Incremental Development Strategy of Geothermal Field Using Wellhead Unit Technology: Case Study Ulumbu Geothermal Field

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Abstract. Geothermal development in Indonesia is still dominated by the utilization of conventional geothermal power plants with large capacities. Generally, it requires a long time development phase and often experiences delays before an operation. This study aims to provide alternative field development options with an incremental development strategy. This study was conducted to show how a wellhead unit’s effective incremental development strategy compared to conventional power plants by applying the probability approach for the Ulumbu geothermal field’s case study in East Nusa Tenggara. Besides, this study also provides a comprehensive economic condition of the obtained revenue and project investment costs. Therefore, geothermal power plant development could be more feasible and minimize the barriers in the investment. The methods used in this study is a technical and economic approach, from total project investment cost and the financial return achieved for each development strategy. The technical analysis compares the power plant’s specific steam consumption (SSC) and the generated capacity. The total investment is determined for different development scenarios of 40 MW (conventional) scenario 2×20 MW, 40 MW (incremental) scenario 8×5 MW, and 40 MW (incremental) scenario 16×2.5 MW using condensing power plant. The economic analysis shows P90 for the investment cost in millions of US$/MW is 5.84, 5.58, and 5.60, respectively. Regarding the tariff-based, which is 80% under Average Cost of Electricity Generation (BPP) of the relevant local grid, P90 for the Rate of Return is 16.85%, 17.33% 17.21%, respectively. Evaluation done by comparing investment cost, economic parameters, tariff variation, and risk assessment, for incremental development scenarios of 8×5 MW and 16×25 MW is feasible as development alternative scenario of Ulumbu field.

1. Introduction
The Ulumbu Geothermal Working Area (WKP) is the area with the most significant geothermal potential in East Nusa Tenggara. It has an estimated potential of 100 MWe and the proven reserves of 12.5 MWe [1]. Geothermal development in Indonesia generally takes a long time, and it often experiences delays before an operation. The Ulumbu geothermal field is a system that has a steam cap reservoir overlying water reservoir with a temperature of 230-240°C [2, 3, 4]. Based on the 2019-2028
Electricity Supply Business Plant (RUPTL), this field will be developed for the capacity of 2×20 MWe with the target Commercial Operation Date (COD) in 2024 and 2027, which experienced delays from the previous 2018-2027 RUPTL target that is 2021 and 2026.

The development of geothermal resources has a high risk and requires a large number of funds. Therefore, before the geothermal field is developed, it is necessary to carry out a careful feasibility assessment. The feasibility assessment covers several main aspects, including technical, electricity demand, financial, legal, and socio-economic aspects. This study deals with applying an incremental development strategy in the Ulumbu field using a Wellhead Generating Unit (WGU) [5, 6]. The incremental development strategy has advantages, especially in shortening the COD period from the usual 6-7 years to 3 years of the development stage.

WGU is a power plant that is installed at the wellhead and is smaller than the central type. Unlike the conventional power plant, WGU is placed on a portable unit, generally known as skid-mounted, making it not have to wait for all wells in a field to be ready to produce. Steam was extracted and converted to electricity at the WGU [7]. The most promising applications of WGU include on-site industrial use, electricity supply in remote areas, as a tool for developing geothermal fields, and peak units for larger utilities [8].

Based on the estimated existing reserves, the Ulumbu geothermal field can still be developed as electricity infrastructure, especially from renewable energy, to increase the East Nusa Tenggara region’s electrification ratio. Further feasibility study of implementing an incremental development strategy from an economic point of view is required to support the development of the Ulumbu field. The most efficient development plan scheme can be determined by considering several factors involved in it. From the predetermined development scenario, investment feasibility analysis was carried out to investigate risks in geothermal investment through a probabilistic approach to obtain better results [9, 10].

2. Ulumbu Field Overview and Development Scenario

The Ulumbu geothermal field has the largest potential on Flores’ island, with an estimated reserve of 100 MWe and a proven reserve of 12.5 MWe [1]. The Ulumbu Geothermal Working Area (GWA) permit belongs to PT PLN (Persero) based on the Minister of Energy and Mineral Resources Decree Number 5099K/30/MEM/2016 dated 15 April 2016 with a coverage area of 18,280 hectares. The Ulumbu geothermal field was surveyed in 1972-1982 through preliminary geoscience studies (surface geology, geochemistry, geophysics, geohydrology) conducted by the Directorate of Volcanology at the Geological Agency, PT Pertamina, and PT PLN [11]. Figure 1 shows the location map of Ulumbu geothermal field.

