ADMI IJST International Journal Science and Technology

OPEN ACCESS

IJST Vol 4 No. 2 | July 2025 | ISSN: 2828-7223 (print), ISSN: 2828-7045 (online), Page 101-113

A Systematic Review of Geothermal-Solar Hybrid Systems: Design, Performance, Operational Advantages, and Configuration Principles

Richard Wempie Vicky Uguy[1], Estrela Bellia Muaja[2]
[1]Universitas Katolik De La Salle Manado, [2]Politeknik Negeri Manado

Article History
Received : 03 July 2025
Revised : 25 July 2025
Accepted : 26 July 2025
Published : 27 July 2025

Corresponding author*:
ruguy@unikadelasalle.ac.id

Cite This Article:
Richard Wempie Vicky Uguy, & Estrela Bellia Muaja. (2025). A Systematic Review of Geothermal-Solar Hybrid Systems: Design, Performance, Operational Advantages, and Configuration Principles. *International Journal Science and Technology*, *4*(2), 101–113.

DOI:
https://doi.org/10.56127/ijst.v4i2.2204

Abstract: Indonesia's dependence on fossil fuels has resulted in significant environmental degradation and contributes to rising CO_2 emissions, despite the country's vast renewable energy potential. Geothermal and solar energy, as two of the most promising clean energy sources, offer complementary characteristics that can be leveraged in hybrid power systems. This study aims to identify optimal configuration strategies for hybrid geothermal–solar systems and evaluate their operational advantages over standalone geothermal plants in the Indonesian context. Employing a Systematic Literature Review (SLR) approach, this research synthesizes findings from recent literature (2012–2024) across major scientific databases. The review focuses on system design, working principles, thermodynamic performance, and implementation feasibility. Results show that preheating/superheating configurations using solar input can significantly enhance geothermal plant efficiency, increase brine enthalpy, and reduce scaling issues—common challenges in Indonesian geothermal operations. Hybrid systems demonstrate an average efficiency gain of 3–7% over conventional configurations. While these systems offer improved reliability, flexibility, and land use optimization, they also involve technical complexity and high capital costs. This study underscores the potential of geothermal–solar hybrid systems to support Indonesia's clean energy transition by increasing plant efficiency, reducing emissions, and optimizing renewable resource utilization.

Keywords: Geothermal Power Plant, Solar Energy, Hybrid System, Sustainable Energy

INTRODUCTION

Fossil fuels continue to dominate global energy consumption, accounting for 86%, or 80 GW, of the total power generation capacity of 93 GW in 2023. In Indonesia, the development of fossil energy has led to an additional capacity of 26 GW from 2018 to 2023, while renewable energy has only increased by 3.3 GW during the same period (Setyawati & Setiawan, 2024). Dependence on fossil fuels causes significant environmental damage, particularly in mining regions. This reliance can lead to an energy crisis; for instance, in Kalimantan, approximately 143,592 hectares of forest have been cleared and transformed into coal mines (Werner et al., 2023). The process of mining and generating electricity from coal significantly contributes to the increase in CO_2 emissions in the energy sector. To address these challenges, renewable energy sources are expected to play a much larger role in the future to help reduce CO_2 emissions (Sisdwinugraha et al., 2025). Geothermal and solar energy are promising renewable options to replace fossil fuels in power generation (Pambudi et al., 2023).

Indonesia, situated along the Pacific Ring of Fire, has the largest geothermal energy potential in the world, estimated at around 28,000 megawatts. Despite this significant resource, its full utilization has been hindered by various technical and geographical challenges that complicate the exploitation process (Pambudi et al., 2023). In addition, Indonesia has a consistent distribution of solar radiation throughout the year, with a technical potential for solar energy reaching 207.8 GWp and an average radiation intensity of approximately 4.8 kWh/m^2 per day (Afif & Martin, 2022). The process of transitioning from the exploration to the exploitation of geothermal energy involves significant investments and a lengthy development timeline. To address this, a strategy is necessary to optimize the installed geothermal power generation system, enhancing efficiency and ensuring a continuous energy supply. One viable strategy is to integrate the geothermal power generation system with a solar power generation system (Berian & Riyanto, 2021).

