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Technology Innovation in Mechanical Engineering Using Social Strategy for Sustainable Geothermal Business

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ABSTRACT

To know the important role of technology innovation in a company achieving goals to support corporate, economic, social, & environment in geothermal business. Technology innovation could enhance resource assessment, resource development, & resource utilization & management. They could give a competitive advantage & sustainable business for the company that operates among communities. The geothermal field sometimes has different types of comunities, the company should have a social strategy to make sure the operation will run as well as e xpectation. This research uses qualitative methods by undertaking social mapping, observation, interviews, analysis documents, & forum group discussion. Technology innovation in mechanical engineering that is applied by the company can give a competitive advantage & accelerate geothermal development. Social strategy is very important for geothermal developers so that communities can have a good impact to avoid issues of economic, social, & environmental. Technology innovation in the geothermal business is to choose the right power plant technology that use. By using the binary cycle power plant system, the company can sell the electricity power at a cheaper price because the grace period is shorter than others.

Keywords: Innovation Technology; Mechanical Engineering; Social Mapping; Sustainable Business

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INTRODUCTION

Currently, Indonesia still relies on fossil energy relatively high according to the Indonesia National Energy Council (DEN) 2017, Indonesia depends on fossil as primary energy with the total 194 million of tonnes of oil equivalent (Mtoe). Indonesia still depends fossil as the usage of national energy. The usage of fossil energy with the consumption 43% by fossil fuel, 18% natural gas, and 31% coal, as we know they are not as renewable energy. They are formed over thousands of years. So that it will be faster forming than resources. The usage of fossil energy will be negative impact to environment that caused energy fossils have a high carbon dioxide emission & affect the greatest global warming. By having the highest consumption of fossil energy, it will make insufficient the existing of oil & gas so that Government of Indonesia should use National Government Budget (APBN) to buy fuel fossil from abroad to supply energy for community (Ichsan et al., 2022).

Indonesia has abundant geothermal resource. According to Ministry and Energy and Mineral Resources (MEMR) states that 25,386 MW of resource has been discovered in Indonesia (Susmanto et al., 2023). Indonesia is the second resource of geothermal depleting in the world. The progress of installed capacity of geothermal with the total 2,6GW, it is equivalent with 11% of geothermal resources in Indonesia stated by Prof. Dr. Eng. Eniya Listiani Dewi 2024 (Director General of New, Renewable Energy and Energy Conservation). By having abundant geothermal resource, it is possible to get faster transition to renewable energy reducing greenhouse-gas emission (GHG) as the Government of Indonesia has the target for Net Zero Emission in 2060. Using geothermal energy is appropriate for electricity because it is environment friendly & very low impacting to environment. The potential of geothermal in Indonesia as figure below:

Figure 1. Potential & Installed Capacity of Geothermal in the World

1	Amerika Serikat	30.000	3.676
2	**Indonesia**	**23.356,9**	**2.365,43**
3	Filipina	4.000	1.918
4	Turki	4.500	1.526
5	Selandia Baru	3.650	1.005
6	Meksiko	4.600	963
7	Italia	3.270	944
8	Kenya	15.000	646
9	Islandia	5.800	755
10	Jepang	23.400	542
	Total	**117.576,9**	**14.340,43**

No.	Pulau	No. Lokasi	Sumber Daya (MW)					Terpasang
			Spekulatif	Hipotetik	Cadangan			
					Mungkin	Terduga	Terbukti	
1	Sumatera	101	2.167	1.567	3.624	976	1.126,4	912,55
2	Jawa	75	1.259	1.191	3.260	377	1.820	1.263,8
3	Bali	6	70	21	104	110	30	0
4	Nusa Tenggara	34	215	146	783	114,42	19,08	19,08
5	Kalimantan	14	151	18	6	0	0	0
6	Sulawesi	90	1.352	342	989	180	120	120
7	Maluku	33	560	91	485	6	2	0
8	Papua	3	75	0	0	0	0	0
Total		356	5.849	3.376	9.251	1.763,42	3.117,48	2.365,43
					14.131,9			
			23.356,9					

ladan Geologi Kementerian ESDM, esember 2021

Resource: Geological Agency Ministry of Energy & Mineral Resource, December 2021

According to Figure 1. The potential to use renewable energy in Indonesia is as great opportunity. The progress of installed capacity as the previous paragraph stated.

