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Indonesia's Power Sector Scenarios To 2060: Modeling Geothermal, Solar, And Wind Expansion Under Energy Transition Policies

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Abstract - *Indonesia's target to achieve Net Zero Emissions (NZE) by 2060 places the energy sector at the center of decarbonization efforts. Despite vast renewable potential, the current energy mix is still dominated by fossil fuels, and the transition faces technical and policy barriers. This study applies the Long-range Energy Alternatives Planning (LEAP) model to assess four power generation scenarios from 2025 to 2060: Business as Usual (BAU), Geothermal (GEO), Solar & Wind (SAW), and Progressive (PRO). Each scenario evaluates electricity output, installed capacity, and renewable energy share. Results indicate that all scenarios meet the projected demand of 1,425.3 TWh by 2060. The GEO scenario achieves the highest output (1,527.4 TWh), while SAW faces intermittency challenges. The PRO scenario provides the most balanced pathway, with an 83.41% renewable share and 1,432.6 TWh output. Findings indicate that combining geothermal as a stable baseload with integrated solar and wind, supported by storage and smart grids, is key to a sustainable and reliable transition. By integrating the latest national energy plans and extending projections to 2060, this study offers strategic insights for long-term policy formulation toward NZE.*

Keywords - *Energy transition; Geothermal; Solar; Wind; LEAP; Energy mix; NZE 2060*

I. INTRODUCTION

Indonesia's commitment to global climate action is anchored in the Paris Agreement (Law No. 16/2016) and progressively enhanced Nationally Determined Contributions (NDCs), with targets rising from 29%/41% (unconditional/conditional) in 2016 to 31.89%/43.20% in the Enhanced NDC (2022) [1, 2]. These are supported by the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR 2050) and the Just Energy Transition Partnership (JETP), which aims for peak power sector emissions by 2030 and net-zero by 2060, including a 290 Mt CO_2 reduction and 34% renewable share by 2030 [3, 4]. As of 2024, fossil fuels supply >85% of capacity, with renewables at 14.68% [5, 6]. The National Energy Plan (RUEN) targets 23% renewables in the primary mix by 2025 and 31% by 2050 [7, 8], yet progress is hindered by regulatory uncertainty, limited R&D, financing gaps, and fossil fuel subsidies totaling USD 37 billion in 2022 (USD 6.82 billion for electricity) [9]. These distortions undermine renewable competitiveness, requiring reforms such as carbon pricing, cost-reflective tariffs, and competitive procurement.

Indonesia's renewable technical potential totals 584.5 GW—336.5 GW solar PV, 246.2 GW wind, and 1.7 GW mini-hydro—with 333 GW economically viable at EIRR > WACC 6.96% [5]. Geothermal potential is 23 GW, but only ~2.4 GW is installed [9]; Presidential Regulation No. 112/2022 and Geothermal Law No. 21/2014 target 9.3 GW by 2035 and 18 GW by 2050 [7, 9]. The energy transition offers socio-economic benefits such as poverty alleviation and equitable growth [10], supported by declining renewable LCOE—utility-scale solar may fall 20% and onshore wind 30% by 2030, undercutting fossil generation [11, 12]. However, high VRE shares introduce intermittency, integration, and storage challenges [9], with studies suggesting up to 42% of VRE capacity may require storage [13, 14]. Investments in smart grids, transmission, and hybrid systems are critical [15, 16].

This study addresses these challenges using the Low Emission Analysis Platform (LEAP), valued for its accessibility and suitability for data-scarce contexts [17, 18]. Previous LEAP-based studies on Indonesia [19, 20, 21, 22] often have shorter horizons (to 2050), focus on single vectors, or omit updated policy integration. The novelty of this research lies in: (1) an extended horizon to 2060 aligned with NZE; (2) scenarios built on RUKN 2030–2060 and RUPTL 2025–2034 for policy relevance; (3) a dual focus on baseload (geothermal) and intermittent (solar, wind) renewables; and (4) integrated assessment of generation, capacity, and renewable share. By linking policy, technology, and economics, this work provides empirical evidence to guide Indonesia's low-carbon

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electricity strategy, offering actionable insights for policymakers, planners, and investors navigating multiple transition pathways.

