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Techno-economic optimization of hybrid renewable energy systems for household energy management

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ABSTRACT

Housing is a private palace that is safe, comfortable, and private. Techno-economic optimization of hybrid renewable energy systems and energy management for realizing green energy is a fundamental concept for ensuring security, comfort, and privacy in green housing for its residents, enabling them to carry out activities in their environment. The application of techno-economic optimization and renewable energy management to manage electrical energy so that it can be saved so that electricity costs can be reduced as one of the energy efficiency models. The problem of waste emissions and environmental pollution cannot be avoided. Therefore, a techno-economic optimization model for integrated power generation is needed, which is environmentally friendly and related to the housing problem discussed in this study. This study supports the concept that hybrid housing development is the best way to address environmental pollution, emissions, and waste in future housing and can be used as a benchmark for future housing development. In addition, the techno-economics of renewable energy used in households was also discussed.

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1. INTRODUCTION

The threat of climate change to the global economy, the impact on changes in income, and the potential impact of emissions are increasingly concerning, because the impact of emissions is very significant on electricity generation worldwide, which contributes 25% [1]. Therefore, reducing emissions in residential areas will have a significant impact on residents and their environment. Fossil fuel power plants produce emissions and hurt the environment. Indonesia will meet its green energy needs with geothermal power plants (63.4%) and the transition to renewable energy is being pushed for future use [2].

In developing countries, renewable energy sources are very important to meet energy needs, including in remote areas, including in housing. To improve the efficiency of renewable energy, the hybrid renewable energy system (HRES) model is one of the compatible renewable energy generation sources [3], [4]. Emission reduction aims to apply green energy to housing as a special concern in the development of new and renewable energy and this can reduce emissions caused by fossil fuels and climate change that play a role in the current energy supply. Therefore, changing the use of fossil energy to new and renewable energy is one model to

encourage sustainable energy. Integration of comprehensive analysis is very important in providing clean energy supported by the latest technology. Integration of photovoltaic (PV) systems into hybrid energy systems can reduce fossil fuel consumption, making hybrid systems an economical choice to power residential communities [5], [6]. Integrated systems for renewable energy for energy consumption are a challenge in remote and isolated areas, including in housing.

Fulfilling housing energy needs requires an integrated concept in an energy management system by utilizing technological advances in real-time as a form of balancing energy use [7]. The direction of implementing environmentally friendly energy is a joint agreement in the development of green energy in future housing. This is intended so that there is no gap in the application of the integrated environmentally friendly energy concept in housing development, for good coordination is needed between managers and modern social communities [8], [9]. In this study, an integrated optimization and management model is proposed, as well as the utilization of electrical energy in residential areas to save electrical energy in the future [10].

Several studies have focused on the technical and economic aspects of hybrid renewable energy systems. In Indonesia, it was found that PV-diesel systems can effectively reduce annual electricity expenditure [11]. Other research has been done on intelligent systems demonstrated by IEM (electronic device). The energy management system consists of an optimization controller that acts as a central controller and interacts with the operating browser via a communication protocol. In practice, the user interface allows for smooth interaction with connected devices using the same operating browser. In addition, weather information is also taken into account to estimate energy consumption and generation, as shown in Figure 1. Figure 1 shows the integrated system and management of the future environmentally friendly hybrid system.

