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# Integrating the Clean Development Mechanism (CDM) into the Policy Framework of the Bedugul Geothermal Power Plant

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***Abstract:***
The development of the Bedugul Geothermal Power Plant has faced significant public resistance due to its potential environmental consequences. Research indicates that investors must address critical issues to gain community acceptance, specifically regarding procedural irregularities and the socio-cultural and ecological risks involved. From an engineering perspective, these objections require a professional and strategic resolution. This study proposes the adoption of the Clean Development Mechanism (CDM) as a core policy for the project. Technical assessments reveal that the actual power potential is considerably lower than the initial 175 MWe estimate, yielding only 7.02 MWe using steam working fluid and 20.6 MWe through a binary cycle. Given that geothermal energy in Bedugul offers minimal emissions, the project's primary viability lies in CDM benefits. Implementation of the CDM would ensure lower electricity costs, community-centric development, phased construction to protect local ecosystems, and the preservation of vital water resources.

***Keywords:*** Geothermal, power plant, community engagement, environmental impact, socio-cultural impact, CDM

## 1. Introduction

Public opposition to the Bedugul Geothermal Power Plant stems from deep concerns regarding its environmental footprint. Academic and field studies highlight several core challenges that developers must resolve through transparent engagement with affected stakeholders. These issues include:

1. Procedural Flaws: The project lacked inclusive public consultation, depriving the Balinese community of their right to participate in the development process. Furthermore, there has been a lack of transparency regarding permits; for instance, exploitation activities allegedly began while only exploration permits were active. Additionally, the validity of the Environmental Impact Analysis (EIA) remains contested due to questionable data and methodology.
2. Socio-Cultural and Ecological Risks: The EIA identified several unmanageable risks, such as soil subsidence and significant threats to water security (lakes and groundwater) due to deforestation. There is also a high risk of losing endemic biodiversity. Beyond physical impacts, the project threatens 35 sacred temples, posing a spiritual and cultural loss that cannot be quantified financially.
3. Absence of Energy Audits and Alternatives: The project was justified based on Bali's energy needs without a verified energy audit. Moreover, decision-makers failed to prioritize or compare the project against more sustainable alternatives like solar, wind, or micro-hydro power.

To address this resistance, a professional engineering approach is required to identify a model that aligns with community values. This study explores whether the Clean Development Mechanism (CDM) can serve as the definitive policy framework to make the Bedugul project acceptable and sustainable.


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## 2. Literature Review

Energy is a cornerstone of Indonesia's national growth. Under the Indonesian Constitution, the state maintains authority over natural resources and vital production sectors to ensure they are managed for the maximum prosperity of the people. To govern this, several key regulations have been established:

- Energy is a fundamental pillar of Indonesia's national development. Under the Indonesian Constitution, the state is mandated to exercise control over vital natural resources—including land and water—as well as key production sectors that impact public life.
- This authority is exercised through a robust legal framework designed to ensure that the nation's wealth is managed exclusively for the collective prosperity of its citizens.

To achieve these objectives, the Indonesian government has enacted a series of specific laws to regulate the energy sector and its associated impacts:

1. **Geothermal Energy (Law No. 21/2014):** Establishes the authority of central and local governments to issue permits based on specific project phases and operational scales.
2. **Oil and Gas (Law No. 22/2001):** Mandates fair treatment for all market participants while gradually introducing market mechanisms. It aims to boost management efficiency and eliminate monopolies by separating government regulatory roles from commercial operations.
3. **Electricity (Law No. 30/2009):** Provides the legal structure for electricity business licenses, defines the rights and obligations of providers and consumers, and sets penalties for electricity-related offenses.
4. **Regional Governance (Law No. 23/2014):** Empowers local governments to develop regional energy policies and strategic planning.
5. **Forestry Management (Law No. 41/1999):** Restricts energy-related mining to production and protected forest areas. It strictly prohibits open-pit mining in protected zones to preserve their ecological integrity.
6. **Fiscal Balance (Law No. 25/1999):** Outlines the decentralized distribution of natural resource revenue. For instance, the general mining sector allocates 80% of revenue to regions, while oil and natural gas sectors provide 15% and 30% respectively to regional authorities after tax.
7. **Environmental Management (Law No. 32/2009):** Focuses on sustainable development by requiring a comprehensive **Environmental Impact Analysis (EIA)**. This document serves as a prerequisite for business licensing, ensuring that negative ecological impacts are mitigated.
8. **Climate Change (Law No. 6/1994):** Ratifies the UN Framework Convention on Climate Change, committing the nation to stabilizing greenhouse gas levels and protecting the climate for future generations.
9. **Spatial Planning (Law No. 26/2007):** Requires coordinated land-use management to support sustainable growth. It prevents conflicts of interest by designating specific zones for industry, residential use, tourism, and environmental conservation.

Based on the law above, the government of Indonesia has issued government regulations and presidential decrees that regulate various matters related to energy to become more operational. These regulations are as follows:

1. Government Regulations and Presidential Decrees on Geothermal Energy
    - PP No. 31/2003, is the implementation of Oil and Gas Law No. 22/2001 regulates the existing status of cooperation in the geothermal field after PERTAMINA becomes PT (Persero).
    - Presidential Decree No. 76/2000, regulates the government's authority in geothermal resource development activities, licensing services and company supervision at the existing contractor stage.
    - Presidential Decree No. 22 of 1981 jo Presidential Decree No. 45 and 49 of 1991, regulate the exploitation and or ongoing geothermal contracts.
2. Regulation of the Minister of Energy and Mineral Resources Number 33 of 2021 concerning occupational safety and health, environmental protection and management, and geothermal technical principles for indirect utilization.

## 3. Case and Methodology

### 3.1. Power Plant

The types of power plant can be distinguished based on the condition of the geothermal source as a steam producer, as follows:

- Dominated Vapoor System: In this system the steam used must be dry steam, because the steam obtained is directly used to turn the turbine. However, because such steam is rarely found (usually what is present is wet steam), this system is rarely used. This system requires a low cost.
- Liquid Dominated System: In this system hot water is underground, the temperature is between 350 $^0$F (176 $^0$C) to 600 $^0$F (315 $^0$C). Water flowing to the surface is pumped up and out through a faucet that is planted inside. The pressure reaches 100 psi (6.8 atm) or more, resulting in an inferior two-phase mixture. This system is widely used.
- Petrothermal System: Geothermal energy is mostly found in the form of Hot Dry Rock but there is no underground water. Rocks formed at moderate depths have very low permeability and need to be broken for surface heat transfer. HDR thermal energy is absorbed by pumping water or other fluids through drilled wells to the bottom of the rock fragments. Water moving through broken rock absorbs heat. Then it is taken to a second channel that has been drilled to the top of the rock and finally back to ground level. This hot water or steam is used to generate electricity.

There are several methods in estimating the magnitude of the potential of geothermal energy. The most commonly used methods are comparison and volumetric methods. The comparative method is a method specifically used to estimate speculative resource potential by means of simple statistics, while the volumetric method is the estimation of geothermal energy potential in hypothetical resource classes up to proven reserves. There are two approach models that can be used in the volumetric method, namely:

a. Approach model by assuming the reservoir parameters are uniform (lumped parameter model).
b. Approach model by assuming heterogeneous reservoir parameters (distributed parameter model) used in the reservoir simulation method. Reservoir simulation methods are used to help estimate proven reserves potential in geothermal energy that already has producing wells.