![Figure 1](image-url) "Figure 1. The location map of the Ulumbu geothermal field in East Nusa Tenggara."
In 1994-1996, three exploration and production wells were drilled, namely ULB-01 (vertical exploration well), ULB-02 (directional well), and ULB-03 (directional well) with funding from PLN; the drilling contractor was PT Medco Energy under the supervision of GENZL in collaboration with New Zealand government [12]. The construction of power plants in the Ulumbu field has undergone 2 (two) production phases: PLTP Unit 3 and 4, COD in 2012 with 2×2.5 MWe, and PLTP Unit 1 and 2 COD 2014 with the capacity of 2×2.5 MWe.

Based on numerical modeling of the Ulumbu geothermal field using the existing conceptual model, it was found that the calculated reserves were 95 MWe at P50 with the best total generation scenario of 50 MWe [2]. From the model, the Ulumbu reservoir system is water dominated with steam-cap, and the existing wells are in the steam-cap area so that the produced fluid is dry steam [2]. The resource assessment results in the development feasibility study [13] show the power potential of 56.5 MWe at P90, higher than the planned installed power plant capacity of 50 MWe (10 + 40 MWe).

An economic analysis of the Ulumbu field in the previous study [14] was based on the field potential from numerical modeling [2, 3, 4, 5]. In this study, field development is compared between the conventional method and incremental methods using WGU technology (Figure 2). WGU technology was chosen due to its ability to generate electricity from 1 to 15 MW, with the largest offered being 25 MW (McHugh et al., 1985). The other reason to use WGU technology is the effectiveness of fluid transportation. While in conventional development, it requires longer pipelines to transport, but WGU can be placed on the same well pad as the production wells’ location, then it makes WGU uses short pipelines to transport the production fluids from one or a group of wells to the generating unit.

In the conventional development strategy, it uses the same calculation bases and parameters as previous studies. For some of the main field development cost components, data is updated using the value of the work contract that has been carried out by PT PLN (Persero) as the permit holder of the Ulumbu geothermal field. In the first period of development, it is assumed that it does not require make-up wells and uses existing exploration wells. In the second period, a development unit of 2×20 MW is added with different COD times, namely in 2020 and 2024. In the second period, it requires an additional 7 (seven) production wells, 9 (nine) make-up wells, and 1 (one) injection well.

**Figure 2.** Development Strategy Comparison (Conventional and Incremental).
Table 1. Ulumbu Field Development Scenario.

| No. | Development Scenario               | Capacity                   |
|-----|------------------------------------|----------------------------|
| 1   | Conventional (RUPTL)               | 4×2.5 MW (existing)        |
|     |                                    | 2×20 MW (development)      |
| 2   | Incremental (RUPTL) - A            | 4×2.5 MW (existing)        |
|     |                                    | 8×5.0 MW (development)     |
| 3   | Incremental (RUPTL) - B            | 4×2.5 MW (existing)        |
|     |                                    | 16×2.5 MW (development)    |

Table 1 shows the scenarios of the Ulumbu field development plan. In each scenario, the economic parameters will be used to determine whether the scenario is a good development alternative.

3. Methodology

This study begins by determining the field development scheme based on the development targets set in the RUPTL and the development plan. At this stage, a study of the field development scheme based on incremental development is carried out using a wellhead unit according to the development targets set in the RUPTL and the development plan.

There are 3 (three) development strategies used in developing the model: the conventional development strategy (updating), the conventional RUPTL development strategy, and the RUPTL incremental development strategy. In the 3 (three) existing development strategies, a technical, economic, and risk comparison analysis was carried out related to the development of the Ulumbu geothermal field, emphasizing economic development studies.

Figure 3. Working Flowchart of This Study.

The flowchart of the study is shown in (Figure 3). Several assumptions were made based on the exploration drilling activity for 3 (three) Ulumbu wells in 1994-1995. The other assumption is that the project schedule for exploration activities was assumed to be 7 (seven) years before the COD of the first unit. The assumption is made as an adjustment to the previous studies’ scheme to compare and accommodate the geothermal development period. The calculation of economic analysis for each development strategy has been determined with the output in the form of total investment, investment
per MW, rate of return, and other economic parameters based on the evaluation of Cost of Production (BPP) in the East Nusa Tenggara region.

