



Techno-economic analysis of the transition from off-Grid to on-grid electricity in the mining industry

^{1*} Alin Nurliani, ² Ana Noveria

^{1,2} Institut Teknologi Bandung, Indonesia

*correspondence email: alin_nurliani@sbm-itb.ac.id

Article Info	Abstract
<p>Keywords: Decarbonization, Levelized Cost of Electricity, Mining Electrification, Off-Grid to On-Grid Transition, PLN Integration</p>	<p><i>The mining sector's reliance on off-grid diesel generators imposes significant economic and environmental costs, including high energy expenditures and substantial greenhouse gas emissions. While existing techno-economic studies have explored renewable hybrids for off-grid mining operations, there remains a critical gap in evaluating grid-connected transitions—especially in emerging economies with coal-dependent grids like Indonesia. This study aims to find out how can transitioning from diesel to grid electricity in Indonesia's mining sector achieve cost savings and emission reduction. Through integrated Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and CO₂ emission analysis of a mining company as a case study, we demonstrate two key novel contributions: (1) a framework for quantifying trade-offs between cost savings and emission reductions in coal-reliant grids, and (2) empirical evidence that grid adoption reduces energy costs by 66% (from \$0.50/kWh to \$0.17/kWh) while delivering a projected NPV of \$14.46 million (IRR: 32.34%). Moreover, switching to on-grid PLN shows a potential emission reduction of 2,054 tons/year (15% decrease). These findings highlight the dual imperative of grid electrification and renewable integration for sustainable mining, offering policymakers and industry stakeholders a replicable model to balance economic and environmental goals in resource-intensive sectors.</i></p>

1. INTRODUCTION

Mining is one of the most energy-intensive industries globally, accounting for approximately 11% of total energy consumption (Igogo et al., 2021). In remote operations, Off-grid diesel generators have historically been costly to operate, with expenses ranging from \$0.25 to \$0.40 per kWh, and they contribute significantly 4–7% of global CO₂ emissions (Tost et al., 2018; Rodríguez-Gallegos et al., 2018). These challenges are exacerbated in Indonesia, where mining sites often face logistical barriers to grid access, despite PLN's lower electricity tariffs (\$0.08/kWh) (PLN, 2024).

In Indonesia, where the state-owned utility company, PLN, offers electricity at a lower cost (\$0.08/kWh) (PLN, 2024), transitioning to grid electricity presents a viable alternative. While there is a wealth of techno-economic studies on off-grid renewable hybrids, there is a notable deficiency in research regarding grid-connected transitions for mining operations in economically disadvantaged regions, particularly in the context of evaluating cost savings against pollution trade-offs in coal-dependent energy systems.



While grid connection offers immediate cost and emission benefits, hybrid renewable-diesel systems have emerged as an advanced transition strategy for mines facing grid delays or operating in regions with unreliable infrastructure. These systems can achieve up to 40% emission reductions while maintaining energy reliability (Rodríguez-Gallegos et al., 2018), serving as both a bridge to full grid electrification and a long-term solution for remote operations

This study addresses these gaps by asking how can Indonesia's mining sector transition from off-grid diesel to on-grid power while optimizing cost savings and emission reductions? Using a mining company as a case study, we integrate LCOE, NPV, and CO₂ analyses to quantify trade-offs between cost savings and emission reductions in coal-reliant grids and empirical evidence that grid adoption reduces energy costs.

2. LITERATURE REVIEW

Off-grid and On-grid System

Globally, grid extension has been the predominant method for power provision (Ortega-Arriaga et al., 2021). The primary advantage of grid networks is their reliable power supply, characterized by substantial initial connection costs but lower ongoing energy expenses (Alstone et al., 2015). Financial limitations hinder numerous regions from linking to the main electricity grid. Investment is occasionally constrained by challenging terrain or inadequate energy consumption. These regions frequently utilize off-grid electrical systems. Traditionally, off-grid systems relied on fossil fuel-based energy sources, predominantly diesel generators (Rodríguez-Gallegos et al., 2018).

The selection between grid-connected and off-grid power systems has emerged as a pivotal topic in the global endeavor to attain universal energy access. The choice between grid extension and off-grid systems is influenced by the pursuit of the most economical technology with minimal maintenance requirements (Palit & Bandyopadhyay, 2016), alongside several critical factors such as site accessibility, climate change considerations, the economic feasibility of each alternative, and the nature of the electrical load to be accommodated (Adebanji et al., 2021). Diesel generators dominate remote operations but incur fuel volatility (Rodríguez-Gallegos et al., 2018), while grid power's lower costs (\$0.08/kWh in Indonesia) (PLN, 2024) are offset by coal-driven emissions (Ortega-Arriaga et al., 2021). The contradiction underscores a significant deficiency: there is no unified model that evaluates environmental and economic outcomes in a comprehensive manner.

Levelized Cost of Energy (LCOE)

A measure of the total cost of ownership (TCO) across the lifetime of a given energy source is the Levelized Cost of Energy (LCOE). Presented as a single figure showing the cost per unit of electricity generated, this covers all associated expenses, from initial building to final decommissioning and remediation (Matsuo, 2022).

