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Analysis of the Development Hydrogen Production and Utilization Ecosystem in the Energy Transition Era to Increase Generation Revenue in Western Java

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Abstract- The energy transition poses a major challenge for Indonesia, currently ranked 42nd in the ASEAN Climate Change Index and targeting Net Zero Emissions (NZE) by 2060. Hydrogen, as an alternative energy source, holds significant potential in diversifying fossil fuel use, although ongoing technological development is required to achieve an ideal Levelized Cost of Hydrogen (LCOH). In the power generation sector, excess hydrogen production from four generating units in West Java (UBP Suralaya, UBP BSLA, UBP Cilegon, UBP Kamojang) can be utilized for energy conversion. The State Electricity Company (PLN) has tested hydrogen utilization through a Hydrogen Refueling Station and H_2-powered generator. This study employs a descriptive quantitative analysis to calculate production costs, energy consumption, and environmental impact. The results indicate an annual decrease in hydrogen production costs of USD 0.303 per kg H_2. Temperature and production time factors affect costs by approximately 1.93%, with an optimal temperature range of 36–38°C. An excess of 22.6 tons of hydrogen per year could generate additional revenue of IDR 1,222,911,546.37 per year from electricity conversion and IDR 22,336,949,239.20 per year from compressed hydrogen gas products. Hydrogen utilization can reduce CO_2 emissions by up to -1,487,058.65 CO2e Kg/years of (Hydrogen Refueling Station and Generator Hydrogen). This study concludes that hydrogen, as an energy carrier, can support Indonesia's energy transition by reducing carbon emissions, enhancing energy independence, and serving as a basis for the development of a renewable energy-based hydrogen ecosystemKata

Keywords: Hydrogen, Energy Transition, Power Generation, Production Cost, Carbon Emissions, Fuel Cell

I. INTRODUCTION

Energy is a fundamental factor in Indonesia's economic growth. Amid rising global energy demand, which has reached an average of 2.5% per year , Indonesia faces the challenge of providing energy that is not only sufficient but also sustainable. The energy transition has become a global strategic issue reflected in the concept of the energy trilemma—energy equity, energy security, and environmental sustainability. Indonesia's position in the Climate Change Performance Index (CCPI) 2025, ranked 42nd, indicates the need to accelerate the implementation of clean energy policies .

As part of its commitment to the Paris Agreement, Indonesia targets an emissions reduction of 29% (without international support) and 41% (with international support) by 2030. This target is reinforced through the 2025–2034 RUPTL, which allocates a 76% share for renewable energy power generation. The 2025 RUKN also affirms the strategic role of green hydrogen as an energy carrier for transportation, industry, and power generation .

Several power generation units in Indonesia currently have hydrogen site plants used as generator cooling systems, with daily production capacities ranging from 16–57 kg at various locations such as UBP Suralaya, UBP Cilegon, UBP Banten Suralaya 1, and UBP Kamojang. Part of this production has been utilized for Hydrogen Refueling Stations (HRS) as an initial step in integrating hydrogen technology into the transportation sector.

The energy sector is the largest contributor to national carbon emissions, averaging 456,512 tons of CO_2e per year or 39% of total emissions . Thus, the utilization of hydrogen holds significant potential for reducing greenhouse gas emissions and diversifying fossil energy sources. However, hydrogen development—

particularly green hydrogen—still faces cost challenges, with production costs ranging from \$4.5–\$12/kg, which remain higher than those of grey and blue hydrogen.

These conditions highlight the need for a comprehensive study on the utilization of hydrogen in existing power generation systems as a strategy for climate change mitigation and the acceleration of Indonesia's national energy transition.

II. METODE (METHODS)

This study applies a descriptive quantitative analytical framework. The primary dataset comprises hydrogen production capacities and operational parameters of four PLN power generation units in West Java—UBP Suralaya, UBP BSLA, UBP Cilegon, and UBP Kamojang. Secondary data were derived from peer-reviewed literature and institutional reports on energy transition pathways and hydrogen technologies. The analytical procedure includes estimation of the Levelized Cost of Hydrogen (LCOH), expressed in USD/kg, by accounting for electricity input costs and electrolyzer operational expenditures. Further, the analysis quantifies electrical energy demand associated with hydrogen generation and evaluates potential CO_2 emissions abatement relative to conventional fossil-based energy sources.