4. Development and Financial Model

A development scheme is used in the conventional development strategy based on a feasibility study conducted by PLN in 2018 and adjusted to the Ulumbu field development target plan in 2019-2028 (Figure 4). There are 2 (two) main development periods in this strategy, namely the first period (Unit 1, 2, 3, 4) with a capacity of 4×2.5 MW as the existing unit and the second period (Units 5&6) as a development unit with a capacity of 2×20 MW. The power plant cycle type used in the second period is the condensing type wellhead generating unit as in the previous development.

In the incremental development strategy, the power plant development’s total capacity follows the previous feasibility study done by PLN in 2018, with an additional 40 MW (Figure 5). Adjustment of the development stages in this strategy uses the type of wellhead unit, where the development period was divided into 2 (two) scenarios, namely 8×5 MW and 16×2.5 MW. The condensing type choice is based on steam consumption efficiency compared to backpressure units and minimizing the same problems as in the existing Ulumbu unit (noise pollution and corrosion of generating equipment).

The project economic study stages include creating and analyzing economic feasibility through economic modeling as shown in Figure 6, which will calculate economic projections from both the financing and income structures. This calculation obtains economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR) of the project, and Profitability Index (PI).
In the economic calculations, it is necessary to determine several assumptions, including the power plant design parameters, parameters of the financial model development, the financial assumptions used, the cost assumption parameters, well test data, and additional data.

4.1. Development Schedule
In planning the development schedule, an approach is used to calculate project achievements in one year. In general, the development schedule is compiled based on the development guidelines compiled by [16], and the details of the Ulumbu development schedule are in Table 2.

4.2. Tangible and Intangible Capital Investment
The geothermal financial model should integrate all the costs through all development phases and presents the resulting information for users to make the appropriate decision [17]. Capital investment decision in the geothermal business covers upstream and downstream investment capital. Upstream capital investment focused on steam availability and downstream investments related to electricity generation.

Upstream capital investment coverage consists of well cost, access road and site work cost, steam gathering cost, and production facilities (piping and connection) cost. Therefore, upstream capital investment is divided into two tangible and intangible capital investments.

Some references assumed that intangible investment capital is 30% of wells, land, road access, and site work cost, while steam gathering system cost, piping, and production facility cost is tangible investment capital [18]. Downstream investment capital consists of EPC (engineering, procurement, construction) power plant cost, commissioning cost, and supervision cost. Detailed development schedules related to planning for the investment stages in the Ulumbu field are shown in Table 2.
Table 2. Ulumbu Field General Development Schedule modified from [16].

| PARAMETERS                                      | Years |
|------------------------------------------------|-------|
|                                                | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
| STEAM FIELD DEVELOPMENT                        |      |      |      |      |      |      |      |
| Capital                                        |      |      |      |      |      |      |      |
| Exploration Drilling                           |      |      |      |      |      |      |      |
| Production Well                                |      | 50%  | 50%  |      |      |      |      |
| Injection Well                                 |      |      |      |      |      |      |      |
| Make-up Well                                   |      |      |      |      |      |      |      |
| Land cost, access, and site work               |      |      |      |      |      |      |      |
| (incl. Env. Study and Civil Work)              |      |      |      |      |      |      |      |
| Steam Gathering System and Substation, Transmission |      | 50%  | 50%  |      |      |      |      |
| SAGS (Piping and Production Facilities)        |      | 50%  | 50%  |      |      |      |      |
| Connection/ Transmission                       |      |      |      |      |      |      |      |
| (Switchyard, Grid Connection, Transmission)    |      | 50%  | 50%  |      |      |      |      |
| Expense                                        |      |      |      |      |      |      |      |
| Detailed GGG Survey                            |      | 50%  | 50%  |      |      |      |      |
| Core holes                                     |      |      |      |      |      | 100% |      |
| Resource study & Modelling                     |      |      |      |      |      | 100% |      |
| Operating Cost (Upstream)                      |      |      |      |      |      |      |      |
| Feasibility Study                              |      |      |      |      |      |      | 100% |
| PLANT DEVELOPMENT                              |      |      |      |      |      |      |      |
| Capital                                        |      |      |      |      |      |      |      |
| Power Plant (EPCC) - (Condensing Turbine)      |      | 33%  | 33%  | 33%  |      |      |      |
| Expense                                        |      |      |      |      |      |      |      |
| Operating Cost (Downstream)                    |      | 14%  | 14%  | 14%  | 14%  | 14%  | 14%  |
| Others Cost (Administration/Management)        |      | 14%  | 14%  | 14%  | 14%  | 14%  | 14%  |

