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# Lesson Learned from Application of the United Nations Framework Classification for Resources (UNFC) to Geothermal Energy Reources to Mataloko Brownfield Geothermal Projects in Flores Island, Indonesia

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## ABSTRACT

This paper describes a lesson learned on applying United Nations Framework Classification for Resources (UNFC-2009) to Geothermal Energy Reources in Mataloko Geothermal Field, Flores Island, Indonesia. UNFC-2009 is a generic principle-based system in which quantities are classified by three fundamental criteria, which are combined in a three-dimensional system. Those criteria are (1) Geology knowledge, (2) Project feasibility and (3) Socio-economic viability. They are known as G, F and E criteria respectively.

Mataloko is a Brownfield Project where existing plant has been constructed to produce 2.5MWe from two production wells. Those are MT-3 and MT-5 wells which were drilled up to 613.0m and 378.2m respectively. The plant was in operation only few months due to turbine wear and low pressure steam supply issues.

PLN, the State Owned Enterprise, as the current owner of the field, plan to add the production for 2x10 Mwe and to recommission the existing 2.5 MWe plant. The Project Lifetime is limited by a Ministry of Energy & Mineral Resources Decree which assigns Mataloko Geothermal Working Area licence to PLN until 28 December 2050. So the Project is expected to generate 2.5 MWe for 3 years (2020, 2021 and 2022) and 22.5 MWe for 28 years (2023 to 2050, inclusive), with average plant load factor of 92%. Thus, it is proposed to drill 7 production wells at the indicative deeper reservoir from exploration development program.

The well targeting is based on the previous data carried out by Geological Agency, consisting of exploration and shallow gradient wells (MT-1, MT-2, MT-4, and MT-6), geophysical data that include MT, DC-resistivity of Schlumberger array and gravity, surface and sub-surface geology and intensive surface geochemistry data. The exploration data suggest apparent equilibrium temperatures of at least 290-300°C are indicated for the steam discharged by the Mataloko geothermal wells and Mataloko fumaroles. However, the existence and characteristics of the inferred water-dominated deep reservoir need to be proved and evaluated by drilling exploratory wells. Furthermore, the conduction of an appropriate logging and testing program is essential. Additional 3G field data acquisition to confirm reservoir dimensions, physical characteristics and properties are also proposed.

Based on the above data, we may conclude that geothermal resource potential in Mataloko has greater capacity although additional exploration and drilling is required. However, Flores island has modest demand and modest growth of demand, so the proposed development only utilizes a small portion of the possible subsurface resource.

In applying the UNFC classifications, for the project describe above, several problems have been encounter and discussed as mentioned below: 1. The discussion reveals different interpretations of the UNFC texts by different members of the group even among the expert, thus the expert group proposed some modification in terminology of UNFC or suggestion to add footnote on the report to help the reader. 2. There are different interpretation and perspective about evidences sufficiency to infer the level of uncertainty from the same data. 3. The background of understanding from the people who wrote the report, hence Indonesian geothermal community, previously have its own classification that make it difficult to adopt the concept of UNFC. Thus the classification often falls at wrong or arguable axis. A training on this classification is necessary for better understanding.

## 1. INTRODUCTION

At ITB International Workshop 2018, a short course on global classification of geothermal resource has been carried out. The course is about application Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources. This specification was launched by International Geothermal Association (IGA) and UNECE (United Nations Economic Commission for Europe) in 2016. The objective of the course as well as this paper is to have as much as lesson learned in applying this global classification to various geothermal resources and various countries.

## 2. UNFC 2009 GEOTHERMAL CLASSIFICATION

UNFCE 2009 is a generic, principles-based classification system which is initially applied for solid minerals and fossil energy. The detail about the classification is available online and can be downloaded from UNCECE website (UNECE, 2013). Since 2014, geothermal energy sector through IGA has tried to adopt this classification for reporting the energy project, because until this time no single global classification is available.

The classification based on three (3) criteria those are Geological Knowledge, Project Feasibility and Socio Economic Viability. Those three criteria is refered as ‘G axis’, ‘F axis’, and ‘E axis’ respectively. The ‘G axis’ indicate the level of confidence in the estimate of potentially recoverable quantities, the ‘F axis’ designates the maturity of studies and commitments necessary to implement project, and the ‘E axis’ designates the degree of favorability of social and economic conditions for establishing commercial viability of project. Combinations of these criteria create a three-dimensional system. It can be visualized in three dimensions, as shown in Figure 1. In this figure, combinations of these criteria create a three-dimensional system. Categories (e.g. E1, E2, E3) and, in some cases, sub-categories (e.g. E1.1) are defined for each of the three criteria as set out and defined in an annexes that give detail information about the definition of Categories and supporting explanation about each level of Categories. Meanwhile A Class is uniquely defined by selecting from each of the three criteria a particular combination of a category or a sub-category (or groups of categories/sub-categories). It can be concluded from Figure 1, that the smaller the code (e.g. Class 111), the more confidence in the estimate of potentially recoverable quantities, the more feasible and viable the project. On the contrary, the bigger the code (e.g. Class 444) the less confidence of geological knowledge and the resources, and the less feasible and viable the project.