The purpose of this study is to identify effective design configurations for geothermal-solar hybrid systems and to assess their operational benefits in comparison to standalone geothermal systems. The focus is on enhancing efficiency, reliability, and adaptability within the context of renewable energy in Indonesia. This study employs a Systematic Literature Review (SLR) approach, a qualitative method that emphasizes a systematic, structured, and evidence-based examination of existing literature to synthesize relevant previous research findings related to the study topic (Ahn & Kang, 2018). Research from the past decade was accessed through databases such as IEEE Xplore, ScienceDirect, Google Scholar, and other reputable journal sources. The selection criteria focused on studies that address geothermal-solar integration, design parameters, system performance, operational benefits, and the working principles of various configurations.

RESEARCH METHOD

This study employs the Systematic Literature Review (SLR) method to comprehensively examine various research articles discussing the integration of geothermal-solar hybrid energy systems. This includes an analysis of design parameters, system performance, working principles, and operational advantages. The SLR method was selected because it facilitates the identification, evaluation, and synthesis of relevant literature in a structured and transparent way, ensuring that the results obtained are scientifically valid. A systematic literature review (SLR) is becoming more common as a means to enhance the rigor of research synthesis while reducing individual biases. An analysis of the Web of Science (WoS) database shows that 90% of literature review studies using SLR were published between 2012 and 2022 (Ahmad et al., 2023). Figure 1 illustrates the research roadmap, outlining the sequential stages and thematic focus of the study.

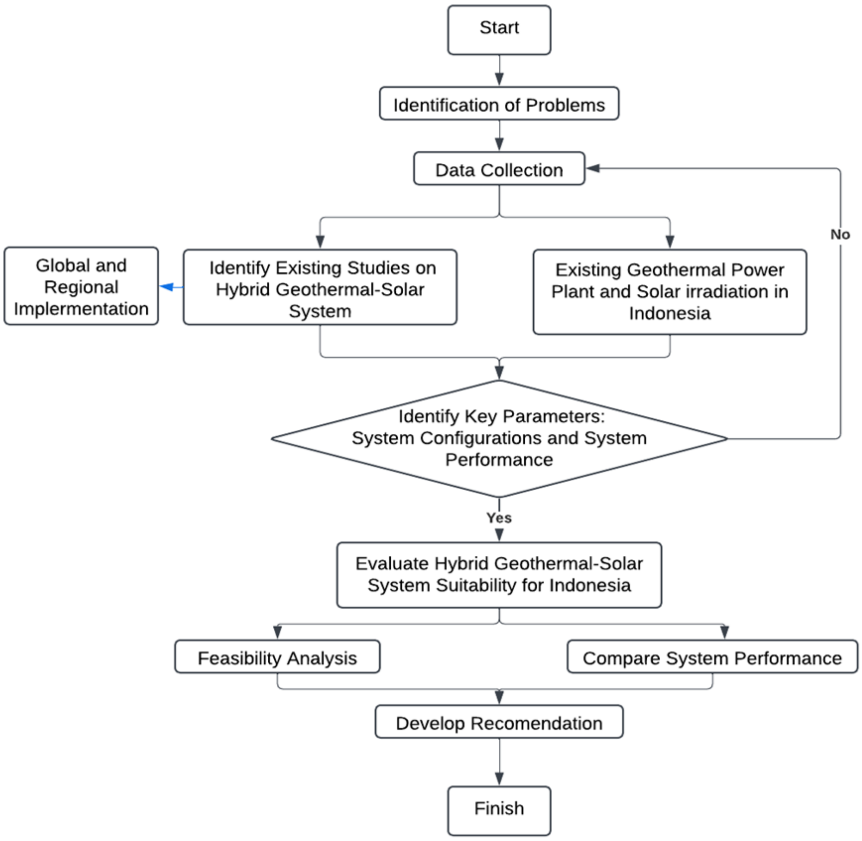

Figure 1. Research road map diagram

The research starts by identifying key issues, particularly the growing demand for reliable and efficient renewable energy systems in Indonesia. While geothermal energy is abundant, it often struggles to meet peak loads and provide a continuous supply. Combining geothermal energy with solar power offers a promising hybrid solution that can improve system stability and efficiency (Li et al., 2020a).