Thermodynamic conversion formulas were employed to translate fuel calorific values into electrical output and equivalent CO_2 emissions. This enables cross-comparative assessments of efficiency and emissions profiles among coal, diesel, natural gas, and hydrogen. The evaluation is conducted under a baseline scenario that reflects current hydrogen production practices without additional capital investment, assuming all hydrogen output is surplus after generator cooling requirements are met.

Multiple operational scenarios were assessed, incorporating variations in electrolyzer temperature (approximately 30–40°C), production scheduling during low-load or off-peak tariff periods, as well as system efficiency parameters and renewable energy capacity factors. Additionally, long-term hydrogen transition trajectories were modeled using the Long-range Energy Alternatives Planning (LEAP) system. The LEAP simulations project the evolution of hydrogen production costs from 2025 to 2050, integrating assumptions regarding Fuel Cell Electric Vehicle (FCEV) penetration, deployment of hydrogen-based Electric Vehicle Charging Stations (H_2 Generators), and anticipated declines in electrolyzer technology costs. This integrated approach yields long-term hydrogen cost-reduction curves and projections of the optimal production scale.

III. RESULTS AND DISCUSSION

Technical Analysis

Currently, hydrogen production at several units is not yet fully supplied by green energy sources. However, at UBP Cilegon, the hybrid scheme—combining solar PV (PLTS) and the PSReC system—offers an alternative that enables hydrogen production to be classified as green. In contrast, the system configuration at UBP Banten Suralaya 1 has not yet ensured that its hydrogen output meets the criteria for green hydrogen. Nevertheless, hydrogen produced from these units still functions as an energy carrier which, in its energy conversion and end-use processes, does not generate adverse environmental impacts.

No	Unit	Series	Tahun Implementasi Electrolysis	H2 Purity (%)	Kapasitas (kg/Day)	Kebutuhan Generator (kg/Day)	Excess H2 ((kg/Day)
1	UBP Suralaya	HMXT-200	1986	97.99	25.5	25.5	0
2	UBP Banten Suralaya 1	DQ-5/3.2	2009	99.8	57.6	22.46	35.14
3	UBP Cilegon	HMXT-100	2024	99.99	12.07	13.08	11.06
		HMXT-100		99.99	12.07		
4	UBP Kamojang	HMXT-100	1997	99.99	16.58	0	100

Table 1 Example of Production Parameters of UBP Cilegon

Log Sheet Date	Waktu	TemA (°C)	H2 pressure (Bar)	Production Rate (%)	Voltage (V)	Current (A)
2025-02-25 00:00:00	24.00	38.00	145.00	100.00	155.00	226.00
2025-02-25 00:00:00	21.00	38.00	145.80	100.00	156.00	226.00
2025-02-25 00:00:00	17.00	39.00	145.90	100.00	155.70	226.00
2025-02-25 00:00:00	13.00	39.00	145.00	100.00	155.00	226.00
2025-02-25 00:00:00	09.00	38.00	133.00	100.00	156.00	221.00
2025-02-25 00:00:00	05.00	35.00	145.00	100.00	156.00	226.00
2025-02-24 00:00:00	24.00	36.00	145.00	100.00	156.00	226.00
2025-02-24 00:00:00	21.00	38.00	132.00	100.00	157.00	220.00
2025-02-24 00:00:00	17.00	39.00	132.00	100.00	155.50	219.00
2025-02-24 00:00:00	13.00	39.00	144.50	100.00	155.00	226.00

Table 2. Hydrogen Production Operation Data

No	Unit	Waktu	TemA (°C)	H2 Deliver pressure (Bar)	Production Rate (%)	Voltage (V)	Current (A)	H2 Purity (%)
1	UBP Suralaya	21-Feb-25	35	150	78%	140	351	97.99
2	UBP Banten Suralaya	17-Apr-25	36	145	100%	50	500	99.8
3	UBP Kamojang	28-May-25	35	150	100	159.75	224.5	99.92

Sumber: Data operasional actual H_2 Palnt

In the electrolysis process, a chemical reaction occurs in which water undergoes electrochemical decomposition through anodic (oxidation at the negative electrode) and cathodic (reduction at the positive electrode) reactions. In this process, water—

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chemically denoted as H_2O—is split into its constituent elements, producing H_2 (hydrogen) and O_2 (oxygen).