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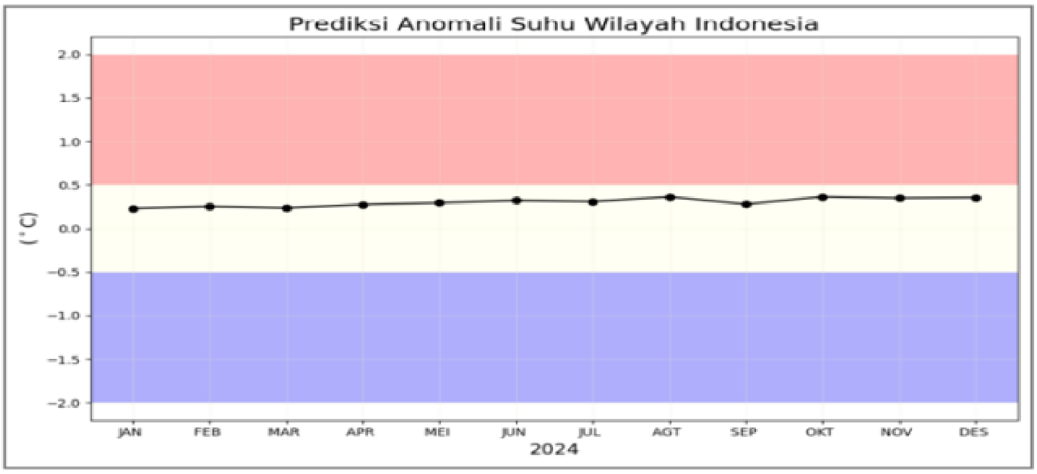
Technology innovation in geothermal business plays the important role in society for satisfying needs, achieving goals, and solving problems of adopters directed to supporting corporate, industrial, economic, and social change for competitive advantage of firms and nations, and improving overall human progress (Barich et al., 2021; Renoth et al., 2023). According to Abernathy and Clark (1985, p. 4ff), geothermal systems require technological innovations to improve both efficiency and sustainability (Yerger, 2024). These advancements cover several key areas, including advanced drilling technologies, material science developments, and energy storage integration. Advanced drilling methods are particularly critical for the success of Enhanced Geothermal Systems (EGS), as they enhance the efficiency and effectiveness of reservoir stimulation (Adeniran et al., 2024).

However, one of the most important strategies is the improvement of power plant technology. The binary cycle power plant system represents a technological innovation that offers cost-effectiveness and enables the utilization of waste heat at medium temperatures, ranging from 90°C to 150°C. Essentially, the Organic Rankine Cycle (ORC) system operates on similar principles to the Steam Rankine Cycle (SRC), with the key difference being the use of organic working fluids. These fluids have lower boiling points and higher vapor pressures than water, making them more suitable for low- to medium-temperature geothermal applications (Charles, 1990).

Geothermal energy is environment friendly, the usage of geothermal as electricity energy is as good energy transition. Because it produces low low levels of greenhouse-gas (GHG) emissions, have an important role to play in realizing targets in energy security, economic development and mitigating climate change. Geothermal resources, as opposed to hydrocarbon ones, are generally renewable since the circulation of heat and fluid is continuous. The sustainable geothermal business needs to be improved to reduce GHG. Currently global warming is as problem seriously over the world (Mikhno et al., 2022). The climate change in Indonesia as figure below:

Figure 2. The temperature of climate change for weather anomaly



Source: Meteorology, Climatology, and Geophysical Agency, 2023

According to Figure 2, the temperature in Indonesia is projected to increase steadily from January to December 2023. This rise is based on an anomaly range of 0.17°C to 0.45°C, indicating that the year will be significantly hotter compared to the 1991–2020 average (Manzella, 2017).

Currently, geothermal development in Indonesia remains in progress but continues to face numerous challenges. One of the primary obstacles is the high level of investment risk, especially due to the uncertainty of resources during the exploration stage. This is further complicated by the lengthy development timelines and the substantial capital required upfront. Additionally, Indonesia's geothermal-rich areas often lie in volcanic regions with difficult terrain, which makes access and development more complex. The presence of acidic fluids in some geothermal sources can also pose technical problems.