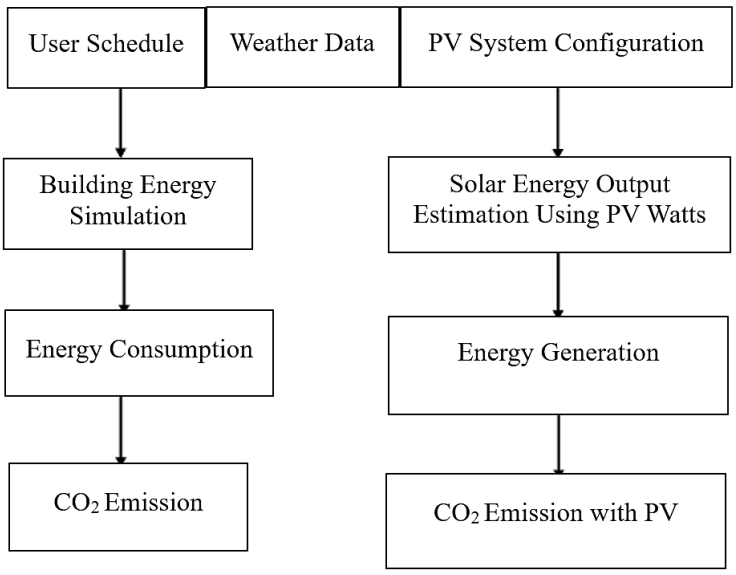

Figure 1. PV system configuration and energy consumption

The photovoltaic (PV) system is a system that utilizes solar energy which is converted into electrical energy, namely changing a direct current (DC) source into an alternating current (AC) source using an inverter, while the wind power (WP) system is a source that utilizes wind power into electrical energy, where both PV and WP systems are first stored in a battery system as energy storage before being used in the consumer system [12]. The configuration of PV, WP, and battery systems as an integrated system for rural energy systems has made a worthy contribution to the HOMER simulation model and has been applied in several regions in Africa and Asia and has provided a worthy evaluation using levelized cost of electricity (LCOE) [13]. Indonesia has discussed hybrid energy sources to optimize intelligent energy management systems consisting of economic analysis as a model for integrating human environmental climate security (HECS) in housing [14], [15]. In addition, the configuration of the hybrid system will be discussed in finding the best model for use in agriculture and industry. Comparison between WP-PV systems applied in educational facilities to achieve energy and cost savings.

To meet the normal operating load conditions, reducing energy consumption and increasing efficiency are appropriate policies to save energy. To realize emission reduction in housing and sustainable development [16]. This model helps develop communities to maintain a clean and green environment. The eco-friendly housing model is an extension of the green and eco-friendly building concept [17], [18]. The strategy system for implementing and managing energy emissions to realize green and environmentally friendly energy in housing is very important to be studied in more depth. Environmental protection is needed in the logical management process, saving water and electricity to achieve the goals of a green environment and preserving natural resources. Comprehensive analysis of housing energy consumption is a primary requirement in housing and environmental development. In the development and planning of the green and environmentally friendly housing development process, it becomes a standard for improving energy management for housing development [19], [20].

One of the commonly used simulations is a simulation model using HOMER, which can provide the best solution to identify a model that approaches the load profile variation and is reliable for certain conditions [21], [22]. Residential areas require effective and efficient management of electrical energy to meet certain standards in realizing green and environmentally friendly energy [23], [24]. Therefore, it requires professional and expert personnel who are able to handle this. The green energy management model is the basis for housing development to realize environmentally friendly information and automation, as well as housing energy management [25], [26]. This research contributes in the form of implementing a real system in realizing environmentally friendly energy in housing. In addition, it also contributes to the modeling of an integrated system in managing green energy for energy savings in housing.

2. METHOD

The rapid demand for electrical energy in the future must be supported by the management, analysis, and regulation of electrical energy to realize savings in electricity use. Development strategies, electrical energy management, and stakeholder support are benchmarks for the success of green and environmentally friendly housing [27]. Regulation and support to enhance the development of energy service companies in several developing countries need special attention and proper analysis. Such support has been proven by several studies that support financial and non-financial policies to encourage the development of effective electric energy services. A draft law on energy efficiency financing models and energy management has been proposed to implement energy management. A growth rate of 5% for the coming period can be used as a benchmark for energy savings by modeling economic stability [28].

Techno-economic and management optimization models for energy-saving systems can be realized in housing with green energy models. The discussion of green energy has been reviewed based on analytical data and financial issues [29], [30]. Green energy discussion is an important factor in public and business policy-making for the development of future energy management, as shown in Figure 2. Figure 2 shows that green energy consists of early-stage, automation integration, predictive analytics, machine learning and AI, sustainability and renewable energy integration, and future outlook. This is the evolution of the energy management system going forward.

