cost (LRMC) method known as forward looking. Through the Regulation of the Indonesian Minister of Energy No. 17 of 2013 regulates the procedure for purchasing electricity by PT PLN (Persero) from PV photovoltaic (US $ 25 – 30 sen/kwh) with a domestic consumption rate of 40%. The application of feed-in tariff prices from PV photovoltaic systems through the formulation of electricity purchase tariffs obtains a fit price range between Rp. 1,987/kWh – Rp. 4,503/kWH (Ashadi, 2012).

2.2 Levelized Cost of Energy (LCoE)

LCoE is a measure of costs which attempts to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCoE can also be regarded as the minimum cost at which electricity must be sold in order to achieve break-even over the lifetime of the project. The aim of LCoE is to give comparison of different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, different capital cost, risk, return, and capacities (Lai & McCulloch, 2016). The main cost components in the LCoE calculation include (1) Investment Cost / Capital Cost (CAPEX) which includes the purchase of equipment/technology and projects, (2) O&M costs include operation (fuel) and maintenance, (3) Capacity Factor which is the ratio of the amount of electricity generated divided by installed capacity and (4) Cost of Funding (Interest and WACC) includes the expected profit from investors as well as interest costs on debt (Arinaldo & Pujantoro, 2019). In previous research, the deployment of clean energy alternatives is clearly needed, but these must be selected systematically using multiple but possibly conflicting criteria. Currently, the decision on which technology to use is derived based on the levelized cost of electricity primarily (Ocon et al., 2018). Research on the Influence of Operation Expenditure on LCoE in Photovoltaic projects was conducted by (Muñoz-Cerón et al., 2018).

2.3 Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgements that represents, how much more, one element dominates another with respect to a given attribute. The judgements may be inconsistent, and how to measure inconsistency and improve the judgements, when possible to obtain better consistency is a concern of the AHP (Saaty, 2008). Investigation of the techno-economic feasibility of a hybrid system that consisting of solar photovoltaic, biogas, wind turbines, syngas and hydrokinetic energy is proposed to meet the demands of the city. They have used the Analytical Hierarchy Process to optimize energy generation costs and system area. They have also performed a sensitivity analysis of the system for changes in different system parameters (Chauhan et al., 2021). AHP can assist decision makers to evaluate a problem in the form of a hierarchy of references through a series of pairwise comparisons of relative criteria. Briefly, relative weights are determined through pair- wise comparison. The method can be applied by breaking down the unstructured complex scorecard problems into component parts. Based on AHP, solar electrical power plants have the potential to be the best type of system for electricity production in Jordan. They are followed by wind and then hydro-power plants. One can argue that all three technologies or any of the two combined can be used since they have close relative weights (Akash et al., 1999). The AHP method in the selection of renewable energy technology is used by (Ali et al., 2020) in Rohingya refugee camps in Bangladesh. The selection of a solar power plant investment project in Spain was researched by (Aragonés-beltrán et al., 2013) using AHP. (Rubio-Aliaga et al., 2021) used AHP for the selection of optimal groundwater pumping system.

2.4 Goal Programming

Goal programming is one of the methods which can provide understanding, or one can say it can help in solution of multiple objectives simultaneously. Goal programming consist of an objective function and a series of goals constraints. The objective function is set to minimize the deviation with the set of goals. The goal programming model has been used to determine the optimal value in Megawatt Hours (MWh) for all energy sources and optimal energy portfolio model is suggested for both economic and ecological sustainability (Jain et al., 2019). The objective of goal-programming is to minimize the deviations from the set targets. This is opposite to the linear and mixed-integer linear programming models, where the objective is to minimize or maximize the parameter itself. Goal programming is especially more beneficial in cases where all the constraints are difficult to meet (Hussain & Kim, 2020). Goal programming (GP) has been (and still is) the most widely used approach to solve MODM problems based on a 'satisfactory' and 'sufficient' philosophy. The purpose of GP is to minimize deviations between the achievement of goals and their aspiration levels (Hocine et al., 2018). Goal Programming is used by (Khan et al., 2021) to find the optimal solution to increase renewable electricity sources installed on hydro, PV and small hydro by having a lower LCoE than non-renewable energy.