The next step involves collecting data through two parallel approaches:

a. Identifying existing studies on geothermal-solar hybrid systems from reputable databases, such as Scopus, ScienceDirect, and IEEE Xplore.

b. Gathering contextual information on Indonesia's geothermal power plants and solar irradiation levels from national sources like ESMAP and ESDM

To provide broader context and benchmarking, the study also reviews global and regional implementations of hybrid systems.

The next step is identifying the key parameters that define system performance and architecture is essential. These include:

1. System configurations: Examples are cascade, parallel, or sequential setups.
2. Performance indicators: Key metrics include thermal efficiency and energy output

These parameters provide a solid foundation for evaluating technical feasibility and establishing benchmarks (Azarian et al., 2023). This study assesses the feasibility of geothermal-solar hybrid systems in Indonesia by analyzing relevant parameters and contextual data. It takes into account the country's solar energy potential alongside the existing geothermal power plants.

The evaluation provides valuable insights that lead to actionable recommendations—both scholarly and practical—about system design, operation, and potential applications in Indonesia (Giedraityte et al., 2025). These recommendations focus on strategically integrating solar and geothermal resources to improve reliability and sustainability within the national energy mix (Li et al., 2020a). The methodology concludes once all review stages have been completed, and the results are presented in a clear, structured, and reproducible format to support further research and practical implementation.

RESULT AND DISCUSSION

Geothermal Power Plants in Indonesia

In Indonesia, the most commonly used technology in geothermal power plants is the single-flash system, which is suitable for water-dominated reservoirs. However, the Kamojang and Darajat plants utilize a vapor-dominated reservoir, necessitating the use of a dry steam power plant.

Table 1. Geothermal power plant in Indonesia

Province	Field	Total Capacity (MW)	Reservoir	Technology
West Java	Kamojang	239	Vapor dominated	Dry steam
	Salak	381.97	Water dominated	Single-flash
	Wayang Windu	227	Water dominated	Single-flash
	Darajat	293.21	Vapor dominated	Dry Steam

	Patuha	59.88	Water dominated	Single-flash
	Karaha	30	Water dominated	Single-flash
Central Java	Dieng	72.8	Water dominated	Single-flash
NTT	Ulumbu	10	Water dominated	Single-flash
	Mataloko	2.5	Water dominated	Single-flash
	Sokoria	11.58	Water dominated	Single-flash
North Sulawesi	Lahendong	123.71	Water dominated	Single-flash
North Sumatra	Sibayak	13.3	Water dominated	Single-flash
	Sarula	418.135	Water dominated	Single-flash
	Sorik Marapi	279.17	Water dominated	Single-flash
West Sumatra	Muaralaboh	89.25	Water dominated	Single-flash
Lampung	Ulubelu	229	Water dominated	Single-flash
South Sumatra	Lumut Balai	59.92	Water dominated	Single-flash
	Rantau Dedap	98.4	Water dominated	Single-flash
TOTAL	**2,638.8 MW**			

In the field of power plant technology, Table 1 presents the most recent data as of 2024, detailing various technologies, including unit capacities and reservoir types.