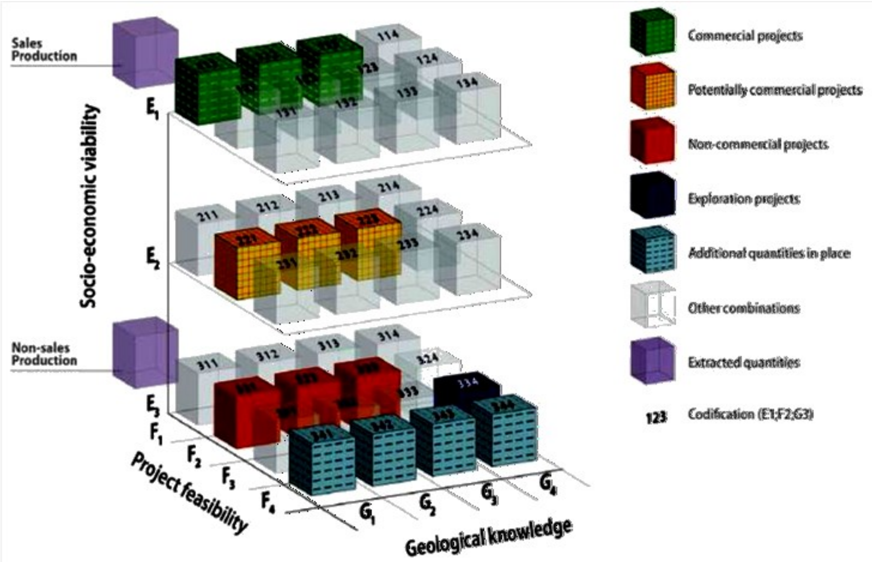


Figure 1. UNFC-2009 Categories and Examples of Classes

## 3. MATALOKO HISTORY

The Mataloko geothermal working area (‘WKP’) covers 996.2 Ha in the Bajawa area of Flores Island, Indonesia (Figure 2). All the WKP is classed as ‘Other’ land use. It includes many surface thermal manifestations that indicate the likely existence of a commercial scale geothermal energy source suitable for power generation. These include fumaroles, steaming ground, hot springs and hydrothermal alteration zones, with maximum discharge temperature measured at 88.9°C (Ditjen EBTKE dan Badan Geologi, 2017). Koseki & Nagashima (2006) considered the heat source to be residual magma under a nearby volcanic cone and that the location of the steaming ground is at least partly controlled by the Wae Luja Fault, which runs through the play area.


Figure 2. Mataloko location map

The first two exploration wells, MT-1 and MT-2, were drilled under the Japan-Indonesia Cooperation Research Program in 2000 and 2001. MT-1 was planned to a depth of 1,000 m but was terminated, killed and abandoned at 207 m when it encountered a shallow steam zone. MT-2 was completed in the steam zone at a total depth of 180 m. A wellbore simulation of the results of a discharge test carried out on MT-2 immediately after drilling estimated a flow rate of 16 tons/hour from a dry steam reservoir with transmissivity 3.5 darcy-meters, a pressure of 1.47 MPa and a temperature of 197.37°C (Sueyoshi et al., 2002). Akasako et al. (2002) proposed a conceptual model of a meteoric-recharged reservoir at 270°C–306°C underlying the steaming ground but separated from it by impermeable cap rocks ~400 m thick. They supposed that the steam cap intersected by MT-1 and MT-2 derived from steam and other gases leaking up the Wae Luja Fault from the deeper reservoir.

The Directorate General of Geology and Mineral Resources drilled wells MT-3 and MT-4 in 2003 to 613 m and 756 m, respectively, to intersect the predicted deeper reservoir. Measured temperature exceeded 200°C in both wells, but steam flow was much lower than MT-2 (Kasbani et al., 2004). In 2004, the Government of Indonesia entered into an agreement with the local government of Ngada District and PLN to develop a 2.5 MWe power plant, with PLN tasked to develop and operate the power plant. Additional drilling was required to supply the required steam supply of about 40 tons/hour (10 kg/s). MT-5 and MT-6 were subsequently drilled. MT-5 produced 18 tons/hour (4.5 kg/s) steam from a depth of 378 m, while MT-6 was drilled to 200 m and designated as an injection well (Hochstein et al., 2010).