Infrastructure limitations are another significant issue, particularly in remote areas where geothermal potential is high. Poor road access and lack of support facilities hinder the transport and operation of drilling equipment and other essential tools. Beyond technical and logistical barriers, there is also resistance from local communities in certain regions, such as Mount Tampomas and Mount Lawu. This opposition often stems from concerns over the proximity of geothermal projects to residential zones, cultural heritage sites, and environmentally sensitive areas. In some cases, proposed development overlaps with conservation or protected forest zones, adding further complexity to the approval and implementation process (Ezquerro et al., 2023).

Overall, while Indonesia holds great potential for geothermal energy, realizing this potential requires addressing a combination of technical, financial, social, and environmental challenges.

LITERATURE REVIEW

The study by Kumar et al. (2022), titled Technological Advancements and Challenges of Geothermal Energy Systems: A Comprehensive Review, classifies geothermal technologies into four major categories: conventional hydrothermal systems, low-temperature geothermal systems, enhanced geothermal systems (EGS), and direct-use applications such as geothermal heat pumps (GHPs). While the first three categories are primarily focused on energy generation, the fourth is more commonly used for heating and cooling purposes. The study emphasizes geothermal energy as a sustainable and environmentally friendly resource with global potential. It suggests that integrating geothermal with other renewable sources in a hybrid system can enhance energy sustainability (Imran et al., 2024). Despite the global energy consumption of approximately 15 terawatts, geothermal energy remains an underutilized yet promising source that could meet a significant portion of this demand (Kumar et al., 2022; Alami, 2020).

In support of this, Odunaiya et al. (2020), in their research sustainable energy solutions through AI and software engineering: Optimizing resource management in renewable energy systems, argue that sustainable engineering practices are essential in improving the environmental performance of mechanical systems. Through life cycle assessment (LCA), they highlight that using eco-friendly materials and efficient design strategies significantly reduces greenhouse gas emissions and resource consumption. Approaches such as lightweighting, modular design, and circular economy principles contribute to energy efficiency and prolonged product lifespans, while promoting recycling and reducing waste.

Meanwhile the literature by Renoth et al. (2023), It discusses the importance of social strategies to increase acceptance of geothermal energy projects among communities. Based on past experience, they argue that community engagement, mitigation of environmental and social impacts, and providing tangible benefits to local populations are key strategies to enhance social acceptance. However, the study also notes that active community participation in decision-making remains limited, with most engagement limited to consultation and communication stages.

Based on these insights, this research intends to further investigate the topic "Technology Innovation in Mechanical Engineering Using Social Strategy for Sustainable Geothermal Business." As climate change continues to be a pressing global issue, advancing geothermal development becomes increasingly urgent. This study aims to explore the forms of technological innovation that contribute to geothermal development, examine how social strategies play a vital role in supporting and accelerating geothermal projects, and analyze the involvement of mechanical engineering in improving the effectiveness and sustainability of geothermal energy systems.

RESEARCH METHOD

This research adopts a qualitative descriptive approach, utilizing a literature review as the primary method. The data sources include theoretical frameworks, scholarly articles, previous research, and reference books that are relevant to the topic of geothermal development, technological innovation, mechanical engineering, and social strategy. The data analysis process involves carefully reviewing and interpreting these sources, followed by comparing the findings with real-world practices of geothermal developers in Indonesia who have implemented technological innovations, mechanical engineering solutions, and social strategies. This comparative interpretation aims to provide deeper insights into the practical applications and impacts of these elements in the context of sustainable geothermal business development.

RESULTS

Technology Innovation for Geothermal Development

According to previous research by Uzuegbu et al. 2024 stated that technological innovations play a pivotal role in enhancing the efficiency and sustainability of Enhanced Geothermal Systems (EGS). These advancements encompass several key areas, including advanced drilling technologies, material science innovations, and energy storage integration. Advanced drilling technologies are crucial for the success of EGS, particularly in improving the efficiency and effectiveness of reservoir stimulation (Li et al., 2022). Directional drilling and hydraulic fracturing are two prominent techniques that have significantly advanced the field. Directional drilling enables the precise targeting of geothermal resources by allowing wells to be drilled at various angles rather than vertically. This technique enhances access to geothermal reservoirs that might otherwise be challenging to reach with traditional vertical wells, thereby increasing the potential for successful heat extraction (Zhang et al., 2021). Hydraulic fracturing, also known as fracking, involves injecting high-pressure fluids into the subsurface to create fractures in the rock, thus enhancing its permeability and facilitating the flow of geothermal fluids. This method has become a cornerstone of EGS operations, as it enables the creation of artificial reservoirs where natural permeability is insufficient (Uzuegbu et al., 2024).