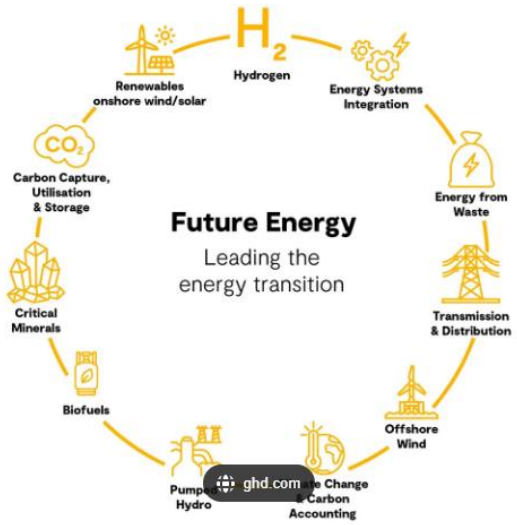

Figure 2. Future energy leading the energy transition

Figure 2 shows the future energy evolution and management scheme. In addition, Figure 2 depicts the future of energy integration and management. Analysis of the development of energy-saving services in Asia and beyond, where financing plays a major role [31]. There are obstacles in the development of energy-saving service industries in small industries, residential areas, and government policies. The results of the analysis and discussion conducted by other researchers have contributed to the policies and provisions for funding energy-saving service projects and funding constraints.

Energy-saving projects are an energy management method for cheaper financing [32]. This financing is a proposal for an energy efficiency model and an exploration model in energy management by considering several obstacles faced, such as investment, policies, and policies that do not yet support the development of environmentally friendly green energy [33]. To avoid the impact of the growth of new renewable energy on the gap between investors and the government, an in-depth analysis is needed regarding the financing and transition from fossil fuels to new renewable energy in a good and mutually beneficial way [34], [35].

A combination of promotion, government support, valid projects, and investment and financing have been designed to build energy conservation. The investment and financing model is the right assessment for energy-saving development. Risk analysis of contract energy management projects needs to be carried out in-depth [36]. Fuzzy analysis is a tool used to evaluate energy conservation in project implementation. In addition, the right to waste and emissions serves as a model for buying and selling. Conceptual modeling of total control, mechanisms, etc. can be used as considerations in energy management related to carbon sales [37].

2.1. Energy green

The artificial energy management model still has shortcomings, especially in terms of technology, personnel, and costs, but the current conditions are still acceptable [38]. Therefore, several ideas are needed, namely:

- Periodic inspections are carried out by personnel in charge of managing the electricity distribution room operated by the operator. Increasing the electrification of services will provide an increase in wise and targeted energy use. Energy management can also improve understanding of energy savings in housing. However, proper energy use will result in low failure.
- Scheduling meter usage checks is one solution, in addition to using other information technologies. Computers are one of the tools for monitoring energy usage in housing that have been integrated into the system through smart meters and can change the attitudes and behavior of energy users in housing. However, management for manufacturers regarding the use of software is also very important for careful analysis in running housing projects and to avoid errors in energy management in housing and impacting the sustainability of the surrounding environment.
- Failures that occur can be analyzed as feedback for improving the energy management system in the future. However, some obstacles that occur are caused by human factors that are less knowledgeable and less skilled in saving energy.
- Control and maintenance of the electrical energy system, if there is a failure in energy management, can be coordinated with personnel involved in energy management to obtain the best system that can be applied to housing.

2.2. Energy management

Currently, people's housing is very dependent on the availability of an electrical energy supply system. One of the technologies that can be applied is technology area network (TAN), where this technology uses a database and server model [39]. TAN technology can improve system reliability and short power outages and can improve energy management.

Residential energy management is an environmentally friendly housing management system because it uses a green energy system. This study aims to manage the use of electrical energy in housing, improve the concept of electricity use, and provide a basis for monitoring, analyzing, and assessing electricity use in the provision of electricity so that there is no waste of electricity use. The residential electrical energy integration and management system calculates, analyzes, and manages the energy used in housing while maintaining consistent power quality [40].

3. RESULTS AND DISCUSSION

Integration and management in housing depend on the electricity supply system. This is due to the development of TAN technology which is the development of software and databases that can be used as an energy system management model that is useful in increasing the reliability of the electricity system and can improve the quality of operational management in intelligent systems [41]. Power quality is a parameter in ensuring the quality of the transmission and distribution system in the provision of electrical energy.