Hydrogen production using an electrolysis system is influenced by the amount of electrical energy supplied, which is converted through thermochemical reactions. The greater the electrical energy input, the higher the volume of hydrogen produced, which in turn affects the overall production cost. Accordingly, the production cost can be calculated using the following equation:

The equation for calculating power..(1)

Calculating Power $P = V \times I$ ……… (Watt)

Where :

- P (Power)
- V (Voltage)
- I (Current)

The power system costs at UBP Cilegon and other units are regulated under internal provisions, with an average electricity tariff of Rp 2,104.99. Using this cost parameter, the Levelized Cost of Production for the electrolysis process as the hydrogen generation method can be determined accordingly.

Table 3. of results of calculation of Electrolysis power consumption and costs

Log Sheet Date	Waktu	TemA (°C)	Voltage (V)	Current (A)	Daya Produksi (kWh)	USD
2025-02-25 00:00:00	24.00	38.00	155.00	226.00	35.03	5.13
2025-02-25 00:00:00	21.00	38.00	156.00	226.00	35.26	5.16
2025-02-25 00:00:00	17.00	39.00	155.70	226.00	35.19	5.15
2025-02-25 00:00:00	13.00	39.00	155.00	226.00	35.03	5.13
2025-02-25 00:00:00	09.00	38.00	156.00	221.00	34.48	5.05
2025-02-25 00:00:00	05.00	35.00	156.00	226.00	35.26	5.16
2025-02-24 00:00:00	24.00	36.00	156.00	226.00	35.26	5.16
2025-02-24 00:00:00	21.00	38.00	157.00	220.00	34.54	5.05
2025-02-24 00:00:00	17.00	39.00	155.50	219.00	34.05	4.98
2025-02-24 00:00:00	13.00	39.00	155.00	226.00	35.03	5.13
2025-02-24 00:00:00	09.00	36.00	155.00	226.00	35.03	5.13
2025-02-24 00:00:00	05.00	36.00	157.00	222.00	34.85	5.10

Note: Sample calculation from data UBP Cilegon

Based on the calculation results, the data were further processed to generate a visual representation in the form of a heatmap. A heatmap serves as a tool to help interpret patterns, trends, and key insights within the dataset in a clear and efficient manner. Field observations indicate that several parameters have not yet been fully met; therefore, using a visual approach derived from operational data allows for a more objective assessment of the influence of each parameter. The resulting heatmap visualization is presented as follows :

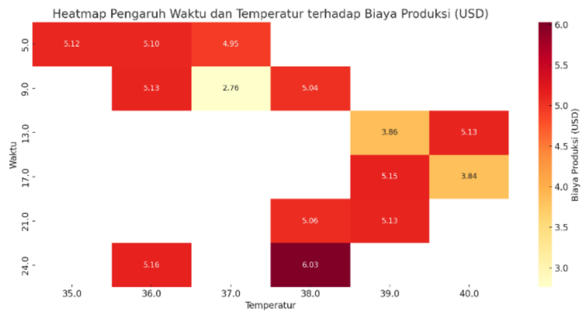

Figure 1. Heatmap of Temperature and Time against Production Costs

From the visual heatmap, data information is obtained :

1. Production costs tend to be higher at certain temperatures in the morning.
2. The temperature range of around 36–38°C shows a consistent production cost of around USD 5.13/kg.
3. Unstable ambient air temperature affects production costs due to the influence of ambient air on the rate of electrolysis reactions.

Based on observations of the hydrogen production units, it was found that the system operates at an average output and storage pressure of 150 bar, with a hydrogen purity level of 99.99%, which meets the required fuel-grade standards. The potential excess hydrogen available for alternative uses is approximately 62.78 kg H_2/day from four units, equivalent to 1.88 tons of H_2 per month, and an annual reserve of 22.06 tons of H_2. The collected data also indicate that technological advancements over the years have contributed to a continuous reduction in production costs, thereby demonstrating the increasing economic viability and cost competitiveness of hydrogen.