2.5 Integration AHP-Goal Programming

Goal Programming cannot determine its own priorities and decision-making criteria that it wants to fulfill and a number of intangible or non-finance factors cannot be measured or optimized directly with Goal Programming (Ansori & Ciptomulyono, 2005). AHP also has a number of limitations, among others, the dependence of this model on input in the form of expert perceptions which will affect the final result, so this model is meaningless if the expert gives the wrong perception. Besides, AHP cannot be used to solve optimization problems (Ansori & Ciptomulyono, 2005). Considering several weaknesses in each approach, this research will offer an integrated approach between Analytical Hierarchy Process and Goal Programming to choose alternative generator management by accommodating many objective functions by considering many criteria. (Ciptomulyono, 2006) has also conducted research on decision support models for the selection of power plant projects by integrating AHP and Zero-One Goal Programming. (Jain et al., 2019) used integration of Fuzzy AHP and Goal Programming to set goal optimization for electricity management.

3. Methods

Through the AHP method, a survey was conducted on 6 respondents from PLN management in East Java where these experts have experience in the field of power generation. The main steps to solve an MCDM problem using AHP are the following☹ (Figure 1)

1) Determine the problem and determine the expected solution
2) Create a hierarchical structure with general objectives, criteria, sub-criteria and alternative choices in sequence.

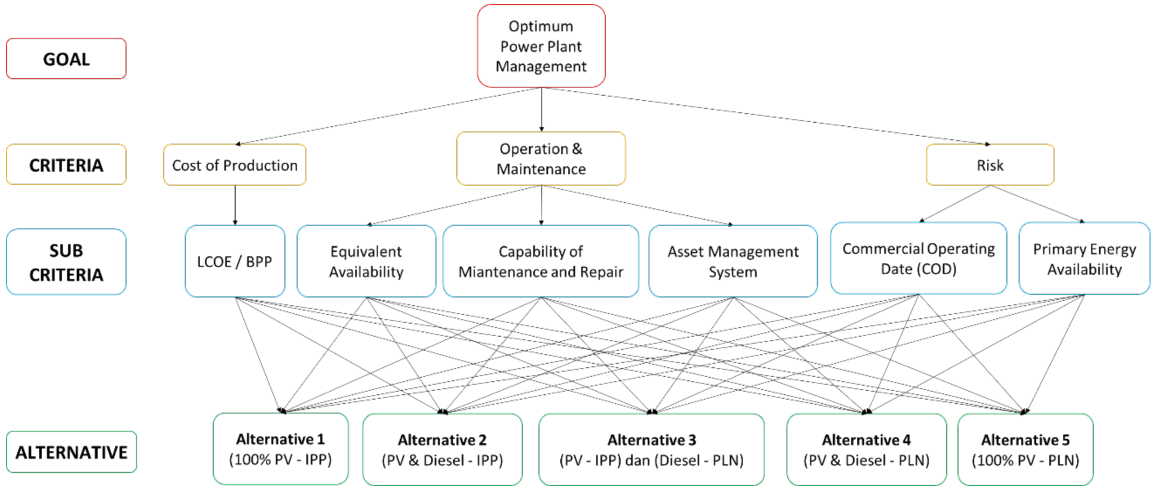

Figure 1. AHP Hierarchy of Goal, Criteria and Alternative

3) Forming a pair wise comparison matrix that describes the relative contribution to each goal or criterion at the level above. (Figure 1) Comparisons are made on the choices of decision makers by comparing between elements.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, \text{where } a_{ji} = 1/a_{ij} \;\; i,j = 1, \ldots, n$$

Figure 2. Pairwise Comparison Matrix

The priorities vector is obtained from the pairwise comparison matrix A. (Figure 2)

Table 1. Saaty's Fundamental Scale

Intensity of importance	Definition
1	Equal importance/preference
2	Weak
3	Moderate importance/preference
4	Moderate plus
5	Strong importance/preference
6	Strong plus
7	Very strong or demonstrated importance/preference
8	Very, very strong
9	Extreme importance/preference

4) Normalize the data by dividing the value of each element in the paired matrix by the total value of each column.
5) Calculate the eigenvector value and test its consistency.
6) Repeat steps 3, 4 and 5 at each level in the hierarchy.
7) Calculate the eigenvector value of each pairwise comparison matrix.
8) Test the consistency of the hierarchy. If it does not meet the CR 0.100, the assessment must be repeated.

$$CI = \frac{(\lambda_{maks} - n)}{(n-1)} \quad \textbf{(Eq. 1)} \qquad\qquad CR = \frac{CI}{RI} \quad \textbf{(Eq. 2)}$$

The RI (Random Index) is an experimental value which depends on n. If CR is less than a threshold value then the matrix can be considered as having an acceptable consistency, and the derived priorities from the comparison matrix are meaningful. (Table 2)

Table 2. Random Index Values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