A test plant of 0.1 MWe capacity was constructed in 2008, drawing on steam from MT-2. A 2.5 MWe capacity plant was subsequently commissioned in November 2010 (Suryadarma et al., 2015), which was generating 1.8 MWe from MT-3 and MT-5 in 2011 (Mansoer & Idral, 2015). The plant was in operation only few months in 2012 due to turbine wear and low pressure steam supply issues. Since then the plant has been in idle condition and the routine simple maintenance has been still conducted while waiting new and more stable steam supply coming from the new wells drilled in 2019-2020.

Ditjen EBTKE dan Badan Geologi (2017) stated the capacity of the Mataloko geothermal energy source according to the SNI 6009:2017 framework (Indonesia National Standard for Geothermal Resource and Reserves) as 2.5 MWe Proven Reserves (Cadangan Terbukti), 62 MWe Possible Reserves (Cadangan Mungkin), 10 MWe Hypothetical Resources (Sumber Daya Hipotetis). These values were derived from geophysical data following SNI standard practices. At the time of evaluation, plans are underway to develop two new 10 MWe generators and to recommission the existing 2.5 MWe generator (pers. comm. PLN, March 2018). The geothermal energy source for this new 22.5 MWe project will be the potential deeper, hotter reservoir underlying and/or laterally displaced from the abandoned shallow reservoir.

In 2016, The Government of Indonesia through EBTKE appointed PT Perusahaan Listrik Negara (PLN Persero) to develop the Mataloko geothermal working area (WKP) with a capacity of 22.5 MW. Since then, PLN has actively study the plan of development of Mataloko. The project is endorsed by the issuance of Ministerial Decree No. 2268K/3G/MEM/ (2017) that designated Flores as a 'Geothermal Island' as part of a Government of Indonesia strategy to improve the local economy and alleviate poverty in the eastern part of Indonesia through energy independence.

## 4. MATALOKO PROJECT

Earlier shallow exploration wells (MT-1 to MT-6 with depth ranging from ± 162 m to 760 m including one gradient hole) have confirmed the existence of geothermal resources at Mataloko, although the accurate size and geometry of reservoir still need to be delineated. Most wells encounter only up to clay cap and the deepest well (MT-4) is inferred to encounter the top of reservoir at 700 m depth with the occurrence of Epidote at this depth continues to the total depth (760 m). Yet, the productivity of this deepest well, discharging steam with periodical water slug, is very low. MT-2, MT-3 and MT-5 well has produced water vapor (H2O) in the discharge fluid that indicates a steam-dominated reservoir exists at shallow levels of the Mataloko geothermal system with a temperature of 192 – 230ºC at the bottom of well (180 m depth). Thus deeper water-dominated conditions are expected for the existence of high temperature reservoir in Mataloko. Reservoir temperature higher than 240°C is expected at depth, and likely to approach 300°C in the upflow area. The reservoir temperature estimation is based on the isotopic geothermometers applied from the composition of fumaroles steam in the existing wells. By projecting them at boiling point depth curve, temperatures of 290 °C and 300 °C would be expected at about 1300 m and 1460 m depth, respectively. These depths are minimum reference values for designing future exploratory wells. These depths are also more or less in agreement with iso-resistive line of 20 Ωm of MT data (normally correspond to a cap-rock) occurs at approximate depth of 1,000 m, that is the inferred top reservoir.

Earlier exploration has also indicate faults that probably represents a high-permeability pathway controlling the main upflow zone, along which steam and NCG from the shallow steam section flow towards the surface. Proposed wells are planned to encounter these faults.

Based on the result of GGG survey and six shallow well (including one thermal gradient well), the well targeting has been carried out. Future wells are targeted to intersect reservoir top and fault permeability. It is likely that drilling program will give high probability of success due to thorough geosciences data examination and careful well targeting.

The Mataloko Project is to build and commission two new 10 MWe plants and to recommission the existing 2.5 MWe plant using a new steam supply by 2020. A feasibility study has been completed by PLN in 2017 (PLN, 2017). Hence, study of electricity demand is also conducted using daily average load in six districts of Flores in six months of 2016. It shows that electricity demand is ranging from 15 – 30 MWe in the day time and about 20 – 50 MWe in the night time. The variation is also depending of the months of a year. The average demand load factor (LF) calculated with the available data is about 0.55. Assuming this data is valid for future prediction and in line with PLN's forecast, it is concluded that the future years of geothermal electricity development is reasonable. This is also confirmed that the doubling of the load demand in 7 to 8 years may be a reasonable target (PLN, 2017). The postponement of the Commercial Operation of Mataloko Power Plant Project is likely to occur until 2023 if the base load has been fully met, i.e if other Power Generation Projects such as Ulumbu and Sokoria are operated before Mataloko produces. Nevertheless, the development of Ulumbu (20 MW) by PLN, that is in parallel with Mataloko, is also expected to be in commercial operation in the same year, i.e. 2023. Meanwhile, the increasing demand before 2023 will be covered by Sokoria (see Figure 3 below).

