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Application of United Nations Framework Classification for Resources (UNFC) in Ulumbu Geothermal Field, East Nusa Tenggara, Indonesia

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Abstract. The Ulumbu Geothermal Field, located in East Nusa Tenggara and operated by PT PLN (Persero), is strategically supporting Indonesia's renewable energy goals. Ulumbu Geothermal Power Plant currently operates at a total capacity of 10 MW (4 × 2.5 MW) and has an estimated additional potential of at least 40 MW for future development. Although the field has been in operation for several years, PLN has not yet implemented an internationally recognized classification framework such as the United Nations Framework Classification for Resources (UNFC) to manage its geothermal assets. This paper explores the application of the UNFC to the Ulumbu Geothermal Field by assessing its geothermal resources through three fundamental criteria of environmental-socio-economic viability (E-axis), technical feasibility (F-axis), and degree of confidence in the estimate (G-axis). Utilizing publicly available data and internal reports, the study evaluates how the field's current status aligns with each UNFC axis. The results provide classification of the Ulumbu geothermal resources according to UNFC and highlight the challenges and opportunities of adopting such a system in PLN. The findings suggest that applying UNFC can enhance project transparency, optimize decision-making, and support more sustainable geothermal development in Indonesia.

Keywords: *geothermal, resource, classification, development, UNFC, PT PLN (Persero), Ulumbu Geothermal Field.*

1 Introduction

Located at the Pacific Ocean ring of fire, Indonesia holds one of the largest geothermal potentials globally, with an estimated 23,060 MW in resources and reserves. However, according to EBTKE [1] the current installed geothermal power plant capacity is only 2,417.7 MW. This gap presents a significant opportunity, but also a challenge, in achieving the national energy mix target and supporting the transition from fossil fuels to renewable energy sources—one of the key goals set out in the National Energy Policy (KEN), as stipulated in Presidential Regulation No. 79 of 2014.

In line with these goals, PT PLN (Persero) ("PLN") has been tasked with developing several geothermal working areas across Indonesia, as outlined in the Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PLN 2021–2030 [2]. Most of these geothermal working areas remain at the exploration stage, with only surface data (geological, geochemical, and geophysical) available. Only a few have well data from exploration drilling. This lack of subsurface data leads to high uncertainty in estimating geothermal reserves.

One of geothermal working areas, the Ulumbu Geothermal Field, located in East Nusa Tenggara (Figure 1) and operated by PLN, strategically supports Indonesia's renewable energy goals. Ulumbu Geothermal Power Plant currently operates at a total capacity of 10 MW (4 x 2.5 MW), which has been operating since 2012 and 2014. Ulumbu Geothermal Field has an estimated additional potential of at least 40 MW for future development. Although the field has been in operation for several years, PLN has not yet implemented an internationally recognized classification framework such as the United Nations Framework Classification for Resources (UNFC) to manage its geothermal assets.

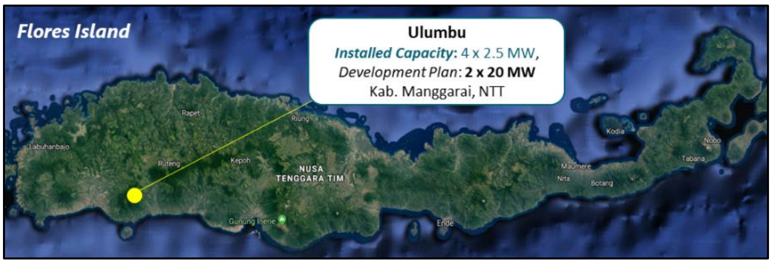

Figure 1 Location of Ulumbu Geothermal Field

Indonesia was selected as the first country to pilot the UNFC geothermal classification system. The pilot project focused on the Mataloko Geothermal Field, located in Bajawa, Flores Island, under the concession of PLN. Although rich in geothermal potential, this area serves a region with modest electricity demand. The implementation was integrated with the ITB International Geothermal Workshop (IIGW) in March 2018. The program included a plenary presentation, a short course with 83 participants, and a full-day technical workshop hosted by Indonesia's Geological Agency. Despite varying attendance, these sessions helped raise awareness and laid the groundwork for practical application. The UNFC classification result for Mataloko Geothermal Field is E2; F3; G4, as reported by IRENA and IGA in [3]. In summary, the pilot project in Indonesia highlighted the potential and the challenges of applying UNFC, emphasizing the need for greater data access, more profound exploration, and sustained capacity building.