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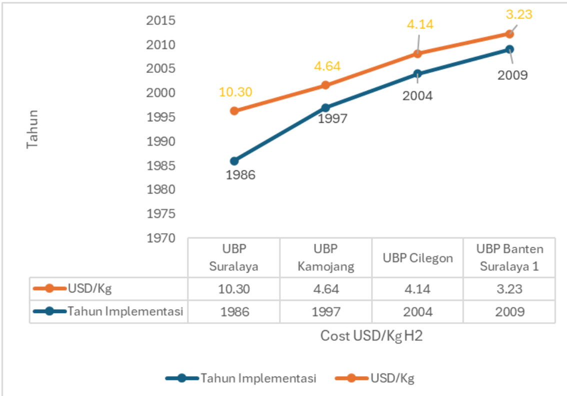


Figure 2 Comparison Chart of Technology Age and Production Cost of H2/Kg

From the graph above, derived from the existing hydrogen plants at the four power generation units (UBP Suralaya, UBP Banten 1 Suralaya, UBP Cilegon, and UBP Kamojang), the decreasing trend in hydrogen production costs can be demonstrated as a result of technological advancements. A descriptive statistical analysis of the four units shows an average production cost of USD 5.57/kg, with a technological development deviation over a 7-year period indicating a cost reduction of approximately USD 3.2/kg.

Product Delivery Procedures

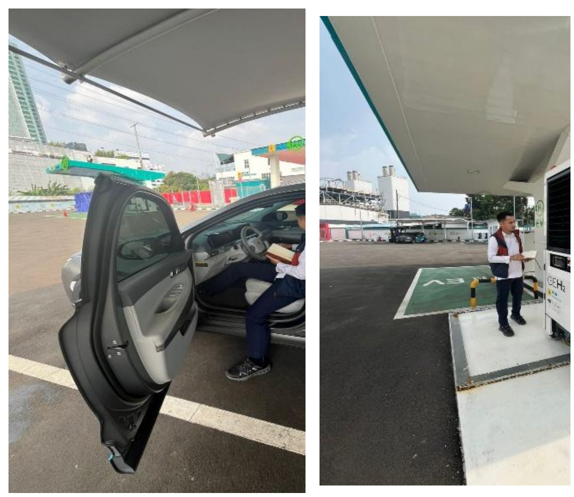
In accordance with the provisions of the Director General of Land Transportation Decree Number SK.725/AJ.302/DRJD/2004, the maximum allowable speed for vehicles transporting hazardous materials is 60 km/h. Therefore, distance and terrain conditions along the delivery route must be carefully considered as part of the risk assessment:

Table 4 Distance and time of Hydrogen delivery to HRS Senayan

Kode	Unit Penyuplai	Jarak ke HRS (Km)	Durasi (Jam)	Kecepatan (Km/h)	Kondisi Perjalanan	Refrensi
A	UBP Suralaya	117	2.22	52.70	Pagi	Google Maps
B	UBP Banten Suralaya 1	117	2.22	52.70	Pagi	Google Maps
C	UBP Cilegon	104	2.05	50.73	Pagi	Google Maps
D	UBP Kamojang	195	3.29	59.27	Pagi	Google Maps
A	UBP Suralaya	117	2.12	55.19	Siang	Google Maps
B	UBP Banten Suralaya 1	117	2.12	55.19	Siang	Google Maps
C	UBP Cilegon	104	2.02	51.49	Siang	Google Maps
D	UBP Kamojang	195	3.5	55.71	Siang	Google Maps
A	UBP Suralaya	117	2.25	52.00	Malam	Google Maps
B	UBP Banten Suralaya 1	117	2.25	52.00	Malam	Google Maps
C	UBP Cilegon	104	2.15	48.37	Malam	Google Maps
D	UBP Kamojang	195	3.3	59.09	Malam	Google Maps

Implementation Technical Procedures

Currently, hydrogen products are utilized and converted into two alternative energy forms: compressed H_2 for Fuel Cell Electric Vehicles (FCEVs) and hydrogen-powered generators for charging Electric Vehicles.