Solar Irradiation in Indonesia

Indonesia is renowned for its abundance of sunny days, receiving solar irradiation ranging from 3.6 to 6 kWh/m² per day. This level of solar potential translates to an estimated annual energy yield of approximately 1,170 to 1,530 kWh per kilowatt peak (kWp) (Solargis, 2019). Notably, several regions in Indonesia—such as Java, Sulawesi, and Nusa Tenggara Timur (NTT) Island—exhibit both high levels of solar radiation and significant geothermal resources, making them ideal candidates for the implementation of hybrid geothermal-solar energy systems, as illustrated in Figure 2.

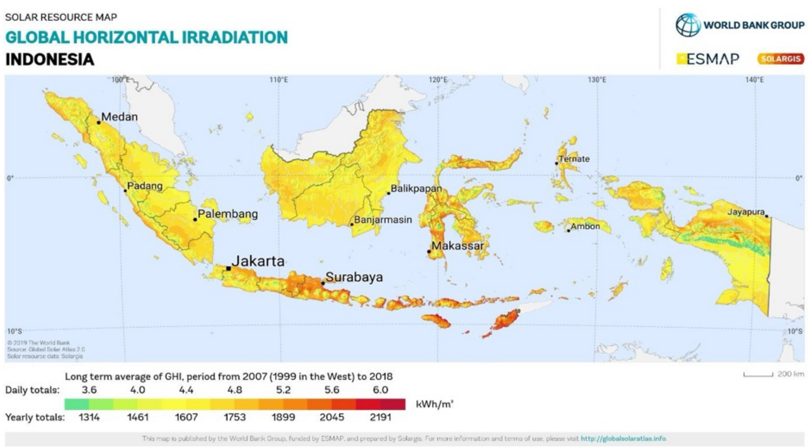

Figure 2. Solar irradiation level in Indonesia

Future Development of Hybrid Solar-Geothermal System in Indonesia

To achieve hybrid solar and geothermal power plants, both geothermal resources and solar energy are needed at the same location. As mentioned in the previous part, there are some places in Indonesia with high geothermal heat flux and high solar irradiation, such as Java, Sulawesi, and the NTT Island. This feature is the physical basis for hybrid solar and geothermal power systems. There are various hybrid scenarios involving solar-geothermal power systems. The scenarios depend on the physical and chemical properties of geothermal fluid, the main system of the geothermal power plant, and also the climate. Based on the available papers and publications, there are only a few existing hybrid solar-geothermal power plants, and most of the current studies focus on modeling hypothetical instead of existing hybrid solar-geothermal power plants. This may be because of the high initial cost and the great complexity of constructing and building total hybrid systems.

Table 2. Key Thermodynamic Parameters of Hybrid Geothermal–Solar Systems: Fluid Temperature, Flow Rate, Main Power Cycle, and Working Fluid

(Author, Year)	Fluid Temperature (^{0}C)	Flow Rate (kg/s)	Main Power Cycle	Working Fluid
(Berian & Riyanto, 2021)	-	61.235	Single-Flash	Steam
(McTigue et al., 2018a)	130-170	48	Double-Flash	Steam
(McTigue et al., 2018b)	138	34	Binary Cycle (dual-pressure-level)	Isopentane and Steam
(Bonyadi et al., 2018)	150	100	Binary Cycle	R-134a
(Cardemil et al., 2016)	205-240	-	Single and Double Flash	Steam
(Calise et al., 2016)	160	40	Binary	Isopentane
(Ayub et al., 2015)	160	40	Binary	Isopentane
(Ghasemi et al., 2014)	145	667.8	Binary	Isopentane
(Zhou, 2014)	150	50	Binary Plant	Isopentane
(Peterseim et al., 2013)	150-200	-	Single Flash	Steam
(Zhou et al., 2013)	120	50	Binary Plant	Isopentane
Zhou et al, 2011	180	50	Binary Plant	Isopentane
Manente et al, 2011	154.4	457.1	Binary Plant	Isobutane
(Astolfi et al., 2011)	150	100	Binary Plant	R-134a