The main objective of this study is to apply the UNFC classification system to one of PLN's geothermal working areas. Ulumbu Geothermal Field is selected to represent various stages of development, which have already been developed with an operational geothermal power plant and holds the potential for further resource utilization. By applying UNFC, geothermal project classification becomes more structured and transparent. Enhancing the classification status can help attract investment and promote further development. Therefore, this study explores the application of UNFC as a strategic tool for managing and optimizing the geothermal potential in PLN's concessions, ultimately aiming to boost project sustainability, economic value, and Indonesia's contribution to energy diversification and climate change mitigation.

2 Overview of UNFC Classification System

2.1 History and Purpose of UNFC

The United Nations Framework Classification for Resources (UNFC) was initially established to provide a standardized system for classifying fossil energy and mineral reserves and resources. The first version of UNFC, United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) was issued at the end of 2013 [4]. In 2017, its scope was expanded and renamed simply United Nations Framework Classification for Resources (UNFC), reflecting its broader applicability to all types of natural resources, including renewable energy, minerals, nuclear fuels, geothermal, hydrocarbons, water, and storage projects. On December 30, 2019, the United Nations Economic Commission for Europe (ECE) released the update of the United Nations Framework Classification for Resources (UNFC (2019)) in [5]. This development necessitated an update to the Specifications and additional Guidance to support their implementation and adoption.

The primary purpose of UNFC is to support: (i) sustainable resource management, (ii) policy formulation, (iii) investment decision making, and (iv) harmonization of resource reporting systems. In alignment with the United Nations 2030 Agenda for Sustainable Development, the updated 2019 version of UNFC incorporates environmental and social considerations as central to the classification process. This makes UNFC particularly valuable for guiding the development of resource projects that balance economic, technical, environmental, and social priorities.

2.2 Explanation of UNFC Categories and Classes

UNFC is a project-based, principles-based classification system. It evaluates projects based on three fundamental criteria-key dimensions: (i) Environmental-socio-economic viability (E-axis), (ii) Technical feasibility (F-axis), and (iii) Degree of confidence in resource estimates (G-axis).

Each dimension is represented numerically (e.g., E1, F2, G3), which allows projects to be systematically categorized and compared using a three-dimensional code (Figure 2). This framework facilitates consistent communication among industries, governments, and financial institutions.

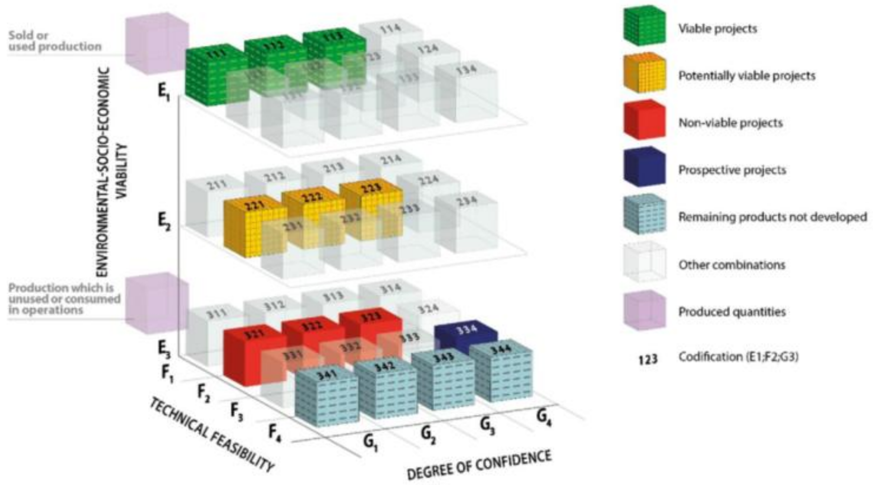

Figure 2 UNFC Categories and Example of Classes by ECE [5]

By combining values from these axes, UNFC defines six primary classes, each representing a distinct maturity level of a resource project as shown in Table 1.