Most of these projects are located in Australia, Europe, Japan, the Philippines and the US. Developments focus on improving permeability via hydraulic, chemical and thermal stimulation. Technical challenges include well architectures, stimulation techniques, use of 3D numerical models, sustainability assurance of fracture opening with respect to unwanted effects. Advanced geothermal systems (AGS) have yet to be demonstrated as a commercially viable technology. The first commercial-scale implementation is the EAVOR-LOOP projectin Germany (Ciucci, 2023). AGS can be applied to geothermal reservoirs with sufficient temperatures and low permeability. It carries low risks of leaks

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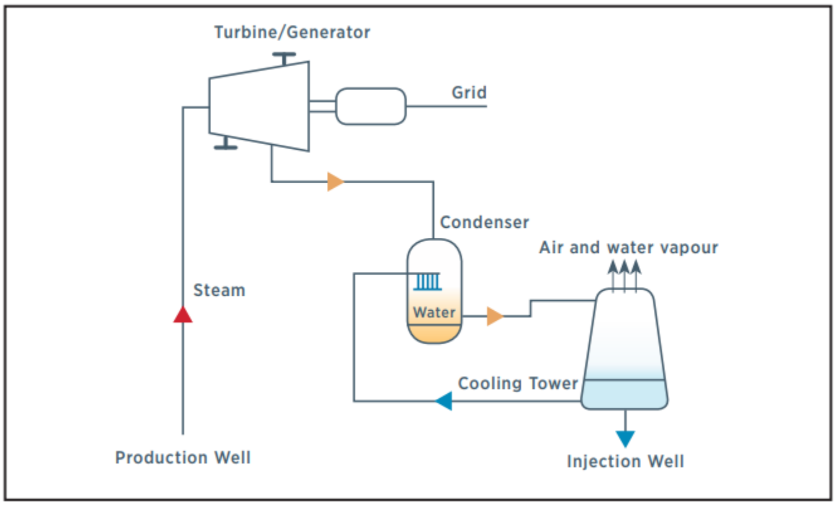
into surrounding aquifers, as wellbores are sealed, and produces no carbon emissions, as its closed-loop by design. AGS developments include reduction of drilling costs and research in innovative working fluids. Supercritical geothermal resources, with temperatures above 374°C under high pressure, exist in volcanic areas: Iceland, Italy, Japan, Kenya, Mexico and the US. The use of these resources has higher thermodynamic efficiency, but they face corrosion, technical, permeability, drilling and well completion challenges (Davoodi et al., 2024).

According to Maisyaroh et al. 2024, stated that low-temperature geothermal resources have the potential to provide large amounts of clean electricity. And it's the modularity of our Heat power systems that can make it a reality. They represent a huge potential to deliver a stable supply of clean electricity. But traditionally, it's been very expensive to build geothermal power plants. With a great deal of financial risk involved and a long wait for profitability. With KS Orka Modular Power Plant with an innovative incremental model, the geothermal power plant can start small and expand step by step. Build decentralized power plants and bring clean electricity to off-grid places. When the power plants need to produce more electricity, simply add more modules. With modular power plants the potential of geothermal heat power can be fully realized. Delivering a stable supply of clean electricity day in and day out throughout the year.

According to the above previous research, the writer summarized that in geothermal development is as crucial strategy in geothermal development to enhance geothermal energy can be achieved. The innovation technology can give cost-efficient, effectiveness, and competitive advantage. Refers to technology that used by one of geothermal developer in Mandailing Natal PT Sorik Marapi PT Sorik Marapi Geothermal Power, it is is one of the largest developing geothermal projects in Indonesia. This project is located in Mandailing Natal Regency, North Sumatera Province. KS ORKA acquired the majority shares of the company in mid-2016 and since then the project has completed with installed capacity 200MW December 2024. The project aims to connect 240 MW power to The PT PLN grid. Geothermal Power use binary cycle power plant. The company applies the modular power plant technology from Kaishan Manufacture. The technology allows us to develop geothermal resources in a more cost-efficient and environmentally friendly manner. As a type of thermal energy equipment which transforms heat into power, the screw expander realizes power output using the low qualification heat sources. The traditional conversion of heat into power is to propel the steam turbine to rotate with high-pressure, high-temperature superheated steam to then drive a synchronous generator. As the energy at the highest level, the electric power is convenient to use and transmit and now is the leading power source for industry and agriculture. According to the previous explanation for technology power plant using for geothermal development can be seen as follows:

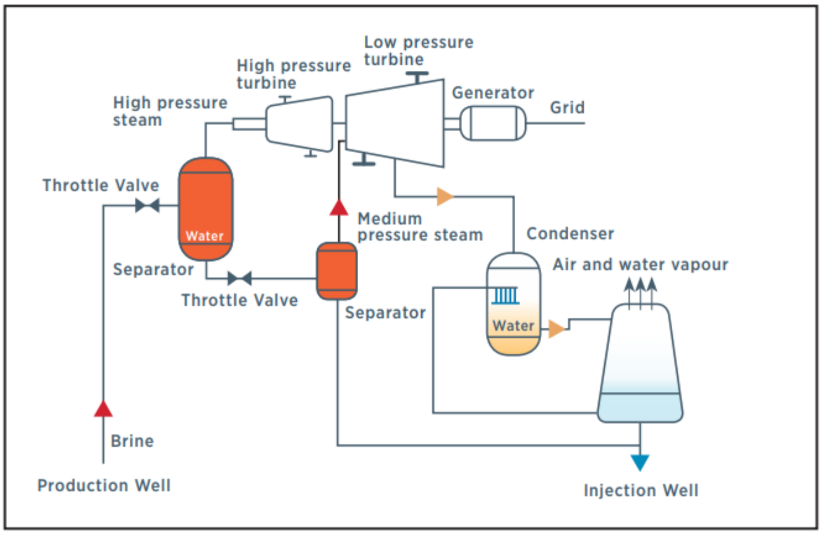
Figure 3. Direct Steam Plant



Source: IRENA, 2017c

According to Figure 3 the conversion device is a steam turbine designed to directly use the lowpressure, high-volume fluid produced in the steam field. Dry steam plants commonly use condensing turbines. The condensate is re-injected (closed cycle) or evaporated in wet cooling towers (IEA-ETSAP, 2010).

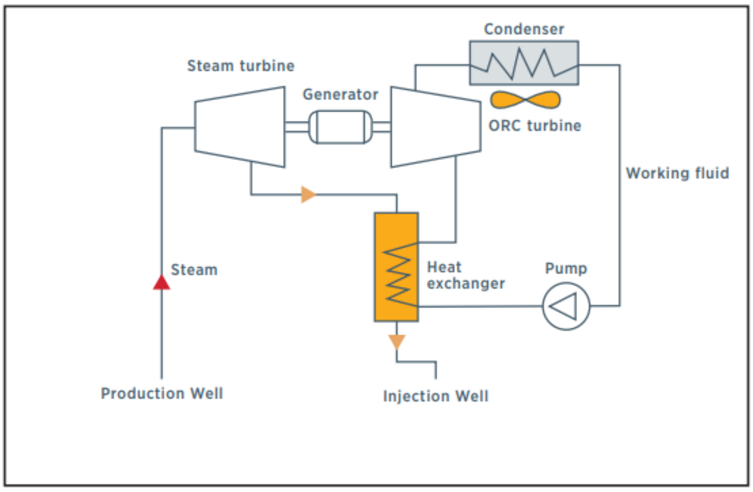
Figure 4. Double Fash Plant



Soure: IRENA, 2017c

According to Figure 4 these are the most common type of geothermal electricity plants in operation today. They are similar to dry steam plants; however, the steam is obtained from a separation process called flashing. The steam is then directed to the turbines, and the resulting condensate is sent for re-injection or further flashing at lower pressure (IEA-ETSAP, 2010).

Figure 5. Geothermal combined-cycle plant



Adapted from: ORMAT, 2017

According to Figure 5 Some geothermal plants use a combined cycle which adds a traditional Rankine cycle to produce electricity from what otherwise would become waste heat from a binary cycle (IEA-ETSAP, 2010). Using two cycles provides relatively high electric efficiency. The typical size of combined-cycle plants ranges from a few MW to 10 Mwe. Hybrid geothermal power plants use the same basics as a stand-alone geothermal power plant but combine a different heat source into the process.