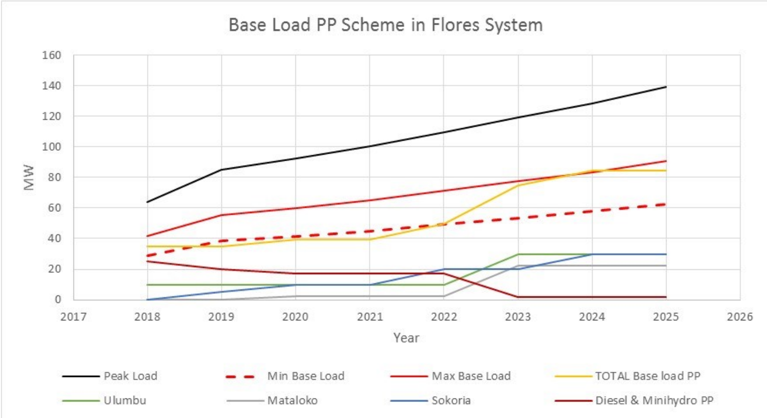


Figure 3. Base Load Scheme in Flores System Compared to the Base Load Power Plants

The result of the feasibility study justify proceeding immediately to development. Activities included in the Project are:

a) 3G field data acquisition to confirm reservoir dimensions, physical characteristics and properties

b) Reach financial closure on a loan agreement

c) Run tender process for drilling

d) Drill 7 production wells (for 20 MWe, assuming 66% success ratio and well capacity 6.5 MWe) and 2 injection wells (see "Expected Production and Injection Capacity of Well" section for more detail discussion)

e) Construct and commission centralized power plant and surface infrastructure

20 MWe plant construction will commence when Step (d) confirms sufficient steam supply for minimum 50% of planned capacity (22.5 MWe). In addition, construction of new Steam Gathering System (SGS) to supply the existing 2.5 MWe plant will be commenced once a production well is success and able to supply steam. The product type will be electricity and the reference point is the station switchyard where power is exported into the distribution wires. Internal energy use has already been subtracted. The design life of the plants will be 30 years.

Environmental and Social Impact Assessment (ESIA) has been conducted as part of feasibility study. The purpose of the implementation of the ESIA study is the identification and management of environmental, social and health risks associated with the proposed project. No significant risk is identified, however mitigation and management has been planned. Social issue such as appearance of mud volcano due to drilling, similar to Sidoarjo Mud in East Java Province is one of major concern during ESIA study. Rejection to geothermal project due to the issue had appeared since 2009 until recently in 2018. At the last, discussion between PLN and local people managed to have agreement with local people and the project can be continued.

## 5. RESOURCE QUANTIFICATION

The evaluation of stored heat and of sustainable power plant capacity for a geothermal prospect is usually performed in the preliminary stages of field exploration and development. Whereas, 3D numerical reservoir simulation is always preferred when enough reservoir engineering and well production data are available to build and calibrate the numerical reservoir model. The inferred deep water-dominated reservoir has still to be confirmed, the volumetric heat stored method, complemented with a Monte Carlo statistic approach, is used to evaluate the resource of the Mataloko geothermal prospect.

To account for the risks associated to the incomplete knowledge of reservoir extension and characteristics within the decision-making process, the Monte Carlo approach is customarily used in calculating the heat stored and its conversion to electric power (Sarmiento and Steingrímsson, 2007). Unlike a deterministic approach, where a single value representing a best guess value is used, the probabilistic method of calculation is considered to account for the uncertainty on many variables in geothermal reserves estimation.

The present evaluation is focused on prospect areas delineated mainly by MT and geomagnetic surveys as well as to the exploitation of inferred deep water-dominated reservoir. The basic input data for the resource evaluation of Mataloko geothermal prospect are listed in the Table 1 below.