This system monitors important parameters of the electrical power supply system according to the field situation and household and national electricity quality standards. Monitoring parameters include voltage, current, harmonics, power, frequency, and quantities that can be reflected effectively [42]. All parameters such as voltage in the distribution system are effectively monitored and controlled which can provide circuit breaker signals. For residential components in the application of electrical energy management and system integration, direct data monitoring can be expressed. The operating parameters of electrical equipment for residential areas are continuously monitored and the actual needs of residential locations are expressed to accurately reflect the situation of residential electrical energy consumption [43]. Configure monitoring facility visualization providers, simulation process diagrams, and suitability for internally applied data collection and queries. Manage historical data, and system operational data, and present them in the form of tables and curves [44].

The components and total energy consumption summarized at any time can provide quality information for analysis as a basis for decision-making in future operations. Availability for staff to create voice forms and other indicators. Voice alarms can be received at all operator stations and flash if the alarm is not confirmed [45]. Remote meter reading monitoring from various departments can be viewed and read. Thus, the possibility of errors will be reduced. The system can automatically provide a complete energy consumption report with a combination of system report templates, live data, and manual data entry used to generate a general report. The control center is a parameter for operators to control real-time conditions recorded for historical retrieval as a means of operational coordination to avoid similar errors in the future. Preservation of stored signals can be used as recommendation data in the following month [46].

The future of renewable energy is shown in Figure 3 which consists of energy that can contribute to the provision of energy in housing. The contribution of hydro energy makes a large contribution to other energy and nuclear energy makes a fluctuating contribution, but the development of PV, WP, and bioenergy energy follows the growth of housing development [47]. The use of environmentally friendly and reliable energy sources also contributes to future electricity needs. Figure 3 shows future energy use, where renewable energy will take over the role of future energy sources that are emission-free and environmentally friendly.

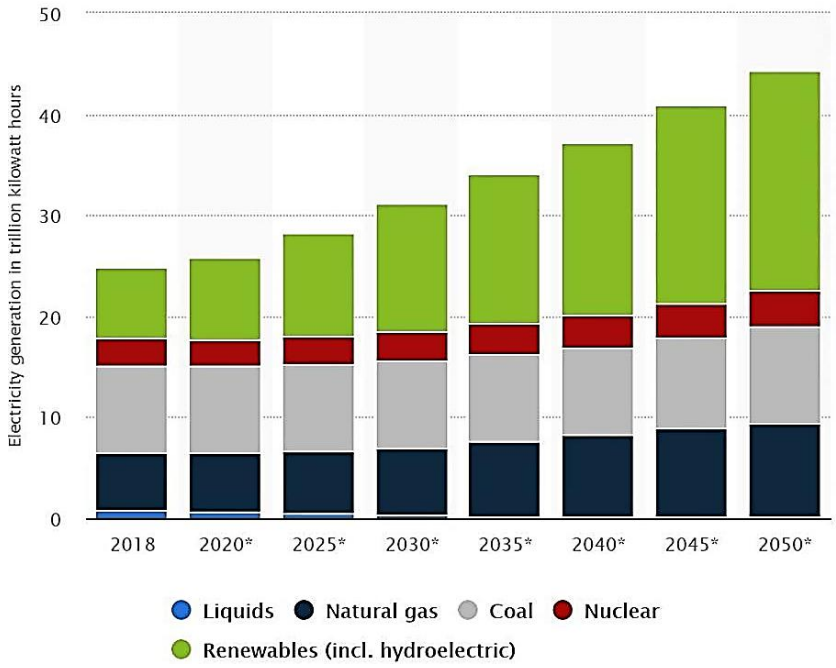

Figure 3. Renewable energy in the future

4. CONCLUSION

Efficient and scheduled energy use is a system and integration of green energy management needed to save energy in housing. This system can reduce emissions for energy management operations and become an effective and efficient construction management model. In addition, wise energy use can maintain the environment in housing with an integrated energy-saving system and is an important capital for future life.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Ahmad Taufik		✓				✓		✓	✓	✓	✓	✓		
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Muhammad Reza Aulia	✓		✓	✓			✓			✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] International Energy Agency (IEA), "Global energy review: CO2 emissions in 2021 global emissions rebound sharply to highest level," *International Energy Agency (IEA)*, pp. 1–14, 2022. [Online]. Available: https://www.iea.org/news/global-co2-emissions-rebounded-to-their-highest-level-in-history-in-2021.