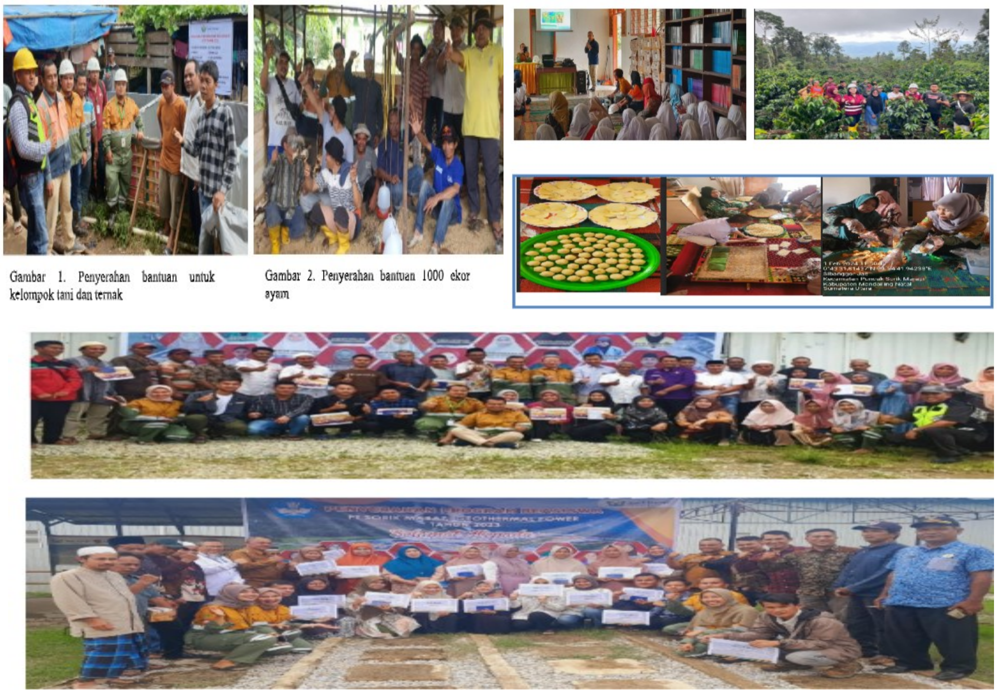
The Social Strategy in Geothermal Development

According to Karytsas et al. (2019), stated that the examination of the social acceptance practises applied so far reveals specific differences between time periods and types of countries. Referring to emerging and developing economies, the first reports on social acceptance practices concerning specific geothermal power plants indicate that focus had been given mainly on providing benefits to local communities and minimizing any undesirable side effects. In such cases, the role of the local stakeholders was mainly to provide input for the planning of community development programs and / or Corporate Social Responsibility (CSR) activities, as presented for example for different cases in Philippines, Indonesia and El Salvador.

According to the previous research by the EU Horizon Europe Programme, COMPASS Project, under the grant agreement stated the perception of deep geothermal energy projects is influenced by project activities, the engagement process, and the context. Good public acceptance requires transparent, continuous communication and active engagement of local communities in decision-making. Projects should be well-integrated into the locally, with clear communication about risks and mitigation actions. Proposing and communicating direct socioeconomic benefits for the local area is essential. Approaches to increase social acceptance should be tailored to local conditions and adapted over time. Effective communication, citizen engagement, and proposing tangible benefits are crucial to avoid project contestation.

According to the above reference, the writer makes the conclusion that geothermal projects often have significant impacts on local communities including land use changes, potential environmental effects, and social disruption. So, a well-defined social strategy is essential for successful development of geothermal energy project. As seen on web site Community Development & Community Relation program PT Sorik Marapi Geothermal Power as follow:

Figure 6. CDCR Programme PT SMGP



Source: web

CDCR program to local communities is as the commitment of company to respect with local community where company operates to development geothermal energy. That program including 5 pillars target of sustainable development health, education, economic, social, environment.

Mechanical engineering in geothermal development

According to American Society of Mechanical Engineers (ASME) described mechanical engineers as the one who create and develop mechanical systems for all of humankind. The principles of force, energy and motion are being concern, mechanical engineers use their knowledge of design, manufacture, and operational processes to advance the world around us, improve safety, ability to manage economic with strength and enjoyment throughout the world (Alami, 2020). Mechanical also developed machine and tool that produce product that range from sport equipment to pharmaceutical devices, medical devices, personal computers, humidifiers, dehumidifiers, automobile engines, robotic arms, electrical power plants and solar driers. Mechanical engineer usually touches all section of life, spanning industries with limited barriers, opportunities for mechanical engineers to build up their career are enormous as opportunity are available worldwide throughout many companies ranging from large multinational to small local companies.