### 3.2. Principles of Comparison Method

The basic principle of the comparison method is to equalize the energy potential of a new geothermal area where the potential is not yet known with another field where the potential is known which has similar geological conditions. The magnitude of the energy potential of an area can be estimated in the following way:

$$Hel = A \times Qel \quad (1)$$

Hel = Amount of resources (MWe)
A = Geothermal prospect area (km$^2$)
Qel = Electrical power that can be generated per unit area (MWe/km$^2$)
Qel = 10 for T < 125$^0$C
= 12.5 for T between 125 - 225$^0$C
= 15 for T > 225$^0$C

### 3.3. Principles of the Volumetric Method

The basic principle of the volumetric method is to consider a geothermal reservoir as a box whose volume can be calculated by multiplying the area of the distribution and the thickness. In the volumetric method, the amount of potential energy resources or reserves is estimated based on the content of heat energy in the reservoir. The heat energy content in the reservoir is the sum total of the heat content in the rock and fluid. The heat content contained in the reservoir is calculated by the equation:

$$He = A\ h\ \{(1-F)\ rr\ Cr\ T + F\ (rL\ UL\ SL + rvUvSv)\} \quad (2)$$

Where :

He = Heat energy content (kJ)

A = Geothermal area ($m^2$)
h = reservoir thickness (m)
T = reservoir temperature ($^oC$)
SL = Water saturation (fraction)
Sv = Steam saturation (fraction)
UL = Energy in water (kJ/kg)
Uv = Energy in steam (kJ/kg)
F = Porosity of reservoir rock (fraction)
Cr = rock heat capacity (kJ/kg$^oC$)
rr = rock density (kg/$m^3$)
rL = water density (kg/$m^3$)
rv = steam density (kg/$m^3$)

The heat content that can be used is:

$$Hth = A\ h\ \{(1-F)\ rr\ Cr\ Ti + F\ (rL\ UL\ SL + rvUvSv)i\} - A\ h\ \{(1-F)\ rr\ Cr\ Tf + F\ (rL\ UL\ SL + rvUvSv)f\} \quad (3)$$

If all these parameters are known, the geothermal potential in Bedugul can be calculated carefully. The overall potential in the Bedugul reservoir is expressed in the following formula:

$$H_{re} = (He.\ \eta/(t.\ 365.\ 24\ .\ 3600)) \quad (4)$$

### 3.4. Reservoir Simulation Method

This method uses a heterogeneous parameter approach model (distributed parameter approach). Modeling activities can be carried out by dividing the reservoir system into a number of blocks or grids that are interconnected with one another. Block division is carried out by considering several factors including the type and characteristics of the rock, the rock structure and the location of the well. In this way, the variations in permeability, porosity, water content and vapor content in the reservoir and the fluid properties, both laterally and vertically, can be taken into account.

## 4. Results & Analysis

### 4.1. Engineering Review

According to the field data in Bedugul, proposed power plant system is the Dominant Fluid System with a binary cycle, because the steam condition is wet. The total steam mass can be calculated based on the mass of water in the separator, namely:

$$\text{Total steam mass} = \text{water mass} /(1\text{-vapor fraction}) \quad (5)$$

Based on the data, the geothermal vapor content in Bedugul has a fraction of 0.49. By calculating the mass of water in the separator, the mass of steam in one well can be calculated. Thus, to obtain a geothermal potential of 175 MWe, a geothermal prospect area of 17.5 $km^2$ is required. With notes, all site area is reservoir.

To be able to generate thermal energy of 175 MWe in 15 years, the amount of geothermal reserves in all Bedugul reservoirs is a minimum of 91,980,000,000,000 kJ. If the average hot steam content is 2800 kJ/kg, then the minimum geothermal reserves in the reservoir are 32,850,000,000 kg, or around 20,598,819,165,000 $m^3$. If the thickness of the reservoir is assumed to be 2,000 m, then the area of the reservoir, assume is in the form of plates, is 10,299,409,582.5 $m^2$ or equivalent to 10,299.4 $km^2$, which in other words exceeds the area of the island of Bali itself.