After using the AHP method, the next step is to use the Goal Programming method to create a mathematical model of the objective function, constraint. To formulate any of the GP models following steps that can be found in Goal Programming : Methodology and Applications (Schniederjans, 1995) are (1) define the decision variables, (2) state the constraints, (3) determine the preemptive priorities if need be, (4) determine the relative weights if need be, (5) state the objective function, (6) state the non-negative or given requirements. (Figure 3)

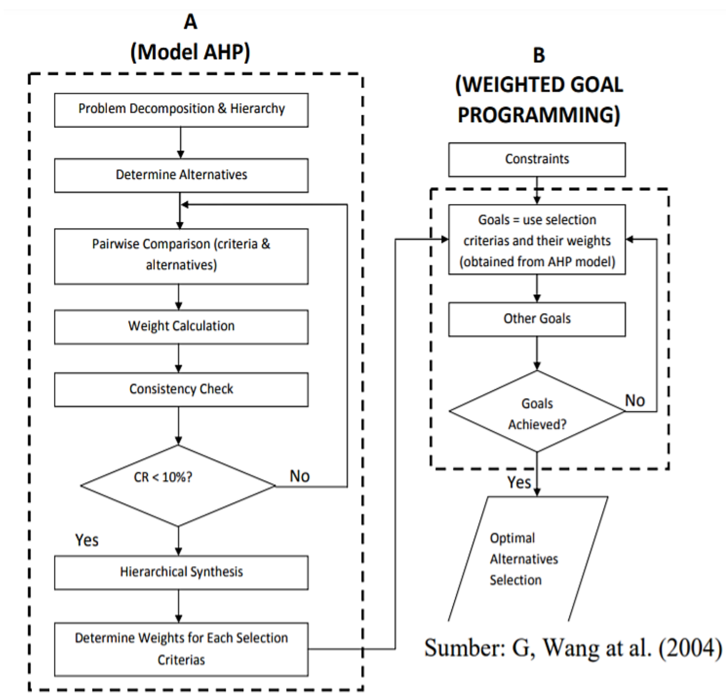

Figure 3. Integration Flowchart of AHP and Goal Programming

The decision variable used is the selection of 1 generator manager from the 5 alternatives given.

X_i : Decision variable to choose power plant management

i : 1, 2, 3, …, n

n_j : The negative variable (under achievement) at the level value that becomes the aspiration of the objective function j

p_j : The positive variable (over achievement) at the level value that becomes the aspiration of the objective function j

Parameters quantitatively assessed data used in this study include:

r : Interest rate considered (%)

t : System life (years)

LCC : Life Cycle Cost (Rp)

E_t : Total electricity generation (kWh)
COE_{max} : Maximum Cost of Energy (Rp/kWh)
EAF : Equivalent Availability Factor (%)
PH : Planned Hours
POH : Planned Outage Hours
UOH : Unplanned Outage Hours
EDH : Equivalent Derating Hours

Each weighting parameter is assessed qualitatively based on the preferences and judgments of the sources involved in this study. The index used for each weighting includes:
CMAR : Coefficient of Maintenance and Repair
CEAM : Coefficient of Enterprise Asset Management
CCOD : Coefficient of Commercial Operating Date
CIRE : Coefficient of Intermittency of Renewable Energy

The mathematical model formulation for each multi-objective function for the selection of power plant management in the format of an objective-goal programming model consisting of an objective function sub criteria and a goal objective. The constraint functions formulated are categorized as “rigid” constraint functions that must be met in the search for solutions. (Table 3 & 4)

Table 3. Mathematical Formulation of Objective Function

No	Objective Function Sub Criteria	Goal Objective
1	Minimize LCOE/BPP $\sum_{i=1}^{5} LCC_i \left[\frac{1}{(1+r)^t}\ \frac{(1+r)^t}{E_{ti}}\right] X_i + n_1 - p_1 = COE$	p_1
2	Maximize Equivalent Availability Factor (EAF) $\sum_{i=1}^{5} \left[\frac{PH_i-(POH_i+UOH_i+EDH_i}{PH_i}\right] X_i + n_2 - p_2 = EAF$	n_2
3	Maximize Capability of Maintenance and Repair $\sum_{i=1}^{5} CMAR_i\, X_i + n_3 - p_3 = MAR$	n_3
4	Maximize System Management Asset $\sum_{i=1}^{5} CEAM_i\, X_i + n_4 - p_4 = EAM$	n_4
5	Minimize Late of Project Completion $\sum_{i=1}^{5} CCOD_i\, X_i + n_5 - p_5 = COD$	p_5
6	Minimize Intermittency of Primary Energy $\sum_{i=1}^{5} CIRE_i\, X_i + n_6 - p_6 = IRE$	p_6