According to Okokpujie et al. (2019), system design, infrastructure provision and engineering enterprise management, are main concern of mechanical engineers, as making decision is an act that is performed throughout the life-cycle of the infrastructure, enterprise, process, or product. Mechanical engineers play lots of role of such life circle decision making. The one been utilized in most continent is partitioned into five principal phases, which involve Life Cycle Engineering means to integrate state of the art technologies into subsequent sustainability and to enable information and statistics flow.

According to definition from previous research, the writer make conclusion that mechanical engineering is very needed for every geothermal development to get the sustainable business. Because mechanical engineering has the crucial role in geothermal development how to design turbine, heat exchanger, drilling technology, plant operation & maintenance, and environment consideration.

DISCUSSION

This study reveals that technological innovation, social strategy, and mechanical engineering are key components in advancing sustainable geothermal development. Technological improvements such as directional drilling, hydraulic fracturing, and modular power plants have increased the efficiency and scalability of Enhanced Geothermal Systems (EGS). The case of PT Sorik Marapi Geothermal Power in Indonesia demonstrates how modular and binary cycle systems can reduce costs, minimize environmental impact, and expand energy access, especially in off-grid areas.

Social strategies also play an essential role in ensuring project success. Research shows that transparent communication, community involvement, and Corporate Social Responsibility (CSR) programs help build public trust and minimize resistance. PT Sorik Marapi's Community Development and Community Relations (CDCR) program is a good example of aligning geothermal development with local community needs in areas such as health, education, economy, environment, and social welfare.

Mechanical engineering provides the technical foundation needed to support these developments. From designing turbines and heat exchangers to maintaining plant operations, mechanical engineers ensure systems run efficiently and sustainably. Their role in life cycle engineering helps integrate modern technologies to meet sustainability goals.

In summary, geothermal energy development relies on the synergy between innovative technologies, effective social strategies, and strong mechanical engineering. These three elements support cost-effective, community-accepted, and technically sound geothermal projects that contribute to long-term energy sustainability.

CONCLUSION

In conclusion, technological innovation plays a crucial role in geothermal development, offering a competitive advantage by enhancing efficiency, reducing costs, and supporting environmentally friendly practices. Mechanical engineering also contributes significantly by designing and developing mechanical systems that support manufacturing and operational processes, improving safety and economic management. While Indonesia's national energy supply still relies heavily on fossil fuels, which contribute to high carbon dioxide emissions and environmental degradation, geothermal energy presents a cleaner alternative. However, geothermal projects can have significant impacts on local communities, including land use changes, environmental concerns, and potential social disruptions. Therefore, a well-defined and inclusive social strategy is essential to ensure the success and sustainability of geothermal development, fostering community support and minimizing resistance through active engagement, benefit-sharing, and responsible planning.

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DECLARATION OF CONFLICTING INTERESTS

The authors have declared no potential conflicts of interest concerning the study, authorship, and/or publication of this article.

REFERENCES

Adeniran, J. A., Odediran, E. T., Ogunlade, B. T., Adeagbo, T. O., Akanbi, O. F., & Adesina, O. A. (2025). Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Park Dusts from Lagos, Nigeria: Pollution levels, Sources and Exposure Implications. *International Journal of Environmental Research*, *19*(3), 1-19.

Alami, A. H. (2020). *Mechanical energy storage for renewable and sustainable energy resources* (p. 71). Cham, Switzerland: Springer.

Barich, A., Stokłosa, A. W., Hildebrand, J., Elíasson, O., Medgyes, T., Quinonez, G., ... & Fernandez, I. (2021). Social license to operate in geothermal energy. *Energies*, *15*(1), 139.

Charles, D. (1990). Technological innovation. *Australian Journal of Public Administration,* *49*(3), 332–342. https://doi.org/10.1111/j.1467-8500.1990.tb01976.x

Ciucci, M. (2023). Innovative technologies in the development of geothermal energy in Europe. *Policy Department for Economic, Scientific and Quality of Life Policies-Directorate-General for Internal Policies-European Parliament*.

Davoodi, S., Al-Shargabi, M., Wood, D. A., Slivkin, S., Shishaev, G., & Rukavishnikov, V. S. (2024). Geothermal energy recovery from abandoned petroleum wells: A review of the challenges and opportunities. *Sustainable Energy Technologies and Assessments*, *68*, 103870.