If the reservoir is assumed to be a dome with a reservoir thickness of 2,000 m, then the radius is around 57,271.9 km. However, if it is spherical with a reservoir thickness of 2,000 m, a minimum of 615 reservoirs is required. Various possibilities can occur in underground. Therefore to be able to generate 175 MWe in 15 years of operation, a minimum geothermal reserve in the reservoir is required of 32,850,000,000 kg, or around

20,598,819,165,000 $m^3$. Thus, if Bali Province does have a geothermal potential of 175 MWe within 15 years of operation, then the reservoir can be drilled from anywhere, because the area of geothermal prospects in Bali exceeds the area of the island of Bali itself.

Based on field data obtained in Bedugul, the following steam conditions are obtained:

a. Steam is mixed (mixed steam) with a pressure of 340 psi or equivalent of 23.4 bar and a steam temperature of around 120$^o$C (Kusuma. 2004). Based on these data, the type of power plant that is suitable to be built is a dominant liquid system with Binary Cycle.
b. Binary cycle or binary cycle is best used for Geothermal steam fluid which has a temperature of less than 200$^o$C, using brine technology as the working fluid used to generate electricity. So the electricity generation process is divided into two stages where the first stage uses geothermal steam as the working fluid, while the second stage uses brine as the working fluid.

   In the first stage, geothermal steam flows from the reservoir and is then used to heat the brine. Brine steam which has high pressure and temperature is then used to drive a steam turbine. Then the hot steam is cooled in the Cooling tower and after the temperature drops, the steam is separated in the separator into liquid waste and steam. The liquid waste is reinjected into the ground and the waste vapor is discharged into the open air.

   In the second stage, brine which has reached a superheated condition after being heated by geothermal steam is used to turn a turbine which is coupled to a generator. Then the brine is cooled first in the Cooling tower to produce a temperature according to the ambient temperature, then separated between the liquid waste and the vapor waste. This liquid waste will be heated and used again to turn the turbine, while the steam waste is discharged into the open air.

Maximum power that can be generated by the Bedugul power plant with steam working fluid is 7.02 MWe, therefore a modification is made with a binary cycle, by adding a boiler using $CH_4$ brine, which can generate power up to 20.6 MWe. This result is far different from what was conveyed by investors who stated that the available geothermal energy was 175 MWe.

### 4.2. Laws and Regulations Review

Various laws and regulations regarding energy that are numerous and widespread at present, of course, can create potential conflicts due to not being in line, overlapping, or colliding. In addition, the large number of institutions that directly manage energy and other institutions related to energy policy, for example institutions in the Ministry of Finance, the Ministry of Settlement and Regional Settlements, the Office of the Environment and the Ministry of Forestry, can lead to conflicts of interest caused by different orientations of institutional tasks. To overcome overlapping and conflicting interests regarding energy management –both in terms of policy substance and from an institutional perspective- it is necessary to have a functioning energy law:

1. Regulate that energy policies are properly integrated, able to anticipate future opportunities and challenges, guarantee sustainability, can accommodate various types of businesses that are legal under Indonesian law, protect consumers who have low purchasing power, and are directed to people's welfare.
2. Arrange for proper coordination of various institutions that are directly or indirectly related to energy.
3. Regulate the government's roles in the energy sector which are very important for the prosperity of the people, namely: setting energy prices, subsidy policies, research and development in the energy sector, developing human resources in the energy sector, energy planning, encouraging the domestic energy structure and supporting industries that are independent, efficient and able to compete nationally and internationally, regional and international cooperation, energy emergencies, as well as guidance and supervision.
4. Regulate that energy policies comply with the principles of good governance, including: opening access for the public to participate in policy formulation, being transparent and accountable, such as Regional Regulation of the Province of Bali Number 16 of 1998 concerning Monitoring and Management of Environmental Pollution by Waste, which regulates pollution prevention, special permits from the Governor, compensation, supervision and permissible threshold values.