II. LITERATURE REVIEW

A. Installed Power Generation Capacity in Indonesia

Indonesia's electricity system is powered by a diverse mix of power plants and energy sources, with coal-fired power plants being the primary contributor. As of 2024, approximately 86 GW—or about 85% of the total installed capacity of the national electricity generation system—comes from fossil fuel-based power plants, while around 15 GW, or 15%, is sourced from new and renewable energy power plants. Among fossil-based power plants, coal-fired power plants and mine-mouth CFPPs contribute the largest share, accounting for approximately 53% of total installed capacity. This is followed by gas-fired power plants with a combined share of about 26% of total installed capacity [6].

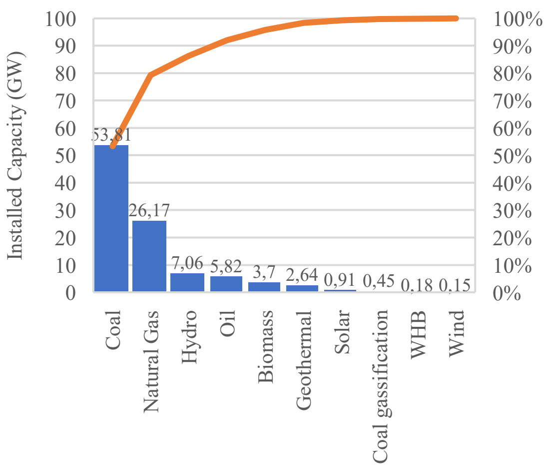

Figure 1 Pareto of Installed Capacity of Power Plants per Type

As of 2024, Indonesia's total installed electricity generation capacity reaches approximately 101 GW, with around 75% operated by PT PLN (Persero), 20.3% by Independent Power Producers, and 4.7% by Private Power Utilities (PPUs). Renewable energy-based power generation is dominated by hydro (7%), followed by biomass (4%) and geothermal (3%). Electricity demand in Indonesia is primarily driven by economic and population growth, while higher tariffs tend to suppress consumption; thus, regions with rising economic activity and electrification rates typically experience significant growth in electricity consumption [6].

Looking ahead, electricity demand is projected to grow beyond the business-as-usual (BAU) scenario due to the national energy transition goals aimed at achieving Net Zero Emissions (NZE) by 2060. The energy transition involves not only shifting from fossil-based to renewable power generation but also transforming primary energy consumption into secondary energy in the form of electricity across end-use sectors, including transportation, industry, commercial, and residential sectors [6].

B. Technical Potential of Renewable Energy

Indonesia has a lot of technical potential for renewable energy, which presents a major opportunity for a balanced and sustainable transition. Geothermal energy provides stable baseload capacity, while solar and wind offer variable yet scalable alternatives. They work together to solve problems with emissions and intermittency while making the system more resilient and energy independent [23, 24]. Adding solar, wind, and biomass to the national grid has been shown to help the economy grow and make the system work better [15]. Indonesia's tropical climate and location near the equator make it a great place for solar and wind energy, especially in remote and off-grid areas. This makes the country a key player in the global energy transition [5, 25]. Hybrid energy systems that use solar, wind, and storage technologies together are becoming better at bringing clean electricity to remote areas [16]. These sources can become the backbone of a strong and inclusive energy system if they get the right policies, technology, and investment.

According to Wood Mackenzie, the LCOE for solar and wind in Asia continues to decline. As of 2023, utility-scale solar LCOE had dropped by 23% due to a 29% reduction in capital costs and is expected to fall an additional 20% by 2030. The cost of onshore wind power is expected to drop by 30%. Offshore wind power is already cheaper than coal in coastal China and is expected to be cheaper than gas by 2027–2028. Renewable LCOEs are already 13% lower than coal, and by 2030 they could be 32% cheaper, as fossil fuel prices go up because of fuel and carbon pricing pressures [11]. By 2030, the cost of solar PV systems is expected to drop by 30–60%, and by 2050, it could drop by 75%. A similar cost trajectory is also expected for wind power technologies. Because of this, the LCOE for solar PV could drop to €0.01–0.03/kWh by 2050, while onshore wind could reach €0.02/kWh and offshore wind could fall below €0.06/kWh [12].