Table 4. Mathematical Formulation of Constraints

No	Constraints
1	LCoE/BPP must below than Rp 3,965 / kWh $\sum_{i=1}^{5} LCC_i \left[\frac{1}{(1+r)^t}\ \frac{(1+r)^t}{E_{ti}}\right] X_i \leq COE_{max}$
2	EAF must greater than 82% $\sum_{i=1}^{5} \left[\frac{PH_i-(POH_i+UOH_i+EDH_i}{PH_i}\right] X_i \geq EAF_{existing}$

3	The limitation of selection is only 1 alternative generator manager from 5 alternatives $X_i = 1$

In the Goal Programming model, the "optimal" solution is represented by the value of the achievement vector that must be minimized. This vector reflects the decision-making preference for "over achievement" or "under achievement" towards the target level that has become an aspiration to be achieved in its objectives. The vector of achievement of the project selection model developed with two integrations of AHP and Goal Programming approaches, can be formulated as follows,

$$Minimize\ \bar{\alpha} = [w_1(p_1) + w_2(n_2) + w_3(n_3) + w_4(n_4) + w_5(p_5) + w_6(p_6)]\ \textbf{(Eq. 3)}$$

4. Data Collection

This study uses 6 respondents to carry out AHP weighting, where the six respondents have educational backgrounds, namely 2 people with S2 (Masters) degrees, 3 people holding S1 (Bachelor) and 1 D3 (Diploma). From six respondents, only 1 person has a working period of less than 10 years, 4 people 10-15 years and 1 person above 15 years. (Table 5)

Table 5. Pairwise Comparison Survey

Comparison Between Criteria

Criteria	Weight of Interest																	Criteria
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Cost																		O&M
Cost																		Risiko
O&M																		Risk

Comparison Between Sub Criteria

Sub Criteria	Weight of Interest																	Sub Criteria
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
EAF																		Maintenance
EAF																		Asset Management
Maintenance																		Asset Management
COD																		Primary Energy Availability

Comparison Between Alternative in Sub Criteria

Alternative	Weight of Interest																	Alternative
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Alternative 1																		Alternative 2
Alternative 1																		Alternative 3
Alternative 1																		Alternative 4
Alternative 1																		Alternative 5
Alternative 2																		Alternative 3
Alternative 2																		Alternative 4
Alternative 2																		Alternative 5
Alternative 3																		Alternative 4
Alternative 3																		Alternative 5
Alternative 4																		Alternative 5

For quantitative data obtained directly from field observations at PLTD Kangean (generating operation data), reports on operating & maintenance costs. Table 6 shows the detailed data on PLN's expenditures for the purchase of fuel and lubricants including transportation costs and installed engine capacity, power and peak load.

Table 6. Cost of Production Report and Capacity of PLTD Kangean

DATA BPP PLTD KANGEAN TAHUN 2021 & 2022							
NO	BULAN	KWH PRODUKSI	BAHAN BAKAR		PELUMAS		BPP / KWH
			BIAYA BAHAN BAKAR	ONGKOS ANGKUT	BIAYA PELUMAS	ONGKOS ANGKUT	
1	JANUARI 2021	1,622,456	Rp 2,229,008,048	Rp 448,910,000	Rp 42,447,217	Rp -	Rp 1,676.70
2	FEBRUARI 2021	1,489,041	Rp 2,322,635,968	Rp 499,233,987	Rp 38,461,893	Rp -	Rp 1,920.92
3	MARET 2021	1,743,754	Rp 2,931,285,176	Rp 480,975,000	Rp 40,537,092	Rp -	Rp 1,980.09
4	APRIL 2021	1,779,079	Rp 3,347,052,856	Rp 628,474,000	Rp 43,013,180	Rp -	Rp 2,258.78
5	MEI 2021	1,910,475	Rp 3,637,208,181	Rp 854,852,900	Rp 41,739,762	Rp -	Rp 2,373.13
6	JUNI 2021	1,753,586	Rp 3,462,430,175	Rp 429,671,000	Rp 45,900,923	Rp 11,876,000	Rp 2,252.46
7	JULI 2021	1,776,868	Rp 3,656,514,692	Rp 699,017,000	Rp 45,979,857	Rp -	Rp 2,477.12
8	AGUSTUS 2021	1,875,936	Rp 4,075,051,906	Rp 666,952,000	Rp 41,448,242	Rp 9,382,219	Rp 2,554.90
9	SEPTEMBER 2021	1,803,687	Rp 3,885,835,908	Rp 660,539,000	Rp 38,495,826	Rp -	Rp 2,541.94
10	OKTOBER 2021	1,915,837	Rp 4,074,389,907	Rp 577,170,000	Rp 38,472,945	Rp -	Rp 2,448.03
11	NOVEMBER 2021	1,789,285	Rp 4,310,496,049	Rp 529,713,800	Rp 33,804,006	Rp 3,098,628	Rp 2,725.73
12	DESEMBER 2021	1,856,745	Rp 4,706,467,037	Rp 827,277,000	Rp 38,290,154	Rp -	Rp 3,000.97
13	JANUARI 2022	1,847,382	Rp 4,525,281,871	Rp 525,866,000	Rp 35,858,782	Rp -	Rp 2,753.63
14	FEBRUARI 2022	1,661,457	Rp 4,159,051,052	Rp 615,648,000	Rp 30,553,962	Rp 6,501,000	Rp 2,896.11
15	MARET 2022	1,956,591	Rp 5,493,670,794	Rp 556,531,800	Rp 31,624,033	Rp -	Rp 3,108.38
16	APRIL 2022	2,060,344	Rp 6,988,095,253	Rp 828,326,400	Rp 41,163,608	Rp -	Rp 3,813.72
17	MEI 2022	1,953,114	Rp 6,954,702,726	Rp 750,670,800	Rp 40,321,212	Rp -	Rp 3,965.82
	MAX 2021	**Rp 3,000.97**	**AVERAGE 2021**	**Rp 2,366.88**			
	MAX 2022	**Rp 3,965.82**	**AVERAGE 2022**	**Rp 3,332.02**			
	MAX 2021 - 2022	**Rp 3,965.82**	**AVERAGE 2021 - 2022**	**Rp 2,663.95**			