Widely used is Levelized Cost of Electricity (LCOE) analysis as a means of evaluating the costs of grid versus off-grid options. The LCOE study figures the present monetary worth of every anticipated future cost. Generally stated in dollars per megawatt-hour (\$/MWh),

this formula generates a singular, modern statistic reflecting the cost per unit of energy. One common approach to determine the viability of a project is a Levelized Cost of Electricity (LCOE) study. This allows one to compare the expected income from power sales with the plant-level electricity generating costs. Lucheroni & Mari, 2018 offers the fundamental Levelized Cost of Energy (LCOE) ([Renewable Energy Agency, 2024](#)).

$$\text{LCOE} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \rightarrow \text{eq 1}$$

Where I_t represents investment expenditures in year t , while M_t represents operations and maintenance costs in year t . F_t , fuel expenditures for the year t , E_t , electrical generation in the year t . r , the discount rate. n , the economic life of the system.

Net Present Value

Applying several criteria to evaluate project viability, quantify economic efficiency, and direct decision-making is the essence of capital budgeting. Because it offers the most explicit indicator of how an investment affects shareholder value, the Net Present Value (NPV) technique is regarded as the most theoretically strong method for assessing investments ([Marchioni & Magni, 2018](#)). From first design through construction and operations, net present value (NPV) aggregates all of a project's discounted cash flows across its whole lifetime into a single financial metric ([Mellichamp, 2019](#)).

The formula for Net Present Value (NPV) is:

$$\text{NPV} = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_t}{(1+r)^t} - CF_0 \rightarrow \text{eq 2}$$

Where, $CF_1, CF_2 \dots CF_t$ are the cash flow during periods 1 to t (t is the final or terminal year); CF_0 is the capital invested; ' r ' is the discount rate ([Arjunan, 2022](#)).

CO₂ Emission Reduction

Research into CO₂ emissions are closely linked to analyses of energy consumption (Tost et al., 2018), especially within the mining sector where energy-intensive processes are common. This connection is essential as most CO₂ emissions in mining arise from energy consumption, either via direct fuel combustion or through indirect electricity usage. Carbon dioxide (CO₂) is recognized as a major greenhouse gas that plays a critical role in the intense global warming phenomenon we are currently facing ([Tran et al., 2022](#)). The following formula can be used to determine the amount of CO₂ emissions according to [Peng et al. \(2012\)](#).

$$\text{Emission}_{\text{CO}_2} = EF \times FC \rightarrow \text{eq 3}$$

Where EF is the emission factor and FC is the fuel consumed. Diesel's emission factor can be computed using the default factor specified in the ([Guidelines for National Greenhouse Gas Inventories, 2006](#))

Previous Research

Although there is a lot of scholarly interest in the energy transition in mining activities, current studies are scattered in handling the interaction between environmental sustainability and economic feasibility. To systematically assess these challenges, we first synthesize prior research through a comparative table below.

Table 1. Previous Research

No	Author	Research Focus	Methodology
1	(Pouresmaieli et al., 2023)	Renewable energy integration in global mining	Meta-analysis
2	(Mulenga et al., 2023)	Techno-economic feasibility of PV-diesel hybrids in Zambian mines	LCOE, sensitivity analysis
3	(Cruz-Soto et al., 2022)	Hydrogen storage (P2G2P) vs. diesel-battery systems	LCOE, Emission comparison
4	(Ortega-Arriaga et al., 2021)	Grid vs. off-grid economics (global review)	LCOE Comparison
5	(Emblemsvåg, 2020)	True LCOE of wind farms including opportunity costs	Revise LCOE Framework
6	(Gharibi & Askarzadeh, 2019)	Sizing grid-connected diesel/PV/fuel cell systems	Multi-objective optimization
7	(Rodríguez-Gallegos et al., 2018)	Off-grid to hybrid (PV-battery-diesel) transition in Indonesia	LCOE, NPV
8	(Tost et al., 2018)	CO ₂ emissions from mining operations	Lifecycle assessment
9	(Jasuan et al., 2018)	On-grid vs. off-grid PV in Indonesian households	LCOE
10	(Perkins, 2018)	Solar PV with bio-crude vs. battery storage	Techno economic modelling
11	(Blum et al., 2013)	Cost-competitiveness of off-grid renewables (solar PV, micro-hydro, diesel) in Indonesia	LCOE analysis, subsidy impact evaluation
12	(Dufo-López et al., 2011)	Multi-objective optimization (cost + emissions) of hybrid PV-wind-diesel systems	Genetic algorithm optimization

The mining sector's significant dependence on off-grid diesel generators (PLTD) has prompted extensive research into alternative energy sources. Research indicates that the integration of renewable energy offers significant environmental and economic benefits; hybrid systems can substantially reduce emissions and costs. Pouresmaieli et al. (2023) found that grid-connected renewables in mining activities in Chile and Australia reduce emissions by 40–60%. Mulenga et al. (2023) demonstrated that solar PV with storage, at levelized costs of 0.18/kWh, is more cost-effective than diesel, which has a levelized cost of 0.28/kWh, in Zambian mines. The findings suggest that in regions abundant in solar resources, the integration of renewable energy is both environmentally beneficial and financially viable.