Despite their advantages, the intermittency of solar and wind requires investments in energy storage, grid flexibility, and demand response, which can increase their additional cost of energy [9]. However, declining prices for batteries and smart grid technologies are expected to offset these costs, accelerating renewable deployment toward Indonesia's NZE 2060 target. The IESR's Beyond 443 GW study identifies a technical potential of 584.5 GW—336.5 GW from solar PV, 246.2 GW from wind, and 1.7 GW from mini-hydro—with 333 GW deemed economically viable based on an EIRR exceeding the

WACC of 6.96% [5], dominated by solar (165.9 GW) and wind (167 GW), with mini-hydro contributing only 0.7 GW [25].

Table 1 Potential Feasibility of Renewable Energy [7, 5]

Energy	Technical potential (GW)	Potential Feasibility (GW)	Eligible locations
Geothermal	29,544	2,200	52
Solar	336.5	165.9	290
Wind	246.2	167.0	203

Solar and wind also support decentralized energy access, particularly in remote areas. Their complementary generation profiles—solar peaking during the day and wind at night or in specific seasons—reduce dependence on fossil fuels and enhance resilience. Hybrid systems leveraging both can cut costs by up to 20% compared to single-source systems, while reducing storage requirements due to balanced generation patterns. These systems also contribute to emission reduction, green economic growth, and stable supply as costs decline and technology improves [16]. When paired with storage and smart grids, they improve efficiency and equity in clean energy access, aligning with Indonesia's goal of over 30% renewables by 2060 and delivering social benefits such as community participation, job creation, and public awareness [24].

Energy storage remains critical for high VRE penetration, ensuring frequency stability, reserve capacity, and reduced curtailment risk. Large-scale deployment requires significant investment and supportive regulations [13]. Studies indicate that integrating VRE like solar and wind may necessitate storage capacity up to 42% of total VRE capacity to maintain system reliability [8].

C. Relevant Literature Review

This study uses the Long-range Energy Alternatives Planning (LEAP) model because of both theoretical and practical reasons, and there is a growing body of literature that supports this. LEAP has shown to be a flexible and complete tool for analyzing long-term energy transitions. It can combine demand-side modeling and generation mix projections into one framework. Several studies show that LEAP is easy to use, doesn't need a lot of data, and works with optimization models like OSeMOSYS. This makes it very useful for making energy policy decisions based on evidence in situations where data is limited [19]. LEAP is also a good choice for developing countries because it is free to use and is widely used in national energy planning [17, 18]. The model's bottom-up, end-use approach also makes it easier to build and compare policy and technology scenarios. This makes it a strong way to look at Indonesia's energy transition path toward net-zero emissions by 2060 and a strong power sector.

Most scenario-based studies utilizing LEAP typically apply at least three scenarios [19, 20, 18, 26], though a few employ fewer [17, 21], highlighting the importance of tailoring scenario design to specific research objectives and evolving policy landscapes. In Indonesia's case, a developing country with a dynamic and complex energy system, LEAP has become a focal modeling tool for scenario-based energy analysis [19, 27, 28]. Recent trends in energy research point to the sector's mounting challenges in achieving a low-carbon transformation, particularly in the context of Indonesia's Net Zero Emission (NZE) 2060 target [19]. Previous modeling efforts have extended their time horizon to 2050 or beyond 2060 to assess the adequacy of existing energy policies [19, 18, 20, 22].

Many of these studies construct a reference or Business as Usual (BAU) scenario as a baseline to project the implications of current policies [19, 18, 20, 28, 21, 22]. Alternative policy scenarios are then modeled to assess the potential impacts of renewable energy technologies, updated regulatory frameworks, or assumption-driven trajectories. By leveraging LEAP's scenario flexibility, such modeling enables a quantitative evaluation of policy impacts in terms of generation capacity and energy mix, supporting strategic decision-making for sustainable energy development.

III. METHODOLOGY

Overall, the conceptual framework presented in this study illustrates a systematic flow from historical data input to scenario simulation outputs, supporting a more data-driven and strategic formulation of Indonesia's energy transition roadmap. Multiple scenarios are constructed and compared to analyze generation capacity and energy demand under different projections. LEAP operates as an integrated modeling framework, where outputs from one module dynamically influence inputs in others. LEAP adopts a demand-driven, end-use modeling approach, where the analysis begins with final energy consumption [21, 18].

This research utilizes two main modules in the LEAP platform to model the expansion of Indonesia's electricity generation system [19]. First, the Demand Module projects future electricity needs based on historical consumption data and projected growth rates. Second, the Transformation Module estimates the generation capacity and total electricity production required to meet this demand.