Table 1 Abbreviated Version of UNFC showing Primary Classes by ECE [5]

	Produced	Sold or used production / Production which is unused or consumed in operations[a]			
		Class	Minimum Categories		
			E	F	G[b]
Total Products	The project's environmental-socio-economic viability and technical feasibility has been confirmed	Viable Projects[c]	1	1	1, 2, 3
	The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed	Potentially Viable Projects[d]	2[e]	2	1, 2, 3
		Non-Viable Projects[f]	3	2	1, 2, 3
	Remaining products not developed from identified projects[g]		3	4	1, 2, 3
	There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility	Prospective Projects	3	3	4
	Remaining products not developed from prospective projects[g]		3	4	4

To further distinguish between project stages, UNFC defines sub-classes based on project maturity and readiness for development as shown in Table 2.

Table 2 UNFC Classes and Sub-classes defined by Sub-categories by ECE [5]

UNFC Classes Defined by Categories and Sub-categories						
Total Products	Produced	Sold or used production				
		Production which is unused or consumed in operations				
		Class	Sub-class	Categories		
				E	F	G
	Known Sources	Viable Projects	On Production	1	1.1	1, 2, 3
			Approved for Development	1	1.2	1, 2, 3
			Justified for Development	1	1.3	1, 2, 3
		Potentially Viable Projects	Development Pending	2[b]	2.1	1, 2, 3
			Development On Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development Not Viable	3.3	2.3	1, 2, 3
		Remaining products not developed from identified projects		3.3	4	1, 2, 3
	Potential Sources	Prospective Projects	[No sub-classes defined]	3.2	3	4
		Remaining products not developed from prospective projects		3.3	4	4

This organized classification enables governments, industries, and investors to assess resource projects uniformly, prioritize developments, and oversee portfolios in accordance with sustainable development goals.

2.3 Advantages Over Other Classification Systems

The United Nations Framework Classification for Resources (UNFC) provides several advantages over national or industry-specific geothermal classification systems, such as the Australian Geothermal Code by Australian Geothermal Reporting Code Committee in [6], Canadian Code by The Canadian Geothermal Code Committee (CGCC) in [7], and Indonesia's SNI 6009:2017 by Badan Standardisasi Nasional in [8]. These advantages are particularly important for ensuring clarity, interoperability, and sustainable development in resource evaluation.

UNFC offers several key advantages over conventional national classification systems. Its globally standardized structure enables consistent assessment across fossil, mineral, and renewable resources, minimizing discrepancies among stakeholders and enhancing comparability across countries. Unlike other codes that are limited in scope, UNFC is adaptable to all resource types—including geothermal, solar, hydro, hydrocarbons, and minerals—making it especially valuable for integrated energy planning and sustainability reporting. Its clear, transparent framework supports more informed investment and policy decisions by linking resource potential to development readiness and regulatory requirements. Furthermore, UNFC's wide applicability across technical experts, government agencies, corporate entities, and financial institutions fosters cross-sector collaboration and strategic alignment in resource management.

3 Overview of Ulumbu Geothermal Field

The Ulumbu geothermal field is located in Manggarai Regency on Flores Island, in the East Nusa Tenggara Province of Indonesia, roughly 20 km south of Ruteng City. This area has been researched for geothermal power plant development since the early 1970s. Enhanced 3G studies commenced in 1984 and were compiled in a study by Mahon, T., et al. in [9]. Between 1994 and 1996, three wells were drilled: one vertical well (ULB-01) and two directional wells (ULB-02 and ULB-03). Of these, only ULB-02 was used as a production well, yielding a total of 10 MWe. Findings indicate that the Ulumbu geothermal field primarily consists of Quaternary andesitic lava and pyroclastic rocks altered by neutral pH fluids, with various thermal features identified in the crater and on the western slope of the Poco Leok complex, as noted by Kasbani, et al., in [10]. Subsurface data and subsequent studies suggest that the Ulumbu geothermal field is a hydrothermal system with a reservoir mainly in the liquid phase. The field still has significant development potential, with an estimated capacity of at least 40 MW according to PLN in [11].

The Ulumbu geothermal field is located within the Quaternary Rii Caldera, indicating it functions as a volcano-hydrothermal system. Geophysical data imply that the heat source is likely situated beneath Lungar Crater and Ulumbu Crater, at a depth of about 4 km according to LAPI ITB and PLN [12]. The age of the volcanostratigraphic units in the study area aligns with the Older Pleistocene Volcanic Deposits Unit (QTv), which dates back roughly 258,000 to 180,000 years ago. Reservoir identification in the geothermal system is based on the positions of upflow zones. The existence of two distinct upflow zones (Lungar Crater and Ulumbu Crater) suggests there may be two separate reservoirs located beneath each crater at shallower depths, as shown in Figure 3. The heat source factor indicates a favorable likelihood according to the latest conceptual model, supported by recent field data.