[2] D. Hartono, S. H. Hastuti, A. Halimatussadiah, A. Saraswati, A. F. Mita, and V. Indriani, "Comparing the impacts of fossil and renewable energy investments in Indonesia: a simple general equilibrium analysis," *Heliyon*, vol. 6, no. 6, p. e04120, Jun. 2020, doi: 10.1016/j.heliyon.2020.e04120.

[3] S. Suwarno, C. I. Cahyadi, S. Sukarwoto, A. A. Dewi, and D. Pinayungan, "Comparative analysis of wind speed and energy potential assessment of two distribution models in Medan, Indonesia," *International Review of Electrical Engineering (IREE)*, vol. 18, no. 4, p. 275, Aug. 2023, doi: 10.15866/iree.v18i4.22725.

[4] M. F. Zambak, C. I. Cahyadi, J. Helmi, T. M. Sofie, and S. Suwarno, "Evaluation and analysis of wind speed with the Weibull and Rayleigh distribution models for energy potential using three models," *International Journal of Energy Economics and Policy*, vol. 13, no. 2, pp. 427–432, Mar. 2023, doi: 10.32479/ijeep.12775.

[5] S. T. Dwijendra *et al.*, "The uniqueness of architecture and bamboo house environment in Pengotan traditional village, Bali, Indonesia," *Journal of Social and Political Sciences*, vol. 4, no. 1, 2021.

[6] C. Wen *et al.*, "Household willingness to pay for improving electricity services in Sumba Island, Indonesia: a choice experiment under a multi-tier framework," *Energy Research and Social Science*, vol. 88, 2022, doi: 10.1016/j.erss.2022.102503.

[7] T. Falope, L. Lao, D. Hanak, and D. Huo, "Hybrid energy system integration and management for solar energy: a review," *Energy Conversion and Management: X*, vol. 21, 2024, doi: 10.1016/j.ecmx.2024.100527.

[8] M. Norouzi, M. Chàfer, L. F. Cabeza, L. Jiménez, and D. Boer, "Circular economy in the building and construction sector: a scientific evolution analysis," *Journal of Building Engineering*, vol. 44, p. 102704, Dec. 2021, doi: 10.1016/j.jobe.2021.102704.

[9] F. S. Hafez *et al.*, "Energy efficiency in sustainable buildings: a systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research," *Energy Strategy Reviews*, vol. 45, p. 101013, Jan. 2023, doi: 10.1016/j.esr.2022.101013.

[10] Q. Lu, S. Lü, Y. Leng, and Z. Zhang, "Optimal household energy management based on smart residential energy hub considering uncertain behaviors," *Energy*, vol. 195, 2020, doi: 10.1016/j.energy.2020.117052.