Fuel Cell Electric Vihicle Generator Hydrogen

Gamabar 3 Implementasi Pemanfaatan Gydrogen

Technical specifications for the use of Hydrogen products are as follows: :

Tabel 5 Hydrogen Utilization System

No	Sistem Utilitas	Spesifikasi	Durasi / range	Pemanfaatan
1	Hydrogen Refueling Station (HRS)	350 Bar	5 Menit	Refueler FCEV
2	Hydrogen Genset GEH2	110 kVA / 88 kW	30 Menit	Charging EV
3	Fuel Cell Electryc Vihicle	1 Kg/100 Km Tank 6.3 at 700 Bar	570-756 Km	Mobility

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Economic Analysis

In every energy conversion there are of course costs incurred to produce other energy products, from the results of data collection we can of course calculate the potential income that will be obtained :

Table 6 Hydrogen ecosystem Cost

Unit	Biaya H_2 Plant (USD/kg)	Biaya Transportasi (USD/kg)	Biaya HRS$^{(Capex+Opex)}$ (USD/Kg)
UBP Suralaya	10.30	1.47	2.78
UBP Banten Suralaya 1	3.23		
UBP Cilegon	4.14		
UBP Kamojang	4.64		

Note : *) Tariffs using company internal regulations are an average of IDR/kWh on average

Because there is currently no market determination of the price of Hydrogen, a conversion approach to kWh using thermodynamic theory using the HHV and LHV approach is used:

HHV Hydrogen theoretical approach : 141,86 MJ/kg

1 MJ = 0,27778 kWh

Then Convert to kWh:

141,86 MJ/kg × 0,27778 = 39,42 kWh/kg

So for 1Kg H_2 can 39,42 kWh (HHV)

Theoretical approach with LHV Hydrogen: 120,1 MJ/kg

Then Convert to kWh:

120,1 MJ/kg × 0,27778 = 33,36 kWh/kg

So for kWh (LHV) can 33,33 kWh (LHV)

From the conversion value of HHV and LHV values to kWh, it can be used to convert hydrogen production results using an electricity price approach per kWh according to PLN statistics for a period of 10 years with average rates (Household, Business Industry, Social, Government Office Buildings, Public Street Lighting)Rp 1.178,85.

However, in the current hydrogen conversion in Indonesia, especially PLN, it uses a hydrogen generator to produce electrical energy with a maximum efficiency of 60%, so it can be calculated using the formula:

Electrical energy output (kWh)=mass H2(kg)×LHV H2(kWh/kg)×ηFC

Tabel 7 The results of the H_2 Production Excess Calculation are converted using a Generator H_2.

No	Unit	Opex (USD/Kg)	Excess Produksi (Kg H_2/Tahun)	Konversi HHV (kWh/kg)	Konversi LHV (kWh/kg)	Harga Listrik (Rp/kWh)	Pendapatan (Rp) HHV	Pendapatan (Rp) LHV
1	UBP Suralaya	14.25	0	-	0	1,178.85	0	0
2	UBP Banten Suralaya 1	7.48	12,650.40	299,207.26	252,982.70		352,720,479.39	298,228,654.95
3	UBP Cilegon	8.39	3,981.60	94,172.80	79,624.04		111,015,609.05	93,864,795.78
4	UBP Kamojang	8.89	36,000.00	851,472.00	719,928.00		1,003,757,767.20	848,687,122.80

This data shows that optimizing the use of excess hydrogen in generation units can provide the benefit of increasing income significantly. These findings indicate that the development of a hydrogen ecosystem is economically feasible and strategic in supporting the energy transition while simultaneously increasing generation income in a sustainable manner because of the 3 Generation Business units which have excess Hydrogen of 22.06 tons per year with income of IDR 23,559,860,785.57 / year (1,445,390.23 USD) from (electrical energy conversion product scheme and Compressed Gas Products)

Environmental Analysis

The use of hydrogen in the generation sector will make a significant contribution to reducing CO_2 emissions, which can be proven by comparing it with other energy sources with a focus on utilization:

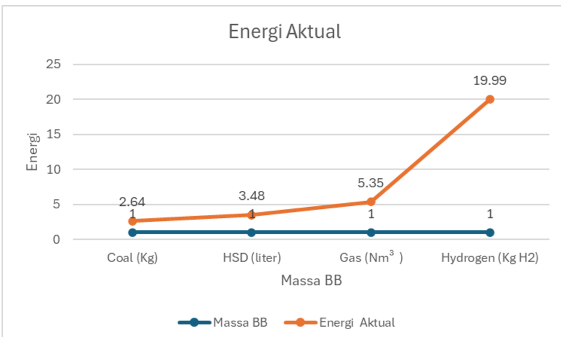
1. Hydrogen for Hydrogen Generators with Electrical Energy products (kW)
2. Hydrogen for Hydrogen Refueling Station with energy products (Km)