No	Unit PLTD	Merk	Tahun Operasi	Kapasitas Terpasang (kW)	Daya Mampu (kW)	Beban Puncak (kW)
1	PLTD Kangean	PLTD Kangean Cummins #12	2017	656	460	**4301**
2		PLTD Kangean Cummins #13	2017	656	460	
3		PLTD Kangean Cummins #14	2017	656	460	
4		PLTD Kangean Cummins #15	2017	656	460	
5		PLTD Kangean Cummins #16	2017	656	460	
6		PLTD Kangean Cummins #17	2017	656	460	
7		PLTD Kangean Cummins #18	2017	656	460	
8		PLTD Kangean Cummins #19	2017	656	460	
9		PLTD Kangean Cummins #20	2017	656	460	
10		PLTD Kangean MAN #1	2022	575	400	
11		PLTD Kangean MAN #2	2022	575	400	
Total (kW)				**7054**	**4940**	
Reserve Margin (kW)				**639**		

Meanwhile, the supporting data on investment costs was obtained based on a previous study by PLN especially for PV with capacity of 15,360 kWp. In this study, it has 2 PV capacities, 25,200 kWp for 100% PV alternatives with an estimated 8 years without using Diesel and a capacity of 15,360 kWp for Hybrid alternatives with an estimated 2 years without using Diesel shows below (Table 7)

Table 7. Parameters of Financial Analysis Calculation

Parameter	PV 25.2 MWp	PV 15.36 MWp
Annual kWh Sales	34,826,000 kWh	23,056,000 kWh
Capacity Factor	15.76%	17.14%
Exchange Rate	Rp 15,000/USD	Rp 15,000/USD
Construction Period	12 Months	7 Months
Project Lifetime	20 Years	20 Years
Interest Rate	9.97%	9.97%
Debt Equity Ratio	70:30	70:30
Repayment Period	12 Years	12 Years
Discount Factor	9.24%	9.24%
IRR	14.10%	11.53%

5. Results and Discussion

5.1 Financial Analysis

Based on the business report data and the estimated investment data, a financial analysis was carried out and the results showed that to build a PV with a capacity of 25.2 MWp, need a budget of Rp. 785,186,291,751 equivalents to USD 52,345,753 while for a PV with a capacity of 15.36 MWp, need a budget of Rp. 477,874,401,150, equivalents to USD 31,858,293. With the scheme of 2 PV capacities, the LCOE for each alternative can be shown in the Table 8 below,