The core objective of this study is to ensure that national electricity demand is met in each scenario within the established technical and policy constraints. Once energy demand projections are established, LEAP models the generation process via the transformation module, incorporating factors such as conversion efficiency, system losses, and reserve margin capacity. Projected generation capacity, energy mix, and annual electricity output are computed automatically based on technology parameters and demand projections. The modeling process begins with the collection of historical data including electricity demand, installed capacity, technology efficiencies, technical lifetimes, and generation costs. This data is used to build a base model of Indonesia's energy system that reflects consumption sectors, conversion processes, and primary energy sources [29, 18]. This base model serves as the reference point for all subsequent scenario analyses within the projection horizon of 2025–2060.

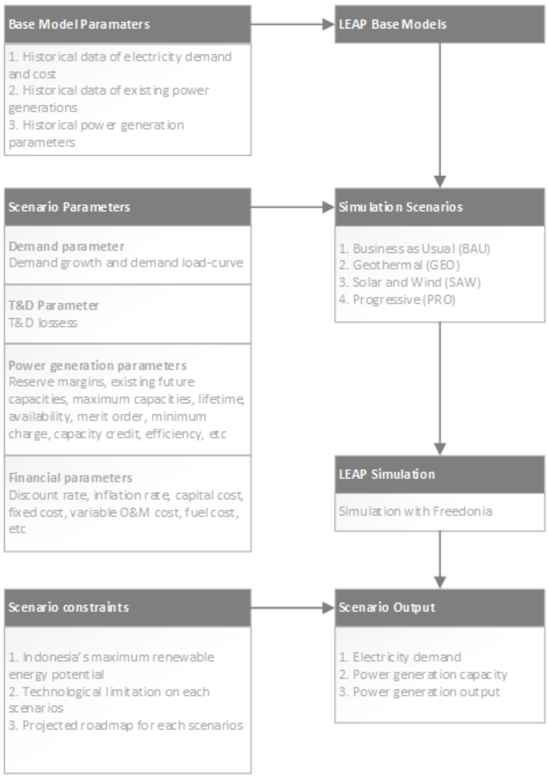

Figure 2. Research conceptual framework

Subsequently, key parameters are integrated into the model, including projected energy demand growth, transmission and distribution losses, and detailed technical and financial assumptions such as generation efficiency, maximum capacity, discount rate, inflation, capital expenditure, O&M costs, and fuel prices. The four developed scenarios are analyzed comparatively using relevant parameters and constraints, including maximum renewable energy potential, technological limitations, and national policy roadmaps. When the optimization mode is enabled, LEAP selects the most cost-efficient mix of generation technologies based on capital, operational, social, and fuel costs [21, 29, 19]. This modeling approach enables a realistic projection of Indonesia's future energy system aligned with the country's long-term energy transition goals.

The base year calibration of the LEAP model was conducted using historical electricity demand, installed capacity, and generation output data from 2015–2024 obtained from PLN and MEMR statistics [30, 9]. The dataset covers four main consumer categories—household, industry, business, and public—along with generation data disaggregated by primary energy source, including coal, natural gas, oil, hydro, geothermal, biomass, solar, and wind. Annual transmission and distribution losses for the same period were also integrated to ensure realistic system efficiency assumptions. This historical dataset serves as the foundation for the demand projections and technology capacity baselines applied in all scenario simulations.

IV. FINDINGS AND DISCUSSION

A. Electricity Demand Projection

Electricity demand in Indonesia is projected to reach approximately 314.3 TWh in 2025. Based on long-term projections by consumer category and assuming an annual population growth rate of 0.7% and an average annual electricity demand growth of 4.4%, total electricity demand is expected to increase significantly, reaching approximately 1,425.3 TWh by 2060. By that year, the projected demand is distributed as follows: households at 445.9 TWh, industry at 412.8 TWh, business at 455.9 TWh, and the public sector at 110.6 TWh.