[11] Syafii, A. Luthfi, Novizon, and R. Fahreza, "Cost of energy sensitivity analysis of PV/Diesel with hydro pumped storage for mentawai microgrid system," in *2021 IEEE 4th International Conference on Computing, Power and Communication Technologies, GUCON 2021*, 2021, doi: 10.1109/GUCON50781.2021.9573985.
[12] Suwarno *et al.*, "Wind speed prediction for hybrid-based energy integration," *Science and Technology for Energy Transition (STET)*, vol. 80, 2025, doi: 10.2516/stet/2024103.
[13] S. W. Chisale, S. Eliya, and J. Taulo, "Optimization and design of hybrid power system using HOMER pro and integrated CRITIC-PROMETHEE II approaches," *Green Technologies and Sustainability*, vol. 1, no. 1, p. 100005, Jan. 2023, doi: 10.1016/j.grets.2022.100005.
[14] D. C. Muller, S. P. Selvanathan, E. Cuce, and S. Kumarasamy, "Hybrid solar, wind, and energy storage system for a sustainable campus: A simulation study," *Science and Technology for Energy Transition (STET)*, vol. 78, 2023, doi: 10.2516/stet/2023008.
[15] M. S. Nkambule, A. N. Hasan, and T. Shongwe, "Performance and techno-economic analysis of optimal hybrid renewable energy systems for the mining industry in South Africa," *Sustainability (Switzerland)*, vol. 15, no. 24, 2023, doi: 10.3390/su152416766.
[16] F. I. Pasaribu, C. I. Cahyadi, R. Mujiono, and Suwarno, "Analysis of the effect of economic, population, and energy growth, as well as the influence on sustainable energy development in Indonesia," *International Journal of Energy Economics and Policy*, vol. 13, no. 1, pp. 510–517, 2023, doi: 10.32479/ijeep.13859.
[17] D. Zhang and Y. Tu, "Green building, pro-environmental behavior and well-being: Evidence from Singapore," *Cities*, vol. 108, p. 102980, Jan. 2021, doi: 10.1016/j.cities.2020.102980.
[18] C. C. Bungau, T. Bungau, I. F. Prada, and M. F. Prada, "Green buildings as a necessity for sustainable environment development: dilemmas and challenges," *Sustainability*, vol. 14, no. 20, p. 13121, Oct. 2022, doi: 10.3390/su142013121.
[19] J. Ayarkwa, D.-G. J. Opoku, P. Antwi-Afari, and R. Y. M. Li, "Sustainable building processes' challenges and strategies: the relative important index approach," *Cleaner Engineering and Technology*, vol. 7, p. 100455, Apr. 2022, doi: 10.1016/j.clet.2022.100455.
[20] F. Zhao, F. Bai, X. Liu, and Z. Liu, "A review on renewable energy transition under China's carbon neutrality target," *Sustainability*, vol. 14, no. 22, p. 15006, Nov. 2022, doi: 10.3390/su142215006.
[21] E. I. C. Zebra, H. J. van der Windt, G. Nhumaio, and A. P. C. Faaij, "A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries," *Renewable and Sustainable Energy Reviews*, vol. 144, p. 111036, Jul. 2021, doi: 10.1016/j.rser.2021.111036.
[22] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "A review of hybrid renewable energy systems: solar and wind-powered solutions: Challenges, opportunities, and policy implications," *Results in Engineering*, vol. 20, 2023, doi: 10.1016/j.rineng.2023.101621.
[23] S. Mischos, E. Dalagdi, and D. Vrakas, "Intelligent energy management systems: a review," *Artificial Intelligence Review*, vol. 56, no. 10, pp. 11635–11674, Oct. 2023, doi: 10.1007/s10462-023-10441-3.
[24] J. Hossain *et al.*, "A review on optimal energy management in commercial buildings," *Energies*, vol. 16, no. 4, 2023, doi: 10.3390/en16041609.
[25] M. Nazari-Heris and S. Asadi, "Reliable energy management of residential buildings with hybrid energy systems," *Journal of Building Engineering*, vol. 71, p. 106531, Jul. 2023, doi: 10.1016/j.jobe.2023.106531.
[26] C. I. Cahyadi, S. Suwarno, A. A. Dewi, M. Kona, M. Arif, and M. C. Akbar, "Solar prediction strategy for managing virtual power stations," *International Journal of Energy Economics and Policy*, vol. 13, no. 4, pp. 503–512, Jul. 2023, doi: 10.32479/ijeep.14124.
[27] H. M. A. Farid, S. Iram, H. M. Shakeel, and R. Hill, "Enhancing stakeholder engagement in building energy performance assessment: A state-of-the-art literature survey," *Energy Strategy Reviews*, vol. 56, 2024, doi: 10.1016/j.esr.2024.101560.
[28] P. D. Necoechea-Porras, A. López, and J. C. Salazar-Elena, "Deregulation in the energy sector and its economic effects on the power sector: A literature review," *Sustainability (Switzerland)*, vol. 13, no. 6, 2021, doi: 10.3390/su13063429.
[29] F. Petropoulos *et al.*, "Forecasting: theory and practice," *International Journal of Forecasting*, vol. 38, no. 3, pp. 705–871, Jul. 2022, doi: 10.1016/j.ijforecast.2021.11.001.
[30] G. Orlando and M. Lampart, "Expecting the unexpected: entropy and multifractal systems in finance," *Entropy*, vol. 25, no. 11, 2023, doi: 10.3390/e25111527.
[31] K. Anantharajah and A. B. Setyowati, "Beyond promises: Realities of climate finance justice and energy transitions in Asia and the Pacific," *Energy Research & Social Science*, vol. 89, p. 102550, Jul. 2022, doi: 10.1016/j.erss.2022.102550.
[32] J. Natividade, C. O. Cruz, and C. M. Silva, "Improving the efficiency of energy consumption in buildings: simulation of alternative EnPC models," *Sustainability*, vol. 14, no. 7, p. 4228, Apr. 2022, doi: 10.3390/su14074228.
[33] S. Zheng, R. Huang, and T. Zhuang, "Evolution of China's building energy service industry based on synergetic theory," *Applied Sciences*, vol. 12, no. 24, p. 12648, Dec. 2022, doi: 10.3390/app122412648.
[34] J. Gupta and M. Chakraborty, "Energy efficiency in buildings," in *Sustainable Fuel Technologies Handbook*, Elsevier, 2021, pp. 457–480, doi: 10.1016/B978-0-12-822989-7.00016-0.
[35] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," *Frontiers in Energy Research*, vol. 9, Mar. 2022, doi: 10.3389/fenrg.2021.743114.
[36] A. A. Londoño and J. D. Velásquez, "Risk management in electricity markets: dominant topics and research trends," *Risks*, vol. 11, no. 7, 2023, doi: 10.3390/risks11070116.
[37] Y. Wang, Z. Li, C. Wen, and J. Zheng, "Carbon emissions trading scheme and regional total factor carbon productivity: based on temporal-spatial dual perspectives," *Environmental Science and Pollution Research*, vol. 30, no. 56, pp. 119434–119449, Nov. 2023, doi: 10.1007/s11356-023-30716-0.
[38] M. S. Bakare, A. Abdulkarim, M. Zeeshan, and A. N. Shuaibu, "A comprehensive overview on demand side energy management towards smart grids: challenges, solutions, and future direction," *Energy Informatics*, vol. 6, no. 1, 2023, doi: 10.1186/s42162-023-00262-7.
[39] S. Panda *et al.*, "Residential demand side management model, optimization and future perspective: A review," *Energy Reports*, vol. 8, pp. 3727–3766, Nov. 2022, doi: 10.1016/j.egyr.2022.02.300.
[40] T. Akhtar, A. U. Rehman, M. Jamil, and S. O. Gilani, "Impact of an energy monitoring system on the energy efficiency of an automobile factory: a case study," *Energies*, vol. 13, no. 10, 2020, doi: 10.3390/en13102577.
[41] J. Paś, "Issues related to power supply reliability in integrated electronic security systems operated in buildings and vast areas," *Energies*, vol. 16, no. 8, 2023, doi: 10.3390/en16083351.
[42] K. Boikanyo, A. M. Zungeru, B. Sigweni, A. Yahya, and C. Lebekwe, "Remote patient monitoring systems: applications, architecture, and challenges," *Scientific African*, vol. 20, 2023, doi: 10.1016/j.sciaf.2023.e01638.