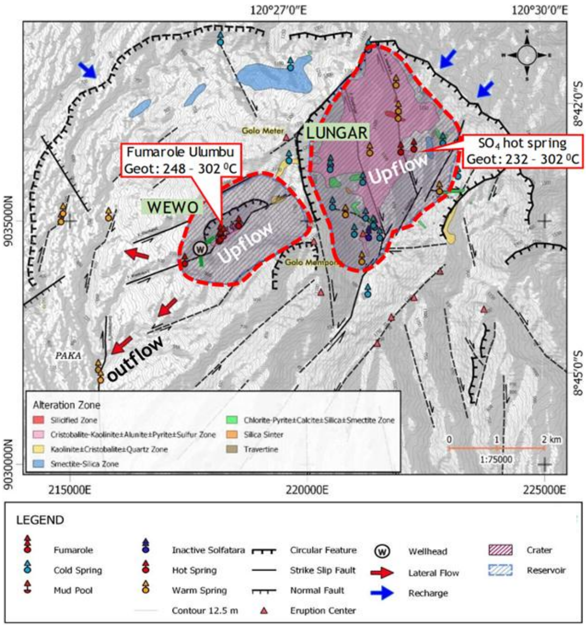

Figure 3 Conceptual Model Ulumbu Geothermal Field (Map View) by LAPI ITB and PLN [12]

The exploitable resource area in the Wewo prospect is estimated at 1.5 to 4.0 km², while the Lungar prospect ranges from 1.6 to 10.2 km². Reservoir thickness is assessed through well and gravity data. The top of the reservoir is marked by the presence of epidote minerals in the well data. Bedrock distribution is estimated through forward gravity modeling, with reservoir thickness around 1,000 to 1,500 meters. The Ulumbu geothermal system cap rock measures 500 to 800 meters thick, based on MT geophysical data showing a conductive zone (7-10 Ωm) at -300 meters elevation. Drilling shows alteration minerals like smectite and chlorite-smectite around ±800 meters depth.

Temperature estimates come from well data and fumarole geothermometry. Gas and liquid geothermometry from Ulumbu crater show temperatures of 248-302°C in the Wewo prospect, while those in the Lungar area suggest reservoir temperatures of 232-302°C. Previous drilling indicated around 240°C in wells ULB-1, ULB-2, and ULB-3 at depths of 700-800 mD. Well data imply a steam-dominated upper section and a water-dominated lower section with temperatures of 230-240°C. The updated model gives a detailed view of the Ulumbu geothermal system, highlighting upflow zones at Ulumbu and Lungar Craters and an outflow zone in the Paka area (flowing west), as shown in Figure 4.

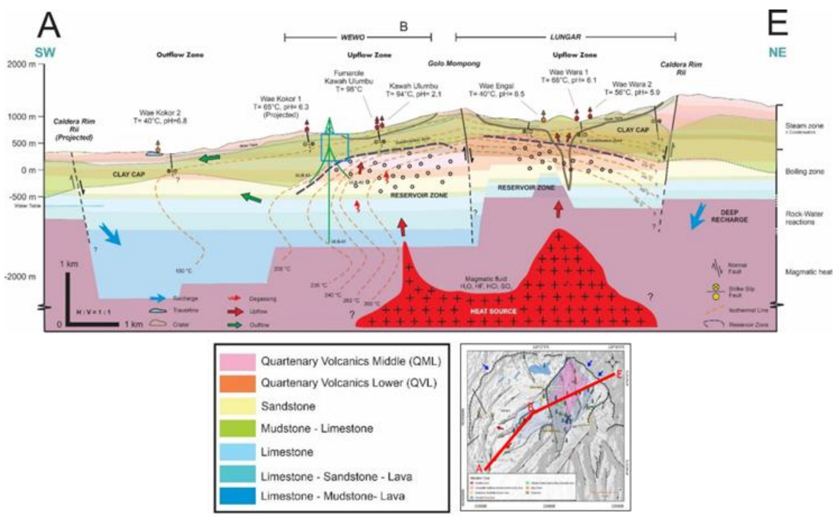

Figure 4 Geothermal Conceptual Model Ulumbu by LAPI ITB and PLN [12]

4 Ulumbu UNFC Case Study

4.1 Technical and Commercial Data for UNFC Application

The Ulumbu geothermal project has accumulated comprehensive technical data from exploration and development phases, supporting its classification under the UNFC framework:

1. 3G (geology-geochemistry-geophysics) Studies by PLN in [11], LAPI ITB and PLN in [12]: Detailed mapping and stratigraphy confirm the volcanic-sedimentary nature of the field, including hydrothermal alteration zones, fracture intensity, and tectonic structures relevant to reservoir identification. Extensive analysis of water, gas, and condensate samples supports temperature estimation and reservoir condition interpretation using geothermometers and isotope studies. Geophysics surveys using magnetotelluric (MT), gravity, and microseismic (MEQ) methods have delineated resistivity structures and reservoir geometry, confirming fluid pathways and heat source configurations.
2. Exploratory Drilling by PLN in [11], LAPI ITB and PLN in [12]: Multiple wells (ULB-1, ULB-2, ULB-3, etc.) have been drilled with data on temperature profiles, fluid chemistry, flow testing, and injection performance. These wells help define reservoir productivity and size.
3. Conceptual Model by LAPI ITB and PLN in [12]: A robust model integrating geological, geochemical, and geophysical data has been established, aiding in power density and stored heat estimation.

4. Resource Quantification by LAPI ITB and PLN in [12]: Volumetric methods and power density analysis have been applied to estimate reserves and resource boundaries.
5. Well Design & Prognosis by LAPI ITB and PLN in [12]: Detailed well targets and logging data from new pads (E, F, G) are available for field expansion, which is crucial for resource upscaling.

The Ulumbu geothermal project has undergone a comprehensive techno-economic assessment that supports its viability:

1. Feasibility Study by PLN in [11]: The comprehensive feasibility report details the design of a plant (2 × 20 MW planned), the steam gathering system, transmission lines, and the layout of the infrastructure.
2. Financial Analysis by PLN in [11]: The cost estimates comprise CAPEX, OPEX, drilling expenses, EPC contracts, and key economic indicators such as IRR and the payback period. Sensitivity analyses assess the impact of various cost and revenue scenarios.
3. Power Market by PLN in [11]: PLN's demand forecast and the expansion of the system in Flores bolster long-term offtake. The geothermal units are anticipated to replace diesel generation, enhancing the reliability of the energy mix.
4. Permitting and ESIA (Environmental and Social Impact Assessment) by PLN in [13]: A comprehensive assessment has been conducted by national regulations and World Bank policies, addressing issues like land acquisition, biodiversity, social acceptance, and environmental risks.
5. Risk Assessment by PLN in [13]: Recognized risks encompass drilling uncertainty, hydrological variability, and community engagement. Strategies for mitigation are outlined in the development roadmap.

4.2 Classification and Assessment Process

To assist in classifying geothermal projects in line with the UNFC (2019) [5], a document named Supplementary Specifications for the Application of the United Nations Framework Classification for Resources (Update 2019) (UNFC (2019)) by UNECE-IGA in [14] was developed specifically for geothermal energy resources.

The decision trees developed by UNECE-IGA in [14] are designed to help classify a geothermal project according to UNFC (2019). Each of the three axes of UNFC (2019)—E, F, and G—is represented by its own decision tree as shown in Figure 5-7. Users can navigate through the arrows from one decision box to another, ultimately reaching a box that provides the best classification at the highest hierarchical level for the specified axis.