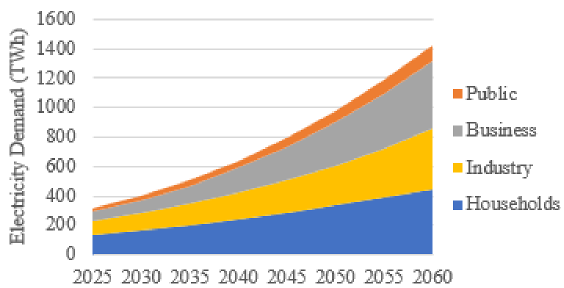

Figure 3 Electricity Demand

Total electricity demand is expected to more than quadruple over the projection period, driven primarily by significant increases in the household and business sectors, which are estimated to reach 445.9 TWh and 455.9 TWh, respectively, by 2060. The industrial sector remains a major contributor, rising from 97.3 TWh in 2025 to 412.8 TWh in 2060. The public sector also experiences a steady increase, although at a more moderate growth. These projections are critical for future power generation capacity planning, ensuring not only the sufficiency of electricity supply but also supporting a transition toward a cleaner, more efficient, and sustainable energy system.

B. Electricity Generation Scenarios

To facilitate a clearer understanding of scenario outcomes, a comparative summary of electricity generation output, installed capacity, and renewable energy share by 2060 is presented in Table 2. The analysis reveals distinct trade-offs among the four modeled pathways. The BAU scenario, reflecting current policies with moderate renewable integration, achieves the highest electricity output at 1,520.8 TWh and installed capacity of 305.0 GW. The GEO scenario delivers the highest electricity output (1,527.4 TWh) and emphasizes geothermal energy as a reliable baseload. The SAW scenario prioritizes the aggressive deployment of solar and wind technologies. Despite having the second-highest installed capacity (325.3 GW), this scenario faces challenges related to intermittency and system reliability due to the dominance of VRE sources. Finally, the PRO scenario represents a balanced and integrative approach, combining geothermal expansion, large-scale solar and wind deployment, and a phased coal retirement strategy. This pathway yields 1,432.6 TWh of output and the highest share of renewable capacity (83.4%) by 2060. Among the four scenarios, PRO demonstrates the most balanced outcome—high renewable share and full coal retirement—offering a strategic pathway aligned with Indonesia's NZE 2060 target.

Table 2 Comparative Summary of Four Energy Scenarios (2060)

Parameter (2060)	BAU	GEO	SAW	PRO
Total Electricity Output (TWh)	1,520.8	1,527.4	1,442.9	1,432.6
Installed Capacity (GW)	305.0	302.8	325.3	326.2
Renewable Share of Capacity (%)	76.3%	76.2%	80.9%	83.4%
Key Feature	Continuation of fossil reliance	Geothermal as primary base-load	Cost-efficient but intermittent	Balanced mix with coal phase-out

V. CONCLUSION

This study projects Indonesia's electricity generation system to 2060 using the LEAP model under four scenarios: Business-as-Usual (BAU), Geothermal (GEO), Solar & Wind (SAW), and Progressive (PRO). All scenarios meet the projected electricity demand of 1,425.3 TWh by 2060 but differ in capacity, generation, and renewable share. The GEO scenario delivers the highest output (1,527.4 TWh), while SAW achieves rapid renewable capacity growth but faces intermittency challenges. The PRO scenario offers the most balanced pathway, reaching the highest installed capacity (326.2 GW) and renewable share (83.41%). By integrating updated RUKN and RUPTL plans into a multi-scenario LEAP framework, this study fills a gap in long-term modeling and provides strategic insights for aligning the power sector with Indonesia's NZE 2060 target.

The policy recommendations emphasize a structured coal phase-out before 2050, coordinated with renewable expansion to sustain system reliability; prioritization of geothermal as a strategic baseload source with fiscal incentives, exploration risk mitigation, and streamlined licensing; and accelerated solar and wind deployment supported by investments in storage, smart grids, and demand-side management. To prevent carbon lock-in, transitional fossil-based technologies such as expanded gas infrastructure or biomass co-firing should be avoided, as they may delay deep decarbonization. Strengthening collaborative governance among government, private sector, academia, and international partners is crucial, alongside policy harmonization and innovation in renewable integration and storage. These measures offer a practical and technically robust roadmap for a sustainable, reliable, and affordable electricity system aligned with Indonesia's long-term climate goals.