(Author, Year)	Fluid Temperature (^{0}C)	Flow Rate (kg/s)	Main Power Cycle	Working Fluid
(Mir et al., 2011)	250		Single Flash	Steam
Greenhut et al, 2010	150	100	Flash-Binary/Binary Plant	R-134a
Alvarenga et al, 2008	154	-	Single Flash	Steam
(Lentz & Almanza, 2006)	300	44.92	Double Flash	Steam

The key thermodynamic parameters of hybrid geothermal–solar systems—including fluid temperature, flow rate, main power cycle, and working fluid—are presented in Table 2. The most commonly used working fluids in such hybrid systems are isopentane and steam. Isopentane is typically employed in binary cycle systems due to its favorable thermodynamic properties at moderate temperatures, while steam is utilized in single-flash geothermal systems. The geothermal fluid temperatures generally range between 120 °C and 300 °C, depending on the specific site characteristics and system configuration.

Table 3. Summary of Hybrid Geothermal–Solar Systems: Operation, Configuration, Efficiency, and Implementation Status

(Author, Year)	Working Principle	Type of Solar System	Efficiency (%)	Description
(Berian & Riyanto, 2021)	Increase steam quality	PTC	14-15	Model-based
(McTigue et al., 2018a)	1. Preheat Brine outlet separator 2 2. Preheat water outlet condenser 3. Preheat geothermal fluid inlet separator 4. Preheat brine outlet separator 1	LFC	17.3	Model-based
(McTigue et al., 2018b)	1. The solar field generates HP steam that is fed to two turbines. The steam exiting each turbine condenses in a heat exchanger and vaporizes isopentane.	-	1. 22.6 2. 22 3. 16.3 4. 13	Model-based

(Author, Year)	Working Principle	Type of Solar System	Efficiency (%)	Description
	2. HP steam is generated in the same way as for Cycle 1 in a single turbine. 3. Steam Preheat Mode 4. Brine Preheat Mode			
(Bonyadi et al., 2018)	Working Fluid Preheat Mode	PTC	20.5	Model-based
(Cardemil et al., 2016)	Steam and Brine Preheat Mode	PTC	-	Model-based
(Calise et al., 2016)	Working Fluid Superheat Mode	PTC	-	Model-based
(Ayub et al., 2015)	Working Fluid, Superheat Mode, Brine Preheat mode	PTC	5-10	Model-based
(Ghasemi et al., 2014)	Working Fluid Superheat Mode	PTC	-	Model-based
(Zhou, 2014)	Working Fluid Superheat Mode	PTC	-	Model-based
(Peterseim et al., 2013)	Superheating the vapor fraction of the brine and/or reheating	PTC	-	Model-based
(Zhou et al., 2013)	Working Fluid Superheat Mode	PTC	27.17	Model-based
Zhou et al, 2011	Brine Preheat Mode	PTC	13	Model-based
Manente et al, 2011	Brine Preheat Mode	PTC	-	Existing
(Astolfi et al., 2011)	Brine Preheat Mode	PTC		Model-based
(Mir et al., 2011)	Working Fluid Superheat Mode	PTC	-	Model-based
Greenhut et al, 2010	1. Working Fluid Superheat Mode 2. Brine Preheat Mode	PTC	Flash : 17.4-18 Binary : 10.8-11.4	The existing seven-unit dual cycle binary plant
Alvarenga et al, 2008	Working Fluid Superheat Mode	PTC	-	Existing
(Lentz & Almanza, 2006)	Fluid Preheat Mode for increasing the vapor fraction	PTC	-	Existing

Table 3 presents a summary of hybrid geothermal–solar systems, covering their operational principles, configurations, efficiency levels, and implementation status. Some scenarios may be chosen to build a geothermal and solar power generation hybrid in Indonesia. Some of the power cycle configurations that have been investigated in the past:

1. Working fluid preheat/superheat mode: This approach utilizes solar heat to raise the temperature of the working fluid (organic fluid or geothermal fluid before enters separator) in a geothermal power generation cycle before it enters the turbines, resulting in higher working fluid exergy and power generation.
2. Steam preheat/superheat mode: This approach utilizes solar heat to raise the temperature of the steam outlet separator before it enters the turbine, resulting in higher brine enthalpy and thus higher power generation.
3. Brine preheat/superheat mode: This approach utilizes solar heat to raise the temperature of the geothermal brine before it enters the heat exchangers or before it enters the turbine, resulting in higher brine enthalpy and thus higher power generation.