### 4.3. Clean Development Mechanism

Using geothermal energy is not easy. The investment to explore geothermal energy is not small because it is classified as high technology and risky. Investment for capacity under one MW is US$3,000-5,000 per kilowatt (kW). Meanwhile, for capacities above one MW, an investment of around US$1,500-2,500 per kW is required. On the other hand, the geothermal potential in an area (usually in the mountains and remote areas) often cannot be utilized because the demand for electricity in that area is small, so it is not yet economical to explore and utilize power plant. Therefore, geothermal with varying depths, must first be explored to determine its capacity and energy potential. contained therein. The risk of exploration failure in finding reserves that are considered large enough for commercial development must be faced from the start. The next challenge is due to the site specific nature of geothermal to local geological conditions. Production practices and production quality will differ from one area to another. The rapid decline in production, for example, is the result of production that must be borne by the entrepreneur or developer, plus the poor quality of production, can cause many problems at the power plant. This means that the calculation of the initial potential for geothermal energy somewhere is very likely to be wrong. A well that is initially estimated to be reliable for five years, for example, may only have a productive life of about three years, so a new well must be prepared as a replacement.

Geothermal entrepreneurs, who generally use foreign loan funds, still have to consider and include a series of other risks, for example political and social factors in the area and location where the investment is planted. This is reasonable considering that the operating contract for each power plant unit is generally set for 30 to 40 years, so that electricity prices are quite affordable. Geothermal energy, which is generally located at a depth of 1,000 - 2,000 meters below the ground surface, is difficult to predict where it is and its character. In West Java, there are 13 known potential geothermal fields, where the reservoir characteristics of each geothermal field are different even though they are located in adjacent areas. The character of the Kamojang reservoir, which is very good due to the dominance of high pressure steam, is different from the character of the Wayang Windu reservoir which is also varied. The reservoir characters in the Gambung, Wayang, and Windu Blocks are very different. There are those that contain a lot of water but weak gas, such as in Gambung. Therefore, not all reservoirs are feasible to be developed further because the production costs are too high.

Geothermal energy in Bedugul, Bali, Indonesia, substantially produces the smallest emissions when compared to coal and gas, and can be categorized as environmentally friendly energy. So that the profit target from this geothermal project is the Clean Development Mechanism (CDM) award which is part of the Kyoto Protocol agreement for environmentally friendly industries (including power plants) from developed countries to developing countries.

A good geothermal power plant will produce electricity at a relatively cheap price and is environmentally friendly. This geothermal source can be managed by injecting the (unused) liquid back into the reservoir. However, the existence of the Bedugul power plant in the middle of a protected area is a question, especially when it is associated with the CDM award. Eventhough there is compensation for the forest to be exploited, of course from a hydrological and land use perspective, this compensation will certainly change the current fluid flow.

In implementing CDM projects, there are several conditions that must be met by developed countries, in accordance with the Kyoto Protocol. These provisions include:

a. Implemented CDM projects must meet the sustainable development criteria set by the developing country where the project is implemented (host country).
b. The host country must provide recognition that the implemented project or investment in a project will result in reduced greenhouse gas (GHG) emissions compared to if the project is not implemented.
c. Supplementary principle, namely the provision that stipulates that GHG emission reduction credits obtained by developed countries through projects in developing countries are additional in nature, apart from reduction efforts carried out within their own country. This means that developed countries are required to meet more GHG emission reduction targets within their own countries, rather than doing so in developing countries.
d. The additionality principle is a provision which states that CDM activities carried out by both parties will actually provide additional benefits when compared to if the project is not running.

e. Some values based on CDM that can make geothermal as the source of renewable energy in Bali, is as follows:
   1. The price of electricity offered is lower throughout its operational cycle
   2. Able to replace fossil fuels, and its designation is for the welfare of society
   3. The development must be flexible in meeting the needs of the electrical energy load, and the development must be carried out in stages
   4. Environmentally friendly, including the habitat and ecosystem around the site, will be no problems with water, both surface water and water sources
   5. The use of land/area is as small as possible and does not damage the existing or future ecosystem
   6. Able to maintain living natural resources around the location/area

## 5. Conclusion

Based on background, method and discussion, it can be concluded that:

1. Maximum power that can be generated by the Bedugul power plant with steam working fluid is 7.02 MWe, therefore a modification is made with a binary cycle, by adding a boiler using $CH_4$ brine, which can generate power up to 20.6 MWe. This result is far different from what was conveyed by investors who stated that the available geothermal energy was 175 MWe.
2. Regulate that energy policies are properly integrated, able to anticipate future opportunities and challenges, guarantee sustainability, can accommodate various types of businesses that are legal under Indonesian law, protect consumers who have low purchasing power, and are directed to people's welfare and comply with the principles of good governance, including: opening access for the public to participate in policy formulation, being transparent and accountable.
3. Geothermal energy in Bedugul, Bali, Indonesia, substantially produces the smallest emissions when compared to coal and gas, and can be categorized as environmentally friendly energy. So that the profit target from this geothermal project is the Clean Development Mechanism (CDM) can be applied. Some values based on CDM that can make geothermal as the source of renewable energy in Bali, is as follows: the price of electricity offered is lower throughout its operational cycle, able to replace fossil fuels, and its designation is for the welfare of society, the development must be flexible in meeting the needs of the electrical energy load, and the development must be carried out in stages, environmentally friendly, including the habitat and ecosystem around the site, will be no problems with water, both surface water and water sources, the use of land/area is as small as possible and does not damage the existing or future ecosystem and able to maintain living natural resources around the location/area

## References

1. Kagel, A. (2008). The state of geothermal technology. Geothermal Energy Association.
2. Kusuma, I. G. B. W. (2004). Ecological study of the Bedugul Geothermal Power Plant, Baturiti District, Tabanan Regency. E-Journal Udayana,
3. Moran, M. J., & Shapiro, H. N. (2006). Fundamentals of engineering thermodynamics (5th ed.). John Wiley & Sons.
4. Directorate General of State Assets. (2023). PT Geo Dipa Energi (Persero), the manager of geothermal energy. Ministry of Finance of the Republic of Indonesia. www.djkn.kemenkeu.go.id
5. Ministry of Energy and Mineral Resources. (2024). Understanding geothermal energy technology in Indonesia for clean electricity. Just Energy Transition. transisienergiberkeadilan.id

6. United Nations Framework Convention on Climate Change. (2021). Clean Development Mechanism (CDM) project standard for project activities. UNFCCC CDM Resources. cdm.unfccc.int
7. Borgnakke, C., & Sonntag, R. E. (2022). Fundamentals of thermodynamics (10th ed.). Wiley.
8. DiPippo, R. (2022). Geothermal power plants: Principles, applications, case studies and environmental impact (5th ed.). Butterworth-Heinemann.
9. Zarrouk, S. J., & Moon, H. (2014). Efficiency of geothermal power plants: A worldwide review. Geothermics, 51, 142–153. doi.org
10. Hakim, A. L. (2023). Geothermal energy potential and utilization in Indonesia. Indonesian Journal of Chemical Science, 12(1). journal.unnes.ac.id
11. Prawiradinata, I. (2021). Geothermal development in Indonesia: Opportunities and challenges. IOP Conference Series: Earth and Environmental Science, 716(1). doi.org
12. Setiawan, A., et al. (2020). Evaluation of geothermal reservoir potential using volumetric methods and numerical simulation. Journal of Exploration Geophysics (Jurnal Geofisika Eksplorasi), 6(2). jge.eng.unila.ac.id
13. Minister of Energy and Mineral Resources Regulation Number 33 of 2021 concerning Occupational Safety and Health, Environmental Protection and Management, and Geothermal Technical Principles for Indirect Utilization. (2021). Legal Documentation and Information Network of the Ministry of Energy and Mineral Resources. jdih.esdm.go.id
14. Law of the Republic of Indonesia Number 21 of 2014 concerning Geothermal Energy. (2014). Legal Documentation and Information Network of the House of Representatives. jdih.dpr.go.id.