Abbreviations

The following abbreviations are used in this manuscript:

BAU	Business as Usual Scenario
CCGT	Combined Cycle Gas Turbine
CFPP	Coal-Fired Power Plants
GEO	Geothermal Scenario
IESR	Institute of Essential Services Reform
IPP	Independent Power Producers
IRR	Internal Return Rate
LCOE	Levelized Cost of Electricity
LEAP	Low Emissions Analysis Platform
NDC	Nationally Determined Contributions
NPV	Net Present Value
NZE	Net Zero Emissions
OCGT	Open Cycle Gas Turbine
PLN	Perusahaan Listrik Negara
PPU	Private Power Utilities
PRO	Progressive Scenario
RUKN	Rencana Umum Ketenagalistrikan Nasional (National Electricity General Plan)
RUPTL	Rencana Usaha Penyediaan Tenaga Listrik (Electricity Supply Business Plan)
SAW	Solar & Wind Scenario
VRE	Variable Renewable Energy
WACC	Weighted Average Cost of Capital
WHB	Waste Heat Boiler

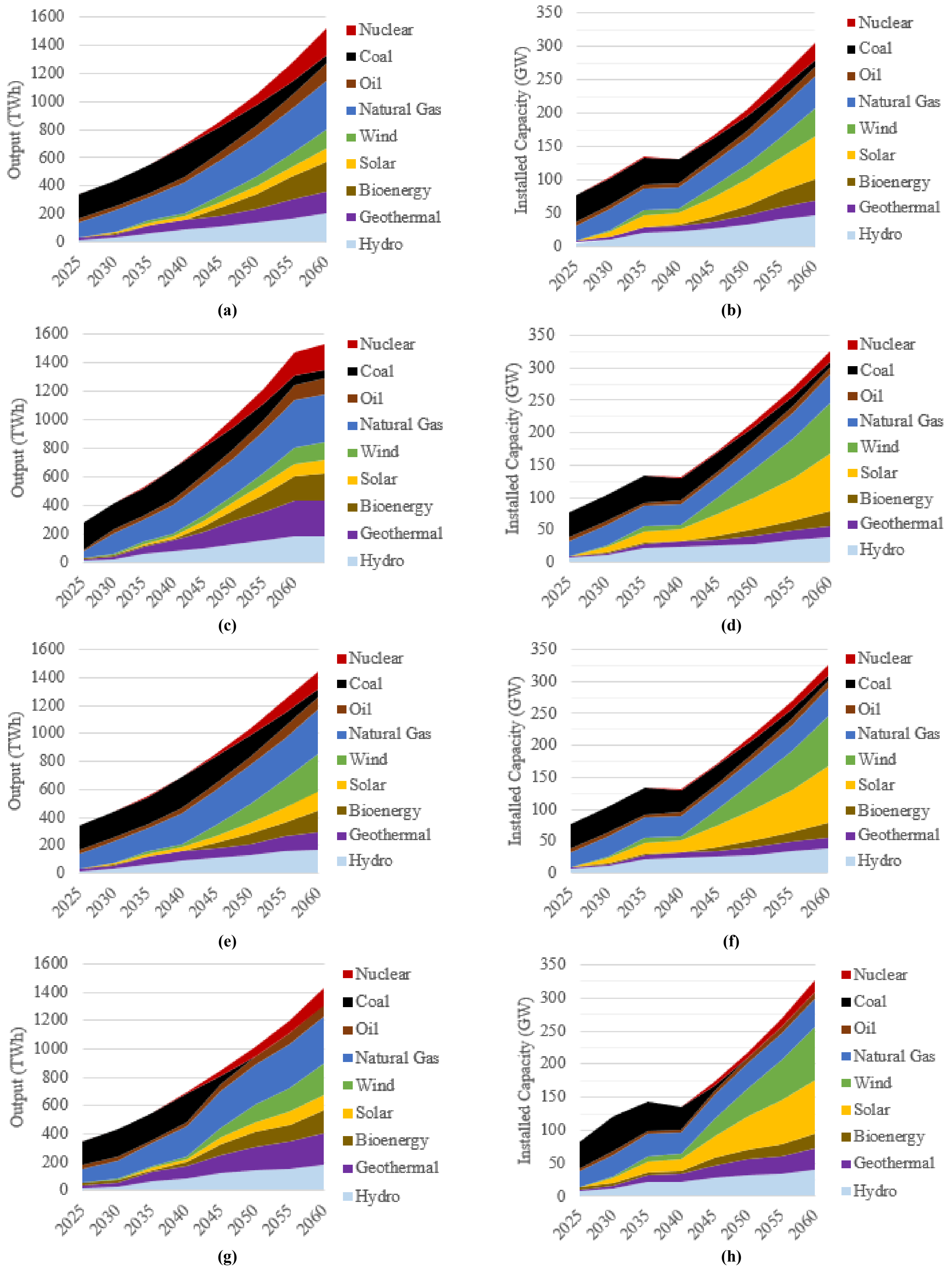

Figure 4 BAU scenario (a) output and (b) installed capacity power generation; GEO scenario (c) output and (d) installed capacity power generation; SAW scenario (e) output and (f) installed capacity power generation;
PRO scenario (g) output and (h) installed capacity power generation

REFERENCES

[1] Peraturan Presiden, "Pengesahan Paris Agreement to The United Nations Framework Convention on Climate Change," Pemerintah Republik Indonesia, Jakarta, 2016.