Steam preheat/superheat and brine preheat/superheat mode is the most common scenarios. It has the highest solar conversion efficiency. Because of the large flow rates and low heat transfer efficiency of two-phase flow from the production well, it requires a very big heat exchanger to meet the heating demand. In addition, the scaling issues can be delayed. So, this scenarios are potential to use in Indonesia, because silica scaling is one of technical problems faced by geothermal power plants in Indonesia. In case of the plant in Dieng, Central Java, the scaling can cause a decrease in electrical power generation by 40% of its 60MW existing capacity.

The average conversion efficiency of geothermal plants is 12%, which is lower than for all conversional thermal power plants. Conversion efficiency ranges from 1% for some binary systems to as high as 21 % for some dry steam plants. Conversion efficiency as a function of the reservoir enthalpy is given for single flash/dry steam, double flash, binary plants, and a generic geothermal power plant (Zarrouk & Moon, 2014). Based on the available paper and publication, the hybrid system had a higher maximum efficiency of about 3-7%, compared to separate geothermal and solar systems at all ambient temperatures.

The advantages of hybrid solar-geothermal power plants are (Li et al., 2020b):

1. They increase the temperature and steam flow rates of low-cost geothermal fluids, achieving up to 650 ºC for higher turbine inlet temperatures.

2. These plants enhance efficiency and boost power generation capacity.
3. They optimize geothermal resource utilization, especially for lower temperature sources.
4. Geothermal fluids can act as storage for solar energy, and the addition of solar heat increases the steam generated, improving capacity factors.
5. They make better use of land by combining energy sources from above and below ground, as solar systems typically need more space.
6. They can prevent salt deposition due to increased salt solubility at higher temperatures.
7. They reduce uncertainties in resource availability and improve reservoir performance through phased construction and flexible operations.

However, there are also drawbacks. The complexity of these systems can complicate maintenance and increase costs. Constant monitoring of fluid mass flow rates is required, which can be challenging. Initial costs are high, making them less competitive short-term, and the low pressure and temperature in geothermal fields necessitate larger solar fields, leading to higher capital investments.

CONCLUSION

Based on the results of the previous discussion and analysis, it is concluded that:

1. Hybrid solar-geothermal systems may perform better than stand-alone geothermal or solar power systems in terms of thermal efficiency. The improvement depends on the hybrid configurations.
2. There are many scenarios and options for hybrid solar and geothermal power systems. It is difficult to choose the appropriate scenario despite supporting modeling studies that consider the increased complexity of the hybrid power generation systems. Furthermore, the high initial cost is another barrier for large-scale adoption towards the construction of such hybrid solar and geothermal power systems
3. It is possible to integrate geothermal and solar energies in Indonesia because there are some locations with both high geothermal heat flux and surface solar irradiation

REFERENCES

Afif, F., & Martin, A. (2022). Tinjauan Potensi dan Kebijakan Energi Surya di Indonesia. *Jurnal Engine: Energi, Manufaktur, Dan Material*, *6*(1), 43–52. https://www.researchgate.net/publication/362433776_Tinjauan_Potensi_dan_Kebijakan_Energi_Surya_di_Indonesia

Ahmad, A. H., Dermanto, P. S., & Juangsa, F. B. (2023). Thermodynamic and Economic Comparison of Organic Rankine Cycle and Kalina Cycle as Bottoming Unit to Utilize Exhaust Steam from Back Pressure Turbine Geothermal Power Plant. *Workshop on Geothermal Reservoir Engineering*. https://www.researchgate.net/publication/369202023