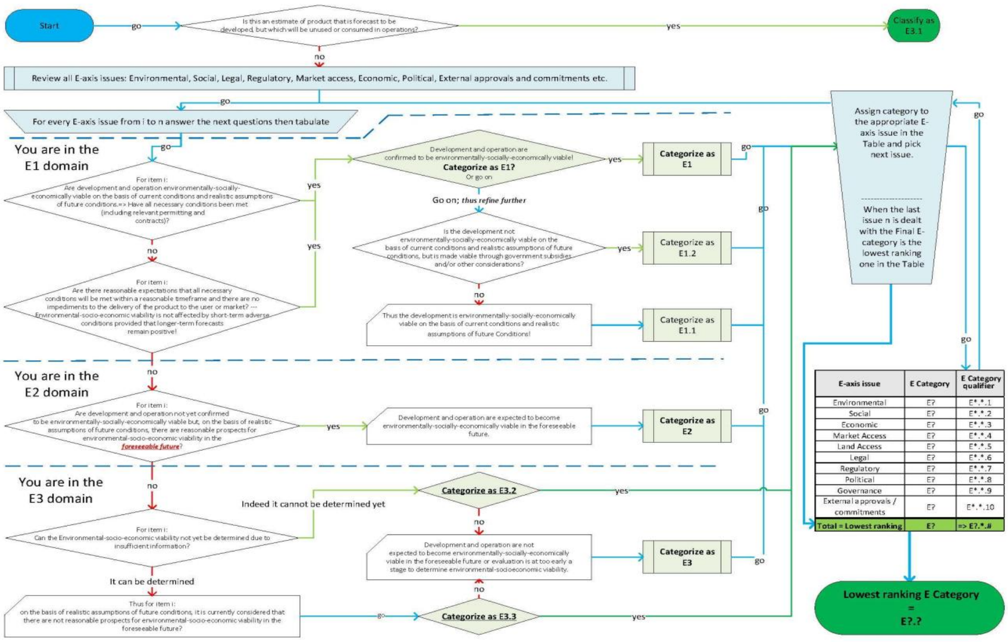

Figure 5 E-axis Decicion Tree by UNECE-IGA in [14]

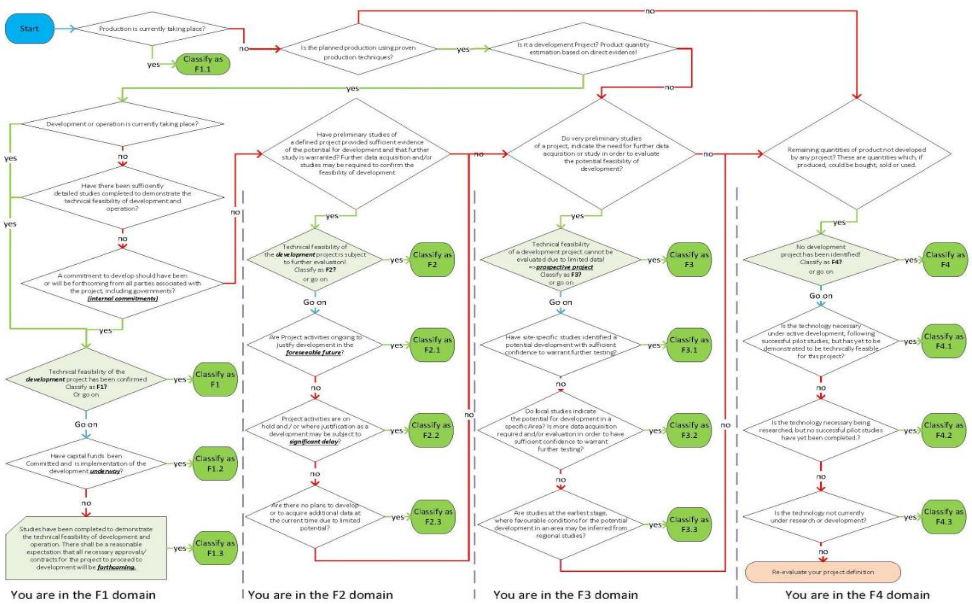

Figure 6 F-axis Decicion Tree by UNECE-IGA in [14]