4.3. Revenue
In each development scenario’s economic modeling, the income comes from the power plant’s electricity generation. In general, the geothermal power plant capacity factor is 90-95% under normal operating conditions [19].

4.4. Tax Component
In the calculation of financial modeling, the tax component refers to the applicable regulations such as the Minister of Finance Regulation No. 21/PMK.011/2010 for incentive tax [20] and Law No. 36/2008 [21] for Indonesia’s corporate tax rate. The investment tax allowance is 30% of the total investment gradually over 6 (six) years (5% per year).

4.5. Loan
Comparison of debt to equity composition in project investment depends on project profitability, tangibility, and total debt, where 70:30 composition is generally used [22].
4.6. Economic Parameters

Table 3 shows the economic parameters used in this study and the reference used to determine the value. Several components were used as development scenarios in the Ulumbu field.

Table 3. Summary of Ulumbu Field Cost Components.

| Parameters                                                   | Unit          | Price per unit (million US$) | Ref. |
|--------------------------------------------------------------|---------------|------------------------------|------|
| STEAM FIELD DEVELOPMENT                                      |               |                              |      |
| Capital                                                      |               |                              |      |
| Exploration Drilling                                         | Well          | 4.00                         | 7.00 | 8.00 | [23] |
| Production Drilling                                          | Well          | 4.00                         | 7.00 | 8.00 | [23] |
| Make-up Well                                                 | Well          | 4.00                         | 7.00 | 8.00 | [23] |
| Injection Well                                               | Well          | 4.00                         | 7.00 | 8.00 | [23] |
| Land Cost, Access Road, Site Work                            | Ls            | 5.00                         | 7.00 |      | [24] |
| Steam Gathering System and Substation                        | Activity/MW   | 0.24                         | 0.32 | 0.44 | [16] |
| SAGS (Piping and Production Facility)                       | Activity      | 0.33                         | 0.35 | 0.40 | [25] |
| Expense                                                      |               |                              |      |
| Detailed GGG Survey                                          | Activity      | 1.00                         | 2.00 | 3.00 | [23] |
| Core Holes                                                   | Activity      | 1.00                         |      | 1.20 | [23] |
| Resource Study                                               | Activity      | 0.10                         |      | 1.12 | [23] |
| Operating Cost (upstream)                                    | Activity/MW   | 0.03                         |      | 0.036| [23] |
| Feasibility Study                                            | Activity/MW   | 0.10                         | 0.14 | 0.20 | [23] |
| PLANT DEVELOPMENT                                            |               |                              |      |
| Capital                                                      |               |                              |      |
| Power Plant – EPCC – Back Pressure                           | MW            | 3.00                         |      |      | [23] |
| Power Plant – EPCC – Condensing                              | MW            | 4.00                         |      |      | [23] |
| Expense                                                      |               |                              |      |
| Operation Cost (Downstream)                                  | /MW/year      | 0.08                         |      |      | [23] |
| Others Cost (Administration and Management)                  | Activity/MW   | 0.20                         |      |      | [23] |

5. Results and Discussion

The economic model was developed for each Ulumbu field development scenarios using a probabilistic approach with the Monte Carlo simulation. Monte Carlo simulation is programmed using Excel® (Microsoft Corporation) spreadsheet. The Monte Carlo simulation is implemented to calculate the probability of 90% ($P_{90}$), 50% ($P_{50}$), and 10% ($P_{10}$) of total investment and economic parameters. The economic parameters applied in the analysis are Net Present Value (NPV), Profitability Index (PI), and Internal Rate of Return (IRR) for each development scenario.