Ahn, E., & Kang, H. (2018). Introduction to systematic review and meta-analysis. *Korean Journal of Anesthesiology*, *71*(2), 103–112. https://doi.org/10.4097/kjae.2018.71.2.103

Alvarenga, Y., Handal, S., & Recinos, M. (2008). Solar steam booster in the Ahuachapán geothermal field. In Proceedings of the Geothermal Resources Council Annual Meeting 2008 (pp. 335–339)

Astolfi, M., Xodo, L., Romano, M. C., & Macchi, E. (2011). Technical and economical analysis of a solar–geothermal hybrid plant based on an Organic Rankine Cycle. *Geothermics*, *40*(1), 58–68. https://doi.org/10.1016/j.geothermics.2010.09.009

Ayub, M., Mitsos, A., & Ghasemi, H. (2015). Thermo-economic analysis of a hybrid solar-binary geothermal powerplant. *Energy*, *87*, 326–335. https://doi.org/10.1016/j.energy.2015.04.106

Azarian, M., Yu, H., Shiferaw, A. T., & Stevik, T. K. (2023). Do We Perform Systematic Literature Review Right? A Scientific Mapping and Methodological Assessment. *Logistics*, *7*(4), 89. https://doi.org/10.3390/logistics7040089

Berian, Z. Y., & Riyanto, H. (2021). A System Design of a Solar and Geothermal Hybrid Power Plant for Flores Island. *IOP Conference Series: Earth and Environmental Science*, *732*(1). https://doi.org/10.1088/1755-1315/732/1/012016

Bonyadi, N., Johnson, E., & Baker, D. (2018). Technoeconomic and exergy analysis of a solar geothermal hybrid electric power plant using a novel combined cycle. *Energy Conversion and Management*, *156*, 542–554. https://doi.org/10.1016/j.enconman.2017.11.052

Calise, F., D'Accadia, M. D., MacAluso, A., Piacentino, A., & Vanoli, L. (2016). Exergetic and exergoeconomic analysis of a novel hybrid solar-geothermal polygeneration system producing energy and water. *Energy Conversion and Management*, *115*, 200–220. https://doi.org/10.1016/j.enconman.2016.02.029

Cardemil, J. M., Cortés, F., Díaz, A., & Escobar, R. (2016). Thermodynamic evaluation of solar-geothermal hybrid power plants in northern Chile. *Energy Conversion and Management*, *123*, 348–361. https://doi.org/10.1016/j.enconman.2016.06.032

Ghasemi, H., Sheu, E., Tizzanini, A., Paci, M., & Mitsos, A. (2014). Hybrid solar-geothermal power generation: Optimal retrofitting. *Applied Energy*, *131*, 158–170. https://doi.org/10.1016/j.apenergy.2014.06.010

Giedraityte, A., Rimkevicius, S., Marciukaitis, M., Radziukynas, V., & Bakas, R. (2025). Hybrid Renewable Energy Systems—A Review of Optimization Approaches and Future Challenges. *Applied Sciences*, *15*(4), 1744. https://doi.org/10.3390/app15041744

Greenhut, A. D., Tester, J. W., DiPippo, R., Field, R., Love, C., Nichols, K., et al. (2010). Solar–geothermal hybrid cycle analysis for low-enthalpy solar and geothermal resources. Paper presented at the World Geothermal Congress, Bali, Indonesia

Lentz, Á., & Almanza, R. (2006). Solar–geothermal hybrid system. *Applied Thermal Engineering*, *26*(14–15), 1537–1544. https://doi.org/10.1016/j.applthermaleng.2005.12.008

Li, K., Liu, C., Jiang, S., & Chen, Y. (2020a). Review on hybrid geothermal and solar power systems. *Journal of Cleaner Production*, *250*, 119481. https://doi.org/10.1016/j.jclepro.2019.119481

Li, K., Liu, C., Jiang, S., & Chen, Y. (2020b). Review on hybrid geothermal and solar power systems. *Journal of Cleaner Production*, *250*. https://doi.org/10.1016/j.jclepro.2019.119481

Manente, G., Field, R. P., DiPippo, R., & Rossi, N. (2011). Hybrid solar-geothermal power generation to increase the energy production from a binary geothermal plant. Proceedings of the New Zealand Geothermal Workshop, January 2011, paper: An in-depth assessment of hybrid solar–geothermal power generation.