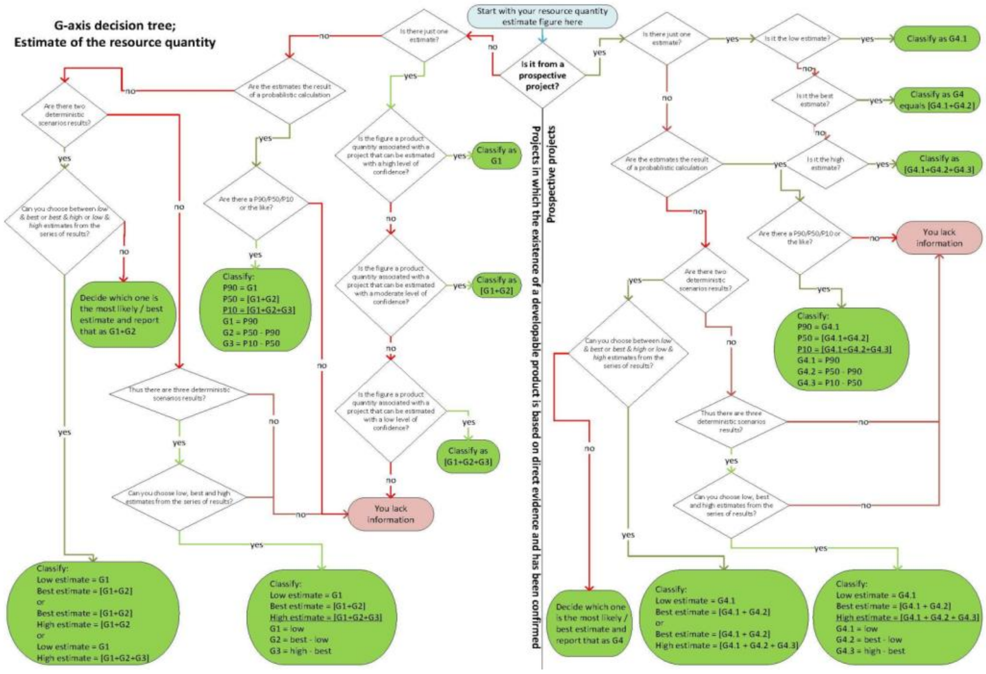

Figure 7 G-axis Decicion Tree by UNECE-IGA in [14]

This document by UNECE-IGA in [14] is designed for a variety of stakeholders, including: (i) policymakers and regulators involved in managing natural resources, (ii) corporate professionals overseeing internal resource governance, and (iii) financial reporting entities.

4.3 Classification Results

Project Location: Manggarai Regency, Flores Island, East Nusa Tenggara Province, Indonesia

Data Date: 2020

Date of Evaluation: May, 2025

Quantification Method: Monte carlo simulation of a volumetric heat assessment and power density method

Estimate Type: Probabilistic

Product Type / Geothermal Energy Product: Electricity

Reference Point: The reference point for all project is the station switchyard, where the power is exported to the Flores Island isolated local grid.

Project Lifetime: 30 years

Table 3 UNFC classification of the present production project (Unit 1-4)

Category	UNFC Definition	Reasoning for Classification
E1	*Development and operation are confirmed to be environmentally -socially - economically viable*	- Energy is being successfully extracted and converted to electricity at the required commercial rate - Social issues occurred several times. PLN and Government helped in solving the issues
Subcategory	**UNFC Definition**	
E1.1	*Development is not environmentally – socially -economically viable on the basis of current conditions and realistic assumptions of future conditions, but is made viable through government subsidies and/or other considerations*	
Category	**UNFC Definition**	**Reasoning for Classification**
F1	*Technical feasibility of a development project has been confirmed*	13 and 11 years of production and selling energy to the Flores Island local grid. Main uncertainty in management reservoir problems: - Production and reservoir pressure decline by Tony Widiatmoro and Yodha Y. Nusiaputra in [15] - Heavy corrosion on turbine by Triyono, S. et.al in [16]
Subcategory	**UNFC Definition**	
F1.1	*Production is currently taking place*	
Category	**UNFC Definition**	**Reasoning for Classification**
G1	*Product quantity associated with a project that can be estimated with a high level of confidence*	Confident that additional heat resource is available in the reservoir for future development by Pratama, H.B. et.al in [17]
G2	*Product quantity associated with a project that can be estimated with a moderate level of confidence*	
G3	*Product quantity associated with a project that can be estimated with a low level of confidence*	

Table 4 UNFC (2019) classification of the future project (Unit 5 & 6)

Category	UNFC Definition	Reasoning for Classification
E2	*Development and operation are expected to become environmentally - socially-economically viable in the foreseeable future*	- Well testing, previous experience and simulation results have shown the feasibility and the viability of the project, also considering the regulatory framework and the social acceptability in Ulumbu area - The Wellpad lock-down has been situated on the most feasible considering not only subsurface but also surface condition such as land availability, environmental effect and surface access constraint
Category	**UNFC Definition**	**Reasoning for Classification**
F1	*Technical feasibility of a development project has been confirmed*	Well targeting and prognosis program has been designed to focus on specific objectives, guided by integrated subsurface interpretations. The
Subcategory	**UNFC Definition**	