Simple equation formula for electrical energy output :

Electrical energy output (kWh)=mass BB (kg)×(LHVor HHV) BB(kWh/kg)×ηFC

With a theoretical approach, 1 kWh = 3.6 MJ and general assumption data and efficiency values:

a. Coal fuel with Efficiency 35 -60 %
b. HSD fuel with Efficiency 35 %
c. Gas fuel with Efficiency 60 %
d. Hydrogen Fuelcell with efficiency 60 %



Picture 4 Actual Energy Graph of each fuel mass

Table 8 CO2 Emission Calculation Results from each Energy Source

Bahan Bakar	Total BB/ Bulan	Energi Aktual	Total (kWh/Bulan)	Factor kali Emisi Kg CO2	Nilai Emisi CO2 (Kg/ Bulan)
Coal	1000.000 Kg	2,64 kWh/Kg Coal	2,640,000.00	0.85	2,244,000.00
HSD	1000.000 liter	3,48 kWh/ Liter HSD	3,480,000.00	0.7	2,436,000.00
Gas	1000.000 Nm^3	5.35 kWh/ Nm^3	5,350,000.00	0.4	2,140,000.00
Hydrogen	1000.000 Kg H_2	19.99 kWh/kg H2	19,990,000.00	0	-

The graph shows the amount of carbon dioxide (CO_2) emissions per month produced from four types of energy sources: Coal, HSD (High Speed Diesel), Gas, and Hydrogen. The highest emissions come from HSD, namely 2,436,000 kg CO_2 per month, followed by Coal at 2,244,000 kg, and Gas at 2,140,000 kg. Meanwhile, Hydrogen shows that there are no direct CO_2 emissions in the conversion process into electricity, because it uses fuel cell technology which only produces water as a residue.

Referring to the IPCC 2006 Guidelines, the average electricity emission factor from coal

0.91 kg CO_2/kWh, if the electricity or other material production system uses a hybrid energy source :

For example
Total Emissions =(pPLTS×0)+(pCoal×0.91)
Average emissions =(50%×0)+(50%×0.91)=0.455 kg CO_2/kWh (faktor kali hybrid)

Table 9 Comparison of Total Emissions from each Energy source

Jenis Kendaraan	Energi / Unit	Kemampuan Jarak Tempuh Unit (Km)	Faktor Kali Emisi (Kg CO_2)	Total Emisi (Kg CO_2)
ICE (Bnesin)	1 liter bensin	15	2.3	34.5
ICEV (Bensin+Electric)	1 liter bensin	22	0.92	20.24
EV (PLTS+Coal)	1 kWh listrik	8	0.455	3.64
EV (Renewable Energy)	1 kWh listrik	8	0	0
FCEV (Hybrid PLTS+Coal)	1 kg Hidrogen	100	0.45	45
FCEV (Hydrogen)	1 kg Hidrogen	100		0

IV. RESULTS AND DISCUSSION

Hydrogen Production Potential in Power Plants: Four power plant units in West Java have electrolyzer infrastructure to produce hydrogen with a purity of 99.99% at a storage pressure of ±150 bar. Total actual hydrogen production from the four units amounts to approximately 52.63 tons per year (or ~144 kg H_2 per day). Of this amount, excess hydrogen that is truly based on renewable energy (green hydrogen) is estimated to be ±9.9 tonnes per year – mainly coming from UBP Cilegon and UBP Kamojang which use hybrid renewable energy sources. This green hydrogen has the potential to be widely used because production at UBP Suralaya still depends on PLTU electricity (producing gray hydrogen with a high carbon footprint).

V. STATEMENT

The author expresses his thanks to PT PLN (Persero) UPDL Suralaya. Thanks are also addressed to PT PLN Indonesia Power (UBP Suralaya, UBP BSLA, UBP Cilegon, UBP Kamojang) and all parties who have assisted in providing operational data and constructive input during the process of preparing this paper and the support and cooperation provided has been very valuable in completing this research.

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