Location and size significantly influence the feasibility of renewable energy sources. Off-grid hybrid systems are more appropriate for remote operations, while grid expansion is economically viable solely for high-demand mining sites exceeding 10 MW as noted by Ortega-Arriaga et al. (2021). Rodríguez-Gallegos et al. (2018) found that photovoltaic-diesel hybrid systems in Indonesia reduce operational costs by 25% relative to diesel-only systems,

highlighting the economic benefits of solar energy integration. [Blum et al. \(2013\)](#) found that micro-hydro, with a levelized cost of electricity (LCOE) of \$0.18/kWh, represents the most cost-effective option in Indonesia, whereas diesel is only viable in the absence of subsidies.

Emerging technologies, including hydrogen storage and bioenergy integration, present alternative avenues for decarbonization; however, they encounter economic obstacles. [Cruz-Soto et al. \(2022\)](#) conducted a comparison between hydrogen fuel cells and diesel-battery systems, concluding that although hydrogen contributes to emission reductions, its elevated costs and low efficiency hinder extensive adoption. [Perkins \(2018\)](#) proposed that bio-crude hybrids may offer greater cost competitiveness than batteries for delivering firm power; however, additional research is required to confirm this in mining contexts.

[Tost et al. \(2018\)](#) emphasized the necessity of moving away from diesel, indicating that mines reliant on diesel produce 2–3 times more CO₂ compared to those connected to the grid. The findings suggest that although alternatives such as hydrogen and biofuels show potential, they presently fall short of conventional hybrid systems regarding cost-effectiveness.

Optimization methodologies and policy support are essential for promoting the adoption of renewable energy in the mining sector. [Gharibi & Askarzadeh \(2019\)](#) employed multi-objective optimization to achieve a balance between cost and reliability in hybrid systems, illustrating the efficacy of algorithm driven design. [Dufo-López et al. \(2011\)](#) demonstrated that the incorporation of diesel in hybrid systems can paradoxically lead to reductions in both costs and emissions through enhanced reliability. [Jasuan et al. \(2018\)](#) demonstrated that the implementation of grid-tied solar PV in Indonesia relies on subsidies, indicating that off-grid solutions necessitate specific financial mechanisms. The studies underscore the necessity for advanced modeling methodologies and supportive policies to expedite the transition to cleaner energy systems within the mining sector.

Important knowledge gaps persist despite advancements. Very little research has focused on the ever-changing energy requirements of mining operations, especially the load profiles of large machines. The scalability of wind and solar electricity for mining is called into question after [Emblemsvåg \(2020\)](#) updated their LCOE models to demonstrate that these sources could not be cost-effective when firm power is needed.

3. RESEARCH METHOD

Figure 1 illustrates a flowchart that employs a quantitative techno-economic analysis to assess the shift from off-grid diesel to on-grid PLN electricity within Indonesia's mining sector. This study aims to clarify the transition of mining operations from off-grid to PLN (on-grid) electricity supply, evaluating its financial viability, long-term economic implications, and environmental benefits, particularly in terms of CO₂ emission reduction.

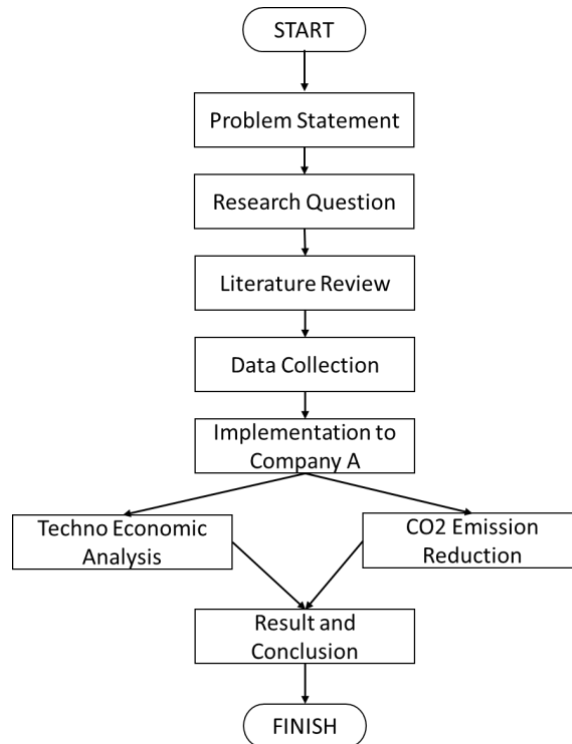


Figure 1. Research Flowchart

This research initiates by recognizing the inadequate comprehension of the interplay among technical feasibility, economic viability, and environmental benefits in the transition from off-grid