F1.3	*Studies have been completed to demonstrate the technical feasibility of development and operation. There shall be a reasonable expectation that all necessary approvals/contracts for the project to proceed to development will be forthcoming*	proposed drilling sequence incorporates alternative plans as a risk mitigation strategy, addressing both resource, related uncertainties, such as temperature and permeability, and also potential development challenges, including fluid acidity and scaling
Category	**UNFC Definition**	**Reasoning for Classification**
G1	*Product quantity associated with a project that can be estimated with a high level of confidence*	Volumetric Monte Carlo assessment by LAPI and ITB in [12] has indicated a 90% probability (low case) of two areas: - Wewo prospect: 11 MW - Lungar potential resource: 15 MW
G2	*Product quantity associated with a project that can be estimated with a moderate level of confidence*	Volumetric Monte Carlo assessment by LAPI and ITB in [12] has indicated a 50% probability (medium case) of two areas: - Wewo prospect: 20 MW - Lungar potential resource: 37 MW
G3	*Product quantity associated with a project that can be estimated with a low level of confidence*	Volumetric Monte Carlo assessment by LAPI and ITB in [12] has indicated a 10% probability (low case) of two areas: - Wewo prospect: 34 MW - Lungar potential resource: 73 MW

5 Discussion

5.1 Benefits of UNFC Implementation for PLN

UNFC provides a consistent, internationally recognized framework that enables PLN to uniformly classify geothermal resources across all its geothermal working areas. This promotes better internal planning and cross-project comparison for future development. UNFC allows PLN to prioritize resource development based on maturity levels and project viability. This helps allocate budgets and resources more effectively while identifying gaps (e.g., data or permits) that need resolution to advance classification status. The classification enables more reliable communication of resource potential to external parties, including investors, lenders, and multilateral banks. The use of UNFC also helps fulfil its role as state-owned utility by supporting transparent and accountable reporting of geothermal assets to government regulators, in line with national resource governance objectives. This supports financing efforts by reducing perceived project risks and aligning with international due diligence standards.

5.2 Challenges in Applying UNFC to Geothermal Field in Indonesia

The implementation of the UNFC classification system in Indonesia's geothermal sector, particularly by PLN, faces several key challenges. First, awareness and understanding of UNFC among local stakeholders remain limited, necessitating extensive training and outreach to build institutional capacity. A significant obstacle is the lack of access to comprehensive and standardized data, such as detailed resource estimates, licensing status, financial commitments, and project lifetime plans, which are critical elements for proper classification. Additionally, the absence of coordination between agencies such as PLN, the Geological Agency, and regulatory bodies has hindered the integration of UNFC across project workflows. Many projects present installed capacity figures without a clearly defined project scope, which conflicts with UNFC's project-based classification requirements. Moreover, PLN currently lacks trained professionals who are certified and experienced in applying UNFC standards. Resistance to change also persists, as national reporting codes like SNI 6009:2017 by BSN [8] are already established and familiar to stakeholders. Finally, the lack of practical tools, such as digital worksheets or decision-making templates makes the classification process labor-intensive and difficult for first-time users. Addressing these issues requires collaborative institutional support, capacity-building programs, improved data accessibility, and the development of user-friendly tools tailored for geothermal resource evaluation.

6 Conclusion

The application of the UNFC to the Ulumbu geothermal field demonstrates the value of a standardized, project-based classification system in assessing geothermal resources. UNFC offers a structured framework that integrates technical feasibility, degree of confidence, and socio-economic viability, making it particularly effective for evaluating project maturity and guiding investment decisions. In the case study of Ulumbu geothermal field, it shows how UNFC classification system can help categorize and organize geothermal working areas for a better understanding of geothermal potential and development. UNFC can be applied for both current production project and future development project which is still in the exploration phase. According to UNFC, Ulumbu future development project (Unit 5 & 6) with known deposits by LAPI ITB and PLN in [12], could be classified as potentially viable project (E2; F1.3; G1+G2+G3). On the other hand, Ulumbu Unit 1-4 which is currently in production could be classified as viable project (E1.1; F1.1; G1+G2+G3). Thus, the application of UNFC to geothermal field supports more transparent resource reporting and facilitates communication among stakeholders, including regulators, financiers, and policymakers.

Despite its advantages, the adoption of UNFC in Indonesia faces several challenges. These include limited stakeholder awareness, gaps in data accessibility, and lack of trained professionals. Overcoming these challenges requires coordinated capacity-building efforts, improved collaboration, and the development of supportive tools to assist in practical implementation. Ultimately, integrating UNFC into PLN's geothermal project portfolio, starting with Ulumbu geothermal field, can attract investment and support national goals for sustainable energy development. As Indonesia aims to expand its geothermal capacity and contribute to global climate targets, the UNFC framework can serve as a valuable tool for resource governance and long-term planning.

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