Table 8. LCoE Estimation of Each Alternative (Year 1 – 20) per kWh

Alternative	Year 1 - 2	Year 3 - 8	Year 9 - 20
#1 PV (IPP)	Rp 3,423 (22.8 ¢)	Rp 3,423 (22.8 ¢)	Rp 3,379 (22.5 ¢)
#2 PV-Diesel (IPP)	Rp 3,151 (21.0 ¢)	Rp 3,061 (20.4 ¢)	Rp 3,061 (20.4 ¢)
#3 PV (IPP) – Diesel (PLN)	Rp 3,151 (21.0 ¢)	Rp 2,964 (19.8 ¢)	Rp 2,964 (19.8 ¢)
#4 PV-Diesel (PLN)	Rp 2,959 (19.7 ¢)	Rp 2,860 (19.1 ¢)	Rp 2,860 (19.1 ¢)
#5 PV (PLN)	Rp 2,965 (19.8 ¢)	Rp 2,965 (19.8 ¢)	Rp 2,933 (19.6 ¢)

From Table 8 it can be seen that for alternatives 1 & 5 from years 1 - 8 there is no change in LCoE with an estimate that PV can meet the electricity needs of the Kangean system. While alternatives 2, 3 & 4 will change in LCoE starting in year 3.

The calculation on alternative 2 specifically for Diesel Power Plant management refers to the Joint Operation & Maintenance (JOM) contract between PLN and IPP which is already running at PLTD Bawean. Service Level Agreement (SLA) is used as a multiplier factor with the value of work per month stated in the contract, which covers all operational and maintenance work (preventive, corrective & predictive). Meanwhile for work that is emergency, modification, overhaul and spare parts that are specific outside the scope of the JOM contract will be charged to PLN as a Variation Order. Calculations on alternatives 3 and 4 for Diesel Power Plant management by PLN refer to the operational & maintenance costs that have been incurred in the previous year plus the depreciation of the power plant itself.

5.2 AHP Analysis

Based on the results of the AHP survey conducted on 6 PLN respondents where 1 person is Middle Management, 1 person is Basic Management, 2 people are Top Supervisors, 1 person is Basic Supervisor and 1 person is Functional Expert, the results are as below,

Table 9. Pairwise Comparison of Criteria, Sub Criteria & Alternative on Each Respondent

Respondent	Cost									O&M							
Hadi Saputra	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Agung W.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Daan Agung	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Bayu K.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Hanif Hendri	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rengga Ade	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Respondent	EAF									Capability of Maintenance and Repair							
Hadi Saputra	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Agung W.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Daan Agung	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Bayu K.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Hanif Hendri	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rengga Ade	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Respondent	PV-Diesel (IPP) / Asset Management									PV-Diesel (PLN) / Asset Management							
Hadi Saputra	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Agung W.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Daan Agung	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Bayu K.	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Hanif Hendri	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rengga Ade	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

From Table 9 above, it can be seen that each respondent has their own preference in terms of weighting criteria, sub-criteria and alternative choices. The weighting of each respondent will be combined so that the results of the combined weighting will show the direction of preference towards the criteria, sub-criteria and alternatives.

The combined weighting results show that the cost criteria weight of 0.304, the O&M criteria weight of 0.306 and the risk criteria weight of 0.390. Meanwhile, for the weighting of the sub-criteria, it is found that LCoE/BPP weight of 0.304, the EAF sub-criteria weight of 0.151, the maintenance and repair capability sub-criteria weight of 0.095, the asset management system sub-criteria weight of 0.06, the COD sub-criteria weight of 0.153 and the sub-criteria for primary energy availability weight of 0.237 so that the total of all sub-criteria is worth 1. Alternative weighting on each sub-criteria results that Alternative 1 PV (IPP) weight of 0.207, Alternative 2 PV-Diesel (IPP) weight of 0.244, Alternative 3 PV (IPP)-Diesel (PLN) weight of 0.199, Alternative 4 PV-Diesel (PLN) weight of 0.208 and Alternative 5 PV (PLN) weight of 0.143.