5.1. Financial Modelling

Some of the parameters used in the economic analysis of the development strategy include technical parameters for calculating cash flow (capacity factor, decline rate, generation time) and financial parameters for calculating cash flow (interest rate, interest during construction (IDC), repayment schedule, depreciation rate and period). Table 4 shows several economic modeling variables used as the basis for calculating each development strategy.
### Table 4. Variables Affecting Financial Modelling.

| Technical Variables          | Parameter                  | Value  | References |
|-----------------------------|----------------------------|--------|------------|
| Capacity Factor             | 90%                        |        | [19], [13]|
| Success Ratio (Dev. Well)   | 80%                        |        | [25], [13]|
| Additional Production Factor| 25%                        |        | Expert Judgement |

| Financial Variables         | Parameter                  | Value        | References |
|-----------------------------|----------------------------|--------------|------------|
| Depreciation Period         | 8 Years                    |              | [20]       |
| Depreciation Rate (Double Decline Balance) | 25%                      |              | [20]       |
| Equity: Debt                | 30:70                      |              | [22], [13]|
| Loan Period                 | 20 Years                   |              | [22]       |
| Interest                    | 4%                         |              | [22]       |
| Interest During Construction| 4%                         |              | [22]       |
| Production Bonus            | 0.50%                      |              | [26]       |
| Tax Rate                    | 25%                        |              | [21]       |
| Investment Tax Allowance    | 30%                        |              | [20]       |
| Discount Rate               | 10%                        |              | [22]       |

Economic analysis on each development strategy: total investment, investment per MW, Net Present Value, Productivity Index, and Internal Rate of Return was made based on the Cost of Production (BPP) in the East Nusa Tenggara region. Table 5 shows the national BPP’s value and the East Nusa Tenggara (West Flores) region in 2019.

### Table 5. The average cost of electricity generation (BPP) in 2019

| Region                        | BPP Rates (US cent/kWh) |
|-------------------------------|--------------------------|
| National – Indonesia          | 7.86                     |
| East Nusa Tenggara (West Flores) | 17.58                   |

5.2. Economic Parameter Calculation

5.2.1. Total Investment. The total investment per MW in the calculation of conventional (2 × 20 MW), Incremental (8 × 5 MW), and Incremental (16 × 2.5 MW) development scenarios are shown in Table 6. The investment cost is still in the range of global geothermal development between 3 to 6 million USS/MW [24]. The investment cost is obtained by assuming the drilling price is in the highest upper limit range.
Table 6. Monte Carlo simulation of the total investment/MW

| Probability | Conventional (2×20 MW) | Incremental (8×5 MW) | Incremental (16×2.5 MW) |
|-------------|-------------------------|-----------------------|-------------------------|
|             | Value                   | Value                 | Value                   |
| P<sub>10</sub> | 5.85                    | 5.56                  | 5.59                    |
| P<sub>50</sub> | 5.93                    | 5.66                  | 5.68                    |
| P<sub>90</sub> | 6.01                    | 5.73                  | 5.75                    |

5.2.2. Net Present Value (NPV). Table 7 shows the results of the Monte Carlo simulation for the conventional (2×20 MW), Incremental (8×5 MW), and Incremental (16×2.5 MW) development scenarios. This value indicates that the development scenario is still feasible because the NPV at P<sub>10</sub>, P<sub>50</sub>, and P<sub>90</sub> are positive.

Table 7. Monte Carlo simulation of NPV.

| Probability | Conventional (2×20 MW) | Incremental (8×5 MW) | Incremental (16×2.5 MW) |
|-------------|-------------------------|-----------------------|-------------------------|
|             | Value                   | Value                 | Value                   |
| P<sub>10</sub> | 41.59                   | 44.53                 | 42.97                   |
| P<sub>50</sub> | 42.92                   | 45.95                 | 44.28                   |
| P<sub>90</sub> | 44.57                   | 47.72                 | 46.02                   |

5.2.3. Profitability Index (PI). Table 8 shows the profitability index of the Monte Carlo simulation for the conventional development scenarios (2×20 MW), Incremental (8×5 MW), and Incremental (16×2.5 MW). This value indicates that the development scenario is still feasible because the PI values at P<sub>10</sub>, P<sub>50</sub>, and P<sub>90</sub> are worth more than 1.2.