Table 1. Input data for the resource evaluation of Mataloko geothermal prospe

| Parameter | Unit | Value | min | max | STDDEV | Functions | Type |
|---|---|---|---|---|---|---|---|
| Area | $m^2$ | 8.000E+06 | 7.000E+06 | 1.160E+07 | | 8866666.667 | triangular |
| Thickness | m | 800 | 600 | 1200 | | 866.67 | triangular |
| Porosity | fraction | 0.07 | | | 0.006 | 0.073 | log normal |
| Initial Liquid saturation | fraction | 0.95 | 0.9 | 0.98 | | 0.943 | triangular |
| Final Liquid saturation | fraction | 0.7 | 0.5 | 0.80 | | 0.667 | triangular |
| Initial Water density | $kg/m^3$ | 768.2 | | | | 768.2 | f (TR) |
| Initial Steam density | $kg/m^3$ | 27.9 | | | | 27.9 | f (TR) |
| Final Water density | $kg/m^3$ | 886.4 | | | | 886.4 | f (TR) |
| Final Steam density | $kg/m^3$ | 5.1 | | | | 5.1 | f (TR) |
| Reservoir Temperature (TR) | °C | 270 | 240 | 300 | | 270.0 | triangular |
| Rejection temperature (TF) | °C | 180 | 175 | 185 | | 180.0 | triangular |
| Initial water internal energy | kJ/kg | 1177.3 | | | | 1177.3 | f (TR) |
| Initial steam internal energy | kJ/kg | 2594.0 | | | | 2594.0 | f (TR) |
| Final water internal energy | kJ/kg | 762.3 | | | | 762.3 | f (TF) |
| Final steam internal energy | kJ/kg | 2582.9 | | | | 2582.9 | f (TF) |
| Rock density | $kg/m^3$ | 2550 | 2500 | 2600 | | 2550.0 | triangular |
| Rock specific heat | kJ/(kg K) | 1.090 | 1.050 | 1.100 | | 1.080 | triangular |
| Recovery factor | fraction | 0.15 | 0.1 | 0.2 | | 0.150 | triangular |
| Conversion efficiency | fraction | 0.127 | | | | 0.127 | f (TR) |
| Plant life | yrs | 30 | | | | | constant |
| Plant load factor | fraction | 0.92 | 0.90 | 0.95 | | 0.923 | triangular |
| | | | | | | | |
| Rock energy | kJ | | | | | 1.767E+15 | |
| Water energy | kJ | | | | | 2.244E+14 | |
| Steam energy | kJ | | | | | -1.623E+11 | |
| Rock energy fraction | % | | | | | 88.73 | output |
| Water energy fraction | % | | | | | 11.27 | output |
| Steam energy fraction | % | | | | | -0.01 | output |
| | | | | | | | |
| Reservoir Energy | kJ | | | | | 1.991E+15 | output |
| Plant capacity | MWe | | | | | 43.43 | output |

The most probable values as well as the range of possible variation have been estimated on the basis of data review, the updated conceptual model, and bibliographic sources. The rejection temperature accounts for both the minimum reservoir temperature making well production still possible at commercial rates, and for the fact that the reinjection of steam condensate drastically reduces the temperature in the reservoir zone affected by injected fluid. The maximum temperature considered is that evaluated by geothermometric calculations.

The Monte Carlo approach was employed by simulating 50,000 realizations and then examining the results in terms of probabilistic power potential, cumulative distribution of power potential and sensitivity of input parameters on power potential results.

## 6. RESULT OF THE VOLUMETRIC MODEL

Figure 4 below shows the frequency and cumulative frequency curves of power potential for the Mataloko prospect. The power potential for cumulative probability values of 90%, 50% and 10%, indicated as P90, P50 and P10 respectively, amount to 30.5 MWe, 43.7 MWe and 63.0 MWe, respectively. The sensitivity analysis shows, as expected, that the highest effects are due to reservoir area and thickness, recovery factor, initial reservoir T, and rock specific heat.

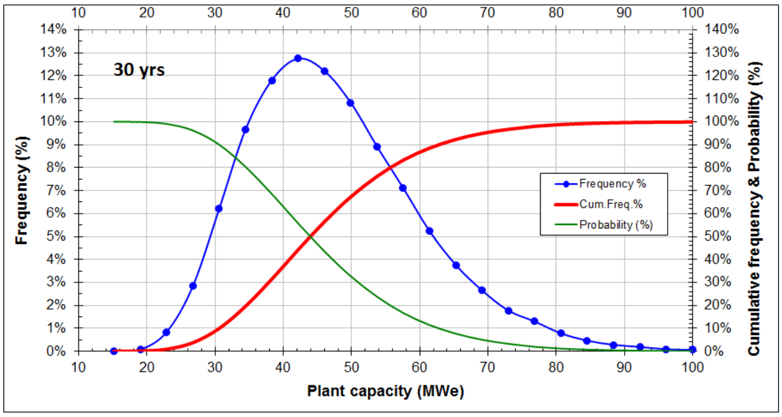


Figure 4. Frequency and cumulative frequency curves of power potential for the Mataloko prospect