Ezquerro, M., Diaz-Balteiro, L., & Pardos, M. (2023). Implications of forest management on the conservation of protected areas: A new proposal in Central Spain. *Forest Ecology and Management*, *548*, 121428.

Ichsan, M., Lockwood, M., & Ramadhani, M. (2022). National oil companies and fossil fuel subsidy regimes in transition: The case of Indonesia. *The Extractive Industries and Society*, *11*, 101104.

Imran, N. F. N. B. A., Effendee, N. F. B. N., Faris, N. H. H. B. M., Puad, N. I. S. B. M., Nitin, N., Verma, V., Mayur, K., Lim, H. L., Ng, W. C., Baiiyan, M., & Kee, D. M. H. (2024). The effect of eco-friendly packaging on consumer purchase intention: A study of beverage sustainable packaging practices. *Journal of The Community Development in Asia,* *7*(1), 1–13. https://doi.org/10.32535/jcda.v7i1/2539

IRENA, R. (2017). *Renewable Energy Prospects: Indonesia, a REmap analysis. Abu Dhabi: International Renewable Energy Agency (IRENA)*.

Karytsas, S., Polyzou, O., Mendrinos, D., & Karytsas, C. (2019). Towards social acceptance of geothermal energy power plants. In *Proceedings of the European Geothermal Congress, Den Haag, The Netherlands* (pp. 11-14).

Kumar, L., Hossain, M. S., Assad, M. E. H., & Manoo, M. U. (2022). Technological advancements and challenges of geothermal energy systems: A comprehensive review. *Energies, 15*(23), Article 9058. https://doi.org/10.3390/en15239058

Li, S., Wang, S., & Tang, H. (2022). Stimulation mechanism and design of enhanced geothermal systems: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *155*, 111914.

Maisyaroh, T., Nasution, Y. S. J., & Syahriza, R. (2024). Analysis of Community Socio-Economic Changes After Land Acquisition on the PT Sorik Marapi Geothermal Power Geothermal Project. *Indonesian Interdisciplinary Journal of Sharia Economics (IIJSE)*, *7*(1), 1046-1065.

Manzella, A. (2017). Geothermal energy. In *EPJ Web of conferences* (Vol. 148, p. 00012). EDP Sciences.

Mikhno, I., Redkva, O., Udovychenko, V., Tsimoshynska, O., Koval, V., & Kopacz, M. (2022). Sustainable energy supply management in the mechanical-engineering industry. *Polityka Energetyczna-Energy Policy Journal*, 39-54.

Odunaiya, O. G., Soyombo, O. T., & Ogunsola, O. Y. (2022). Sustainable energy solutions through AI and software engineering: Optimizing resource management in renewable energy systems. *Journal of Advanced Education and Sciences*, *2*(1), 26-37.

Okokpujie, I. P., Fayomi, O. S. I., & Oyedepo, S. O. (2019). The role of mechanical engineers in achieving sustainable development goals. *Procedia Manufacturing, 35*, 782–788. https://doi.org/10.1016/j.promfg.2019.06.023

Renoth, R., Buchner, E., Schmieder, M., Keim, M., Plechaty, M., & Drews, M. (2023). Social acceptance of geothermal technology on a global view: a systematic review. *Energy, Sustainability and Society*, *13*(1), 49.

Susmanto, A., Paradigma, D., Yuniasih, S., & Saputra, A. (2023, April 17–21). *Update on geothermal development status and working areas potential in Indonesia*. Proceedings of the World Geothermal Congress 2023, Beijing, China. Directorate of Geothermal, Ministry of Energy and Mineral Resources.

Uzuegbu, E. J., Ikevuje, A. H., Gbenga, O., & Soyombo, O. T. (2024). Optimizing enhanced geothermal systems through technological innovations and data analytics for sustainability. *International Journal of Sustainable Energy Research, 13*(9), 298–308.

Yerger Jr, R. H. (2024). Analyzing the effectiveness of state-guided innovation. *Moonshots and the New Industrial Policy: Questioning the Mission Economy*, 95-108.

Zhang W., Wang J., Zhang F., Lu W., Cui P., Guan C., Yu M., & Fang Z. (2021). Heat transfer analysis of U-type deep borehole heat exchangers of geothermal energy. *Energy and Buildings, 237*, Article 110794. https://doi.org/10.1016/j.enbuild.2021.110794