Table 8. Monte Carlo simulation result of PI calculation result.

| Probability | Conventional (2×20 MW) | Incremental (8×5 MW) | Incremental (16×2.5 MW) |
|-------------|-------------------------|-----------------------|-------------------------|
|             | Value                   | Value                 | Value                   |
| P<sub>10</sub> | 1.53                    | 1.60                  | 1.58                    |
| P<sub>50</sub> | 1.56                    | 1.64                  | 1.61                    |
| P<sub>90</sub> | 1.60                    | 1.69                  | 1.66                    |

5.2.4. Electricity Tariff. Table 9 shows the electricity tariff of the Monte Carlo simulation for the conventional (2×20 MW), incremental (8×5 MW), and incremental (16×2.5 MW) development scenarios with a base IRR of 12%. This tariff shows that the development scenario is still feasible because it has a tariff below 80% of the BPP for the East Nusa Tenggara region at P<sub>50</sub>.
Table 9. Comparison of electricity tariff for each scenario.

| Parameter (P50)  | Conventional (2×20 MW) | Incremental (8×5 MW) | Incremental (16×2.5 MW) | Unit   |
|------------------|------------------------|-----------------------|-------------------------|--------|
| Electricity Tariff | 10.12                  | 9.69                  | 9.86                    | Million US$   |
| NPV              | 10.5                   | 9.72                  | 9.65                    | Million US$   |
| IRR              | 12%                    | 12%                   | 12%                     | %        |
| PI               | 1.13                   | 1.13                  | 1.13                    |          |

Table 10 shows the comparative value of economic parameters (NPV, IRR, and PI) in the conventional (2×20 MW), incremental (8×5 MW), and incremental development strategy (16×2.5 MW). It shows that the incremental development scenario, either the scheme (8×5 MW) or (16×2.5 MW), is feasible to be applied in the Ulumbu field and can be adjusted to the projected demand in that area.

Table 10. Monte Carlo simulation of financial parameters for different scenarios.

| Parameter (P50)  | Conventional (2×20 MW) | Incremental (8×5 MW) | Incremental (16×2.5 MW) | Unit   |
|------------------|------------------------|-----------------------|-------------------------|--------|
| Total Cost/MWe   | 5.93                   | 5.66                  | 5.68                    | Million US$   |
| NPV              | 42.92                  | 45.95                 | 44.28                   | Million US$   |
| IRR              | 16.65                  | 17.19                 | 17.03                   | %        |
| PI               | 1.56                   | 1.64                  | 1.61                    |          |

Sensitivity analysis is also carried out on modeling economic parameters to see how the IRR varies depending on each financial parameter. IRR values were shown in Figure 7-9.

Figure 7. The sensitivity of financial parameter for conventional development (2×20 MW).
6. Conclusion

Based on the technical and economic analysis, the investment cost of an incremental development strategy in the Ulumbu field is lower than the conventional development strategy. The investment of the conventional development strategy (2 × 20 MW) is US$5.93 million per MW, while for the incremental development strategy - RUPTL (8 × 5 MW) is US$5.66 million per MW and (16 × 2.5 MW) is 5.68 million US$ per MW for a total capacity of 50 MW including the existing unit. When the electricity price is 80% of the Flores regional BPP (14 cents US$/kWh - 15 cent US$/kWh), the incremental development strategy yields better economic parameters, namely IRR 17.19%, NPV 45.95 million US$, PI 1.64 for 8 × 5 MW scenario and IRR 17.03%, NPV 44.28 million US$, PI 1.61 for 16 × 2.5 MW scenario. Analysis of the total investment and economic parameters show that the incremental development strategy using either the 8 × 5 MW or 16 × 2.5 MW scenarios is an attractive alternative for the Ulumbu field development.

7. Recommendation

Several improvements to the modeling of the Ulumbu field development scheme can be made, including:

1. Economic calculations in the Ulumbu field can be done in more detail based on updating the actual completion targets at each stage of the Ulumbu field development.
2. It is necessary to assess the technical design of the WGU in more detail and power plant cycles, such as backpressure and Organic Rankine Cycle (ORC), to obtain optimal development capacity that fits the resource characteristics and to minimize the development risk.
8. Disclaimer
This study’s development strategy refers to the COD target for developing the Ulumbu field under the 2019-2028 Electricity Supply Business Plant (RUPTL).

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