[2] H. Imelda and M. H. Soejahmoen, "Mengenal Nationally Determined Contribution (NDC)," Indonesia Research Institute for Decarbonization, Jakarta, 2023.

[3] Pemerintah Indonesia, "Enhanced Nationally Determined Contribution Republic of Indonesia," Pemerintah Republik Indonesia, Jakarta, 2022.

[4] JETP, "Just Energy Transition Partnership Indonesia: Rencana Investasi dan Kebijakan Komprehensif 2023," Sekretariat JETP, Jakarta, 2023.

[5] IESR, "Unlocking Indonesia's Renewables Future : The Economic Case of 333 GW of Solar, Wind, and Hydro Projects," Institute of Essential Services Reform (IESR), Jakarta, 2025.

[6] KESDM, "Rencana Umum Ketenagalistrikan Nasional 2030 - 2060," KESDM, Jakarta, 2025.

[7] S. Darma, "Indonesia: Vast Geothermal Potential to Support Net Zero Emissions," *Elsevier,* no. https://doi.org/10.1016/B978-0-443-24750-7.00020-8, 2025.

[8] I. A. Aditya, T. Wijayanto and D. F. Hakam, "Advancing Renewable Energy in Indonesia: A Comprehensive Analysis of Challenges, Opportunities, and Strategic Solutions," *Sustainabilty,* vol. 17, p. 2216, 2025.

[9] KESDM, "Pengesahan Rencana Usaha Penyediaan Tenaga Listrik PT Perusahaan Listrk Negara Tahun 2025 sampai dengan Tahun 2034," KESDM, Jakarta, 2025.

[10] I. Hardi, R. Kurniawan, S. Ray, G. M. Idroes, T. R. Noviandy and M. S. A. Majid, "Reducing the poverty gap and severity in Indonesia: The role of renewable energy access and consumption," *Human Settlements and Sustainability,* no. https://doi.org/10.1016/j.hssust.2025.06.001, 2025.

[11] Wood Mackenzie, "Solar inflation reverses as renewable costs in Asia reach all-time low," 2024. [Online]. Available: https://www.woodmac.com/press-releases/asia-lcoe/. [Accessed 2025].

[12] K. U. Shah, P. Raghoo and P. Blechinger, "Is there a case for a coal moratorium in Indonesia? Power sector optimization modelling of low-carbon strategies," *Renewable and Sustainable Energy Transition 5,* vol. 100074, 2024.

[13] S. K. Suraparaju, M. Samykano, J. R. Vennapusa, R. K. Rajamony, D. Balasubramanian, Z. Said and A. K. Pandey, "Challenges and prospectives of energy storage integration in renewable energy systems for net zero transition," *Journal of Energy Storage 125,* no. https://doi.org/10.1016/j.est.2025.116923, 2025.

[14] A. Amiruddin, A. Liebman, R. Dargaville and R. Gawler, "Optimal energy storage configuration to support 100 % renewable energy for Indonesia," *Energy for Sustainable Development 81,* no. https://doi.org/10.1016/j.esd.2024.101509, 2024.

[15] X. Liao, S. T. Bresciani, W. A. A. Bukhari and A. A. A. Bukhari, "How Solar, Wind, and Biomass Energy Create Sustainable Pathways Towards Green Economic Growth? Insights From the Top Five Global Renewable Energy Economies," *Sustainable Development,* vol. 22, no. https://doi.org/10.1002/sd.3345, pp. 4265-4282, 2024.

[16] Y. I. Febriansyah, D. H. Barus and I. M. I. M. Brunner, "Enhancing of Solar Power Forecasting in Hybrid PV Systems: LSTM-Based Time Series Analysis for lar Irradiance and Temperature Prediction," *International Conference on Technology and Policy in Energy and Electric Power (ICTPEP),* 2024.