These results suggest a high probability (P90) power potential of 30.5 MWe which is about 135% of the power plant potential which has been considered so far for the proposed field development phase amounting to a total of 22.5 MWe (2.5 + 20 MWe). To appreciate the effects of the conservative approach adopted, we can make reference to the power density corresponding to the possible reservoir extensions of 7.0 km2 which amounts to 4.4 MW/km2 for P90 power potential (30.5 MWe), which is much lower below the average power density amounts to about 20 MW/km2 for a reservoir temperature of 275°C, which was compiled for different fields by Grant (2000).

## 7. EXPECTED PRODUCTION AND INJECTION CAPACITY OF WELL

Within the Mataloko prospect, 4 wells, out of the 6 drilled, have been tested (MT-2, MT-3, MT-4 and MT-5) and 2 of them have been used to supply steam to the Mataloko PLTP (MT- 3 and MT-5). The analysis of available flow tests and power plant monitoring data suggested as follows:

- The wells produced mainly dry-steam, either saturated or super-heated, from quite shallow feeds with a remarkable tendency to decline with time due to lack of permeability.
- The quite scattered permeability distribution and the poor production characteristics suggest the tapping of a network of shallow fractures – fissures, recharged by ascending steam and NCG, not representing an exploitable shallow steam cap.
- Geoscience surveys, and the geochemistry in particular, indicate that a deep reservoir should exist at water-dominated conditions and T which might reach 290-300°C in the upflow zone.

The discharge and injection capabilities of existing wells cannot be used to estimate those of future wells tapping the deep inferred reservoir. Thus, a very preliminary evaluation of possible production potential of wells tapping the inferred deep water-dominated reservoir can be performed by accounting for its inferred temperature and looking to statistics about average well potential found in similar geological environments. Data and parameters to be considered are summarized as follows :

- Water-dominated conditions are expected for the deep high temperature reservoir in Mataloko. Reservoir temperature higher than 240°C is expected at depth, and likely to approach 300°C in the upflow area (230°C – 300°C, resource code #5 in IFC, 2013), emplaced in a young volcanic environment (geology code #3 in IFC, 2013).
- Average capacity of commercial wells of 6.5 MWe (IFC, 2013: Success of geothermal wells: a global study).
- Drilling success rate of 66%, in which this success rate is slightly higher than the 60% average world value given by IFC (2013) for the exploration phase of geothermal fields but lower than the 74% average value for the development phase of geothermal projects (IFC, 2013).
- Assuming a preliminary steam consumption of 7.6 (t/h)/MWe, the steam rate to be supplied for the 2 x 10 MWe development (2 x 10.4 MWe gross) amounts to about 158 t/h. As we assume the new wells shall supply steam also to the existing power plant, the needed steam increases to about 178 t/h.

Based on the above data, the planned development of 2 x 10 MWe units and the requirement of supplying steam for 1 x 2.5 MWe existing unit will require a start-up power potential of at least 24.75 MWe (considering 10% of excess steam requirement). Therefore, with a success ratio of 66%, we can estimate the drilling of 3 non-commercial wells, for a total of 7 production wells to be drilled (4 start-up commercial production wells are required).

About the reinjection needs for the existing and planned units, they can be estimated in a very preliminary way by considering that two-phase fluid will be likely produced, requiring the reinjection of the recovered steam condensate and separated brine. The reinjection requirements will strongly depend on the average enthalpy of discharged fluids.

Considering reservoir T in the range of 260 – 300°C, and negligible effects from TDS and NCG contents and enthalpy loss from reservoir to WH, the liquid phase at saturated conditions would have enthalpies in the 1135 – 1345 kJ/kg range. Assuming a tentative separation pressure of 7 bara, steam fraction would be in the range of 0.212 – 0.314. As the required steam supply is 178 t/h, the separated brine rate would be in the range of 662 – 390 t/h. Whereas, by assuming conservative value of steam condensate recovered fraction equal to 30%, reinjected steam condensate rate amounts is 178 t/h x 0.3 = 54 t/h.

Considering the pressure measured in the shallow existing wells, we might infer that reservoir pressure would be substantially lower than hydrostatic, allowing higher reinjection rates for a given injectivity index. We can tentatively assume Injection Capacity in the 350 – 370 t/h range per well, then at least 2 reinjection wells will be necessary at plant start-up, plus 1 non-commercial reinjection well. Thus, 3 reinjection wells need to be tentatively foreseen. This figure accounts for the upper limit of reinjection rate estimated in 662 + 54 = 716 t/h of condensate and separated brine.