[43] T. Csoknyai, J. Legardeur, A. A. Akle, and M. Horváth, "Analysis of energy consumption profiles in residential buildings and impact assessment of a serious game on occupants' behavior," *Energy and Buildings*, vol. 196, pp. 1–20, 2019, doi: 10.1016/j.enbuild.2019.05.009.
[44] T. Lee, C. Jung, K. Lee, and S. Seo, "A study on recognizing multi-real world object and estimating 3D position in augmented reality," *Journal of Supercomputing*, vol. 78, no. 5, pp. 7509–7528, 2022, doi: 10.1007/s11227-021-04161-0.
[45] K. J. Ruskin, C. Corvin, S. Rice, G. Richards, S. R. Winter, and A. C. Ruskin, "Alarms, alerts, and warnings in air traffic control: an analysis of reports from the Aviation Safety Reporting System," *Transportation Research Interdisciplinary Perspectives*, vol. 12, p. 100502, Dec. 2021, doi: 10.1016/j.trip.2021.100502.
[46] N. F. Shayan, N. Mohabbati-Kalejahi, S. Alavi, and M. A. Zahed, "Sustainable development goals (SDGs) as a framework for corporate social responsibility (CSR)," *Sustainability*, vol. 14, no. 3, p. 1222, Jan. 2022, doi: 10.3390/su14031222.
[47] W. Strielkowski, L. Civín, E. Tarkhanova, M. Tvaronavičienė, and Y. Petrenko, "Renewable energy in the sustainable development of electrical power sector: A review," *Energies*, vol. 14, no. 24, 2021, doi: 10.3390/en14248240.

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