McTigue, J. D., Castro, J., Mungas, G., Kramer, N., King, J., Turchi, C., & Zhu, G. (2018a). Hybridizing a geothermal power plant with concentrating solar power and thermal storage to increase power generation and dispatchability. *Applied Energy*, *228*(July), 1837–1852. https://doi.org/10.1016/j.apenergy.2018.07.064

McTigue, J. D., Castro, J., Mungas, G., Kramer, N., King, J., Turchi, C., & Zhu, G. (2018b). Hybridizing a geothermal power plant with concentrating solar power and thermal storage to increase power generation and dispatchability. *Applied Energy*, *228*, 1837–1852. https://doi.org/10.1016/j.apenergy.2018.07.064

Mir, I., Escobar, R., Vergara, J., & Bertrand, J. (2011). *Performance Analysis of a Hybrid Solar-Geothermal Power Plant in Northern Chile*. 1281–1288. https://doi.org/10.3384/ecp110571281

Pambudi, N. A., Firdaus, R. A., Rizkiana, R., Ulfa, D. K., Salsabila, M. S., Suharno, & Sukatiman. (2023). Renewable Energy in Indonesia: Current Status, Potential, and Future Development. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15032342

Peterseim, J. H., White, S., Tadros, A., & Hellwig, U. (2013). Concentrated solar power hybrid plants, which technologies are best suited for hybridisation? *Renewable Energy*, *57*(2013), 520–532. https://doi.org/10.1016/j.renene.2013.02.014

Setyawati, D., & Setiawan, D. (2024). *Laporan Ekspansi energi bersih Indonesia dapat mendorong pertumbuhan dan kesetaraan*. https://ember-climate.org/app/uploads/2024/08/ID-Laporan-Ekspansi-energi-bersih-Indonesia-dapat-mendorong-pertumbuhan.pdf

Sisdwinugraha, A., Hapsari, A., Wijaya, F., Bintang, H. M., & Surya, I. (2025). *Indonesia Energy Transition Outlook 2025* (Vol. 5). Institute for Essential Services Reform (IESR).

Solargis. (2019). *Global Horizontal Irradiation - Africa*. Solar Resource Maps. https://solargis.com/es/maps-and-gis-data/download/africa

Werner, T. T., Toumbourou, T., Maus, V., Lukas, M. C., Sonter, L. J., Muhdar, M., Runting, R. K., & Bebbington, A. (2023). Patterns of infringement, risk, and impact driven by coal mining permits in Indonesia. *Ambio*, *53*(2), 242–256. https://doi.org/10.1007/s13280-023-01944-y

Zarrouk, S. J., & Moon, H. (2014). Efficiency of geothermal power plants: A worldwide review. *Geothermics*, *51*, 142–153.

https://doi.org/10.1016/j.geothermics.2013.11.001

Zhou, C. (2014). Hybridisation of solar and geothermal energy in both subcritical and supercritical Organic Rankine Cycles. *Energy Conversion and Management*, *81*, 72–82. https://doi.org/10.1016/j.enconman.2014.02.007

Zhou, C., Doroodchi, E., & Moghtaderi, B. (2013). An in-depth assessment of hybrid solar–geothermal power generation. *Energy Conversion and Management*, *74*, 88–101. https://doi.org/10.1016/j.enconman.2013.05.014

Zhou, C., Doroodchi, E., & Moghtaderi, B. (2011). A feasibility study on hybrid solar–geothermal power generation. In Proceedings of the New Zealand Geothermal Workshop (pp. 1–7)