## 8. UNFC CLASSIFICATION

### 8.1. E category classification

| *Category* | *Definition* | *Supporting Explanation (UNFC-2009, Part I, Annex I)* | *Reasoning for classification* |
|---|---|---|---|
| ***E2*** | *Extraction and sale is expected to become economically viable in the foreseeable future.* | *Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.* | The fact that recently an IPP has been signed an agreement with the Indonesian Government to develop a new geothermal power plant in the area of Sokoria may result the base load has been fulfilled causing the Mataloko project situation of the power and energy market should be reviewed carefully before starting the commercial exploitation of the Mataloko field. |

**8.2. F category classification**

| *Category* | *Definition* | *Supporting Explanation (UNFC-2009, Part I, Annex I)* | *Reasoning for classification* |
|---|---|---|---|
| ***F3*** | *Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.* | *Very preliminary studies (e.g. during the assessment phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a project in such form, quality and quantity that the feasibility of production can be evaluated.* | The existence of a geothermal resources has been confirmed by six exploration wells drilling with depth ranging from ± 162 m to 760 m, although most wells encounter only up to clay cap, the deepest well is inferred to encounter the top of reservoir at 700 m depth with the occurrence of Epidote continue to the total depth (760 m). |
| *Sub-Category* | *Definition* | *Supporting Explanation (UNFC-2009, Part I, Annex I)* | *Reasoning for classification* |
| ***F3.1*** | *Where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated;* | Pre-successful well drilling exploration complete (if a drilled well is 'dry' or unsuccessful, but further drilling is planned, this sub-category is still appropriate). | Wellhead pressure (WHP) and steam rate produced from MT-02, MT-3 and MT-5 are 5.5 barg-16 t/h, 4.5 barg-7 t/h, and 5.5 barg-17 t/h, respectively. This should be able to drive a 2.5 MW capacity plant. However the pressure decrease is excessive, which is inferred to stem from low pressure support of the reservoir.<br><br>For 20 MWe plant expansion, 7 production wells and 2 injection wells must be drilled to supply steam and for reinjection purpose as well as to further evaluate resource characteristics at the same time. In addition, some supplementary Geology, Geochemistry and MT survey must be carried out to refine the well targeting. |

**8.3. G category classification**

| *Category* | *Definition* | *Supporting Explanation (UNFC-2009, Part I, Annex I)* | *Reasoning for classification* |
|---|---|---|---|
| ***G1*** | *Quantities associated with a known deposit that can be estimated with a high level of confidence.* | *For in situ (in-place) quantities, and for recoverable estimates of fossil energy and mineral resources that are extracted as solids, quantities are typically categorized discretely, where each discrete estimate reflects the level of geological knowledge and confidence associated with a specific part of the deposit. The estimates are categorized as G1, G2 and/or G3 as appropriate. For recoverable estimates of fossil energy and mineral resources that are extracted as fluids, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation. Recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorized on the basis of three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.* | The geothermal energy source is not yet confirmed but the possibility of its existence is present with the six wells drilling and three of them that have been tested.<br>A volumetric Monte Carlo simulation has indicated that there is a 90% probability that 30 MW (28.3 PJ) can be produced for 30 years. Whereas, a 50% and 10% probability that 43 (40.6 PJ) MW and 63 (59.6 PJ) MW, respectively, can be produced for 30 years. This equates to the best estimate, i.e. G1+G2 with G2 being incremental to G1 and G1+G2+G3 with G3 being incremental to G1+G2. Thus, G2 is equal to 40.6-28.3=12.3 PJ and G3 is equal to 59.6-40.6=19 PJ |
| ***G2*** | *Quantities associated with a known deposit that can be estimated with a moderate level of confidence.* | | |
| ***G3*** | *Quantities associated with a known deposit that can be estimated with a low level of confidence.* | | |

**8.4. UNFC Quantification and Classification**

| Classification | Energy Quantity | Supplemental information |
|---|---|---|
| **E2; F3.1; G1** | 28.3 PJ<br>*or (900 $MW_e$yrs)* | 30 $MW_e$ for 30 years; (low estimate) |
| **E2; F3.1; G2** | 12.3 PJ<br>*(G1+G2= 40.6 PJ )*<br>*or (1290 $MW_e$yrs)* | 43 $MW_e$ for 30 years; (medium or best estimate) |
| **E2; F3.1; G3** | 19 PJ<br>*(G1+G2+G3 = 59.6 PJ) or (1890 $MW_e$yrs)* | 63 $MW_e$ for 30 years; (high estimate) |

**9. LESSON LEARNED**

1. Clarify the dates in the second paragraph on page 2, which currently says that the 2.5 MWe plant was commissioned in 2013 but was already generating 1.8 MWe in 2011.