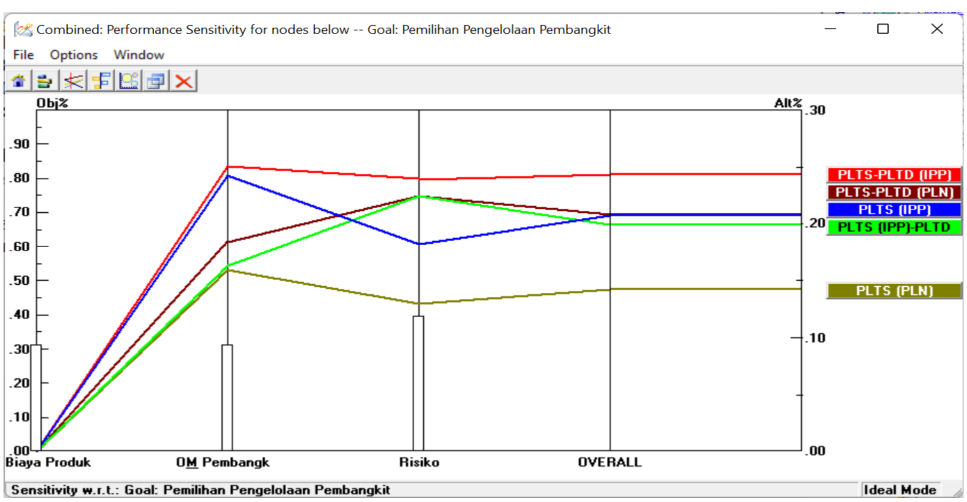

Figure 4. Performance Sensitivity

From Figure 4 above, it can be seen that the preferences of the experts give more weight to PV-Diesel (IPP) followed by PV-Diesel (PLN) and the smallest weight is PV (PLN). By making changes to one of the criteria to test the sensitivity, the results will be obtained as shown in Figure 5 below,

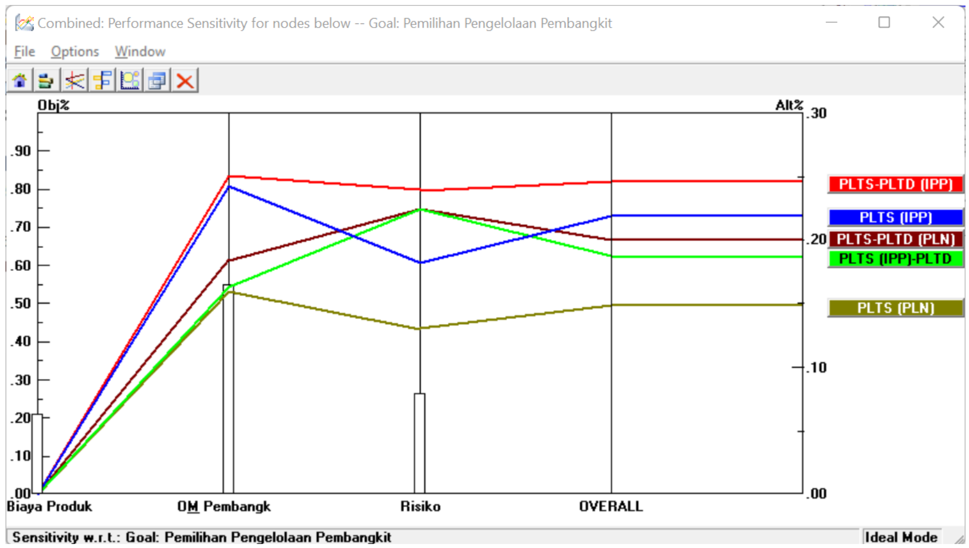

Figure 5. Sensitivity Results (Increasing Weight of O&M Criteria)

By changing the weight of the O&M criteria more than 0.500 the weight of the cost and risk criteria has decreased so that the change in the weight of PLTS (IPP) becomes higher than the weight of PLTS (PLN). While the highest weight is still owned by PV-Diesel (IPP) so it can be said that the alternative is robust.

5.3 Goal Programming Analysis

Hasil pembobotan sub kriteria pada AHP yang merupakan goal pada goal programming maka dapat disubtitusikan nilai bobot tersebut pada model matematis dalam menentukan nilai vektor pencapaian,

$$Min\ Z = 0.304p_1 + 0.151n_2 + 0.095n_3 + 0.060n_4 + 0.153p_5 + 0.237p_6 \qquad \textbf{(Eq. 4)}$$

The mathematical model for the goal objective is substituted by quantitative data from observations in the field or quantitative data which is a conversion of qualitative data using the AHP method.

$$\boldsymbol{Goal\ 1}: \textbf{Minimize LCOE / BPP}$$

$$3424X_1 + 3061X_2 + 2964X_3 + 2860X_4 + 2935X_5 + n_1 - p_1 = 0 \qquad \textbf{(Eq. 5)}$$

In Goal 1, the constants for each alternative X_1 to X_5 are obtained from the calculation of the BPP for each alternative according to Table 8 for the 1st to 8th year period.

$$\boldsymbol{Goal\ 2}: \textbf{Maximize Equivalent Availability Factor (EAF)}$$

$$92X_1 + 93.28X_2 + 93.28X_3 + 93.28X_4 + 92X_5 + n_2 - p_2 = 93.28 \qquad \textbf{(Eq. 6)}$$

In Goal 2, the constant for each alternative X_1 to X_5 is obtained from the EAF calculation for each alternative, where for PLTS it is estimated at 92% and for Hybrid it is calculated at 93.28%.