[17] K. Handayani, I. Overland, B. Suryadi and R. Vakulchuk, "Integrating 100% renewable energy into electricity systems: A net-zero analysis for Cambodia, Laos, and Myanmar," *Energy Reports 10,* pp. 4849-4869, 2023.

[18] S. P. Kanugrahan and D. F. Hakam, "Long-Term Scenarios of Indonesia Power Sector to Achieve Nationally Determined Contribution (NDC) 2060," *Energies,* 2023.

[19] T. Wijayanto, D. F. Hakam and P. N. Kemala, "Vision for Indonesia's 2050 power generation: Scenarios of hydrogen integration, nuclear energy prospects, and coal phase-out impact," *Sustainable Futures,* vol. 9, no. 100438, 2025.

[20] S. P. Kanugrahan, D. F. Hakam and H. Nugraha, "Techno-Economic Analysis of Indonesia Power Generation Expansion to Achieve Economic Sustainability and Net Zero Carbon 2050," *Sustainability,* 2022.

[21] K. Handayani, T. Filatova, Y. Krozer and P. Anugrah, "Seeking for a climate change mitigation and adaptation nexus: Analysis long-term power system expansion of a long-term power system expansion," *Applied Energy,* vol. 114485, 2020.

[22] P. Paiboonsin, G. Oluleye, M. Howells, R. Yenganyan, C. Cannone and S. Patterson, "Pathways to Clean Energy Transition in Indonesia's Electricity Sector with Open-Source Energy Modelling System Modelling

(OSeMOSYS)," *Energies,* vol. 75, no. doi.org/10.3390/en17010075, p. 175, 2024.

[23] G. M. Idroes, M. Afjal, M. Khan, M. Haseeb, I. Hardi, T. R. Noviandy and R. Idroes, "Exploring the role of geothermal energy consumption in achieving carbon neutrality and environmental sustainability," *Heliyon 10,* no. https://doi.org/10.1016/j.heliyon.2024.e40709 , 2024.

[24] C. N. Nwagu, C. O. Ujah, D. V. V. Kallon and V. S. Aigbodion, "Integrating solar and wind energy into the electricity grid for improved power accessibility," *Unconventional Resources 5,* no. https://doi.org/10.1016/j.uncres.2024.100129, 2025.

[25] IESR, "Beyond 443 GW: Indonesia's infinite renewables energy potentials," Institute for Essential Services Reform (IESR), Jakarta, 2021.

[26] Y. I. Siregar, "Pathways towards net-zero emissions in Indonesia's energy sector," *Energy,* vol. 308, p. 6, 2024.

[27] K. Handayani, Y. Krozer and T. Filatova, "Trade-offs between electrification and climate change mitigation: An analysis of the Java-Bali power system in Indonesia," 2017.

[28] K. Handayani, P. Anugrah, F. Goembira, I. Overland, B. Suryadi and A. Swandaru, "Moving beyond the NDCs: ASEAN pathways to a net-zero emissions power sector in 2050," *Applied Energy,* 2022.

[29] C. G. Heaps, LEAP: The Low Emissions Analysis Platform, Software version: 2024.3.0.1 ed., Somerville, MA, USA: Stockholm Environment Institute, 2022.

[30] PLN, "Statistik PLN Tahun 2024," PLN, Jakarta, 2024.

[31] IESR, "Making Energy Transition Succeed: A 2023's Update on The Levelized Cost of Electricity and Levelized Cost of Storage in Indonesia," Institute for Essential Services Reform, Jakarta, 2023.

[32] M. A. Rahmanta, A. C. Adhi, H. B. Tambunan, W. Digwijaya, N. Damanik and R. A. Al Hasibi, "An Analysis of National Position, Opportunity, and Challenge of Indonesia's Nuclear Program to Support Net-Zero Emissions by 2060," *MDPI,* vol. 16, p. 8089, 2023.

[33] M. Shahid, K. Ullah, K. Imran, A. Mahmood and M. Arentsen, "LEAP simulated economic evaluation of sustainable scenarios to fulfill the regional electricity demand in Pakistan," 2021.

[34] G. Liu, J. Hu, C. Chen, L. Xu, N. Wang, F. Meng, B. F. Gianetti, F. Agostinho, C. M. V. B. Almeida and M. Casazza, "LEAP-WEAP analysis of urban energy-water dynamic nexus in Beijing (China)," 2021.