2. Be clear and consistent throughout the document that the Project being reported is 22.5 MWe drawing on a predicted geothermal energy source that has not yet been drilled or tested. This has a strong influence on the choice of E, F and G categories for UNFC classification (see point 7 below).

3. Given that the target reservoir has not yet been drilled, discuss and assess the "Probability of Discovery", the chance that the proposed drilling program will find the predicted reservoir.

4. These two points from the first and second paragraphs of the Mataloko Project section are inconsistent with each other:

    a. The postponement of the Mataloko Power Plant Project is likely to occur until 2023 if the base load has been fully met.

    b. The results of the feasibility study justify proceeding immediately to development. Be very clear about the market demand situation and about what PLN has committed to. Has PLN already approved a budget and set money aside to immediately build the plant but it might not be commissioned until 2023? Is only drilling approved and the plant will be designed and financed once drilling results are known? Or is only the new field data acquisition activity so far approved and drilling and engineering might all be deferred? Perhaps include relevant decision points in the list of activities at the top of page 3. Clarity on this point is critical for a proper definition of the Project(s) and choice of E-category for the UNFC classification.

5. Clarify that Point (d) at the top of page 3 anticipates that drilling seven wells will yield four producers delivering 6.5 MWe each, for a total capacity (26 MWe) sufficient to power the 22.5 MWe plant with the 66% drilling success rate. This would be clear if the "Expected Production and Injection Capacity of Well" section was moved into the "Mataloko Project" section.

6. The document justifies high confidence that the Geothermal Energy Source (if confirmed by drilling) will support a 22.5 MWe plant for 30 years, but this 'reservoir potential' is not the Geothermal Energy Resource. The Geothermal Energy Resource is the cumulative predicted electricity output for the 30-year life of the plant. To this end, provide 'high', 'medium' and 'low' estimates of the future electricity generation profiles for export from the 22.5 MWe project. E.g. the report suggests that the plant could commence operation with an annual average load factor of only 0.55 (i.e. 12.4 MWe average output?) but increase to maximum load factor (0.92 assumed in Monte Carlo analysis) via an undefined trajectory over 7-8 years. Consider the error margins on this prediction and other factors that will influence plant output. E.g. there seems to be a low-side risk that only 12.5 Mwe capacity might be constructed, if that is the maximum the reservoir will support. This comes back to the question of whether PLN has a confirmed budget and money set aside for the full 22.5 MWe, only 12.5 MWe, or only exploration activities? Incorporate all uncertainties in recoverability of the estimated quantities into the predicted production profiles and ideally chart them as three possible production curves ('low', 'medium' and 'high') on a 30-year timeline. What are the total quantities of electricity (in PetaJoules, and optionally MW.yrs) predicted to be generated over the project life for the 'low', 'medium' and 'high' cases? These are the G4.1, G4.1+G4.2, G4.1+G4.2+G4.3 values for UNFC classification, respectively.

7. UNFC classification:

    a. E-axis—Depending on the perceived risk of Sokoria meeting the total market demand in the foreseeable future (i.e. for at least the next five years), the Mataloko Project could be categorised as:

        - E2 Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future (if the risk is perceived to be low), or

        - E3.2 Economic viability of extraction cannot yet be determined due to insufficient information (if the risk is perceived to be significant and/or there isn't sufficient factual information to support E2.)

    b. F-axis—The reservoir has not yet been drilled, and the work program includes "3G field data acquisition to confirm reservoir dimensions, physical characteristics and properties." The Expert Group infers from the current statement that drilling might be indefinitely postponed if 3G is inconclusive. At the current Evaluation Date, this would place the Mataloko Project into category:

        - F3.2 Where local geological studies and exploration activities indicate the potential for one or more deposits in a specific part of a geological province, but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant drilling or testing. If planned 3G activities ultimately justify progressing to drilling, the classification might be upgraded (at a future Evaluation Date) to:

        - F3.1 Where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated. F3.1 might also be justified if PLN is already confident about the existence of the reservoir and will proceed to drilling regardless of 3G outcomes, with 3G activities being carried out only to define optimal locations. This goes back to Point 4 above about clarifying current budget approvals and decision points.

c. G-axis—the deeper reservoir is not yet 'known' in the UNFC sense, so estimated Resources fall into the G4.1, G4.1+G4.2, G4.1+G4.2+G4.3 categories.

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