$$\boldsymbol{Goal\ 3}: \textbf{Maximize Capability of Maintenance and Repair}$$

$$29.6X_1 + 22.3X_2 + 14.9X_3 + 16.3X_4 + 16.9X_5 + n_3 - p_3 = 29.6 \qquad \textbf{(Eq. 7)}$$

In Goal 3, the constant for each alternative X_1 to X_5 is obtained from the value of the maintenance and repair capability based on the judgment of the experts through the AHP method.

$$\boldsymbol{Goal\ 4}: \textbf{Maximize Asset Management System}$$

$$19.6X_1 + 22.4X_2 + 20.2X_3 + 19.2X_4 + 18.6X_5 + n_4 - p_4 = 22.4 \qquad \textbf{(Eq. 8)}$$

In Goal 4, the constant for each alternative X_1 to X_5 is obtained from the value of the asset management system based on the judgment of the experts through the AHP method.

$Goal$ **5 : Minimize Late of Project Completion**

$$12X_1 + 7X_2 + 7X_3 + 7X_4 + 12X_5 + n_5 - p_5 = 0 \quad \textbf{(Eq. 9)}$$

In Goal 5, the constant for each alternative X_1 to X_5 is obtained from the value of the duration of the PV project.

$Goal$ **6 : Minimize Intermittency of Primary Energy**

$$32X_1 + 8X_2 + 8X_3 + 8X_4 + 32X_5 + n_6 - p_6 = 0 \quad \textbf{(Eq. 10)}$$

In Goal 6, the constant for each alternative X_1 to X_5 is obtained from the primary energy intermittent value based on the number of PV months that have decreased below the average monthly GWh production (January, February, November & December) multiplied by the number of years planned for operation without Diesel.
By using software to simulate the script goal programming, the result is that the mathematical model is solved with an objective function value of 877.3938 as the minimum value. For goal 1 (p1) has a parameter value of 2.860 which is the minimum value so that the goal is declared achieved. For goal 2 (n2), it has a parameter value of 0 which is the maximum value so that the goal is declared achieved. For goal 3 (n3), the parameter value of 13.3 is not the maximum value so that the goal is declared not achieved. For goal 4 (n4), the parameter value of 3.2 is not the maximum value so that the goal is declared not achieved. For goal 5 (p5), the parameter value of 7 is the minimum value so that the goal is declared achieved. For goal 6 (p6), the parameter value of 8 is the minimum value so that the goal is declared achieved.

Based on the results of the goal programming, 4 goals were declared to have been achieved from the 6 planned goals. The minimum objective function value and the highest number of goal achievements belong to alternative 4 PV-Diesel (PLN). For the three planned limits, all of them are achieved with an LCoE/BPP value of IDR 2,860/kWh smaller than the constraint of IDR 3,965/kWh, an EAF value of 93.28% greater than the constraint of 82% and there is only 1 alternative chosen, namely the alternative 4 PV-Diesel (PLN).

5.4 Sensitivity Analysis

After obtaining the results of the AHP and Goal Programming analysis, a sensitivity analysis was carried out on 6 parameters, including: (1) Increasing the weight of the O&M criteria by more than 0.500, (2) Increasing the price of land acquisition by more than 500%, (3) Increasing the maintenance cost by PLN to 300 %, (4) Increase Repayment Period from 12 years to 15 years, (5) Increase investment costs by 10% and (6) Increase investment costs by 20%. Based on the sensitivity analysis on these 6 parameters, it was found that Alternative 4 PV-Diesel (PLN) still has an optimal value compared to other alternatives so that it can be stated that the alternative value is "Robust".

6. Conclusion

In research on the selection of power plant management using the AHP method and Goal Programming in the framework of the Kangean PLTD De-Dieselization program, the following conclusions are drawn:

1) Through the AHP method, the importance weight on the cost criteria is 0.304, the O&M criteria is 0.306 and the risk criteria is 0.309.
2) Experts give the largest alternative weight to Alternative 2 PV-Diesel (IPP) of 0.244, greater than other alternatives.
3) Through the Goal Programming method, the optimization results are obtained, namely Alternative 4 PV-Diesel (PLN) is the optimal one with an objective function of 877,3938, the number of goals achieved is 4 out of 6 goals and all constraints are achieved.
4) The new renewable energy mix for alternative 4 PV-Diesel (PLN) is estimated at 72.7% PV and 27.3% Diesel (1st – 8th year).
5) This research can be used as material for consideration or evaluation in decision making as well as material for negotiating the JOM contract on IPP compared to the operating and maintenance costs carried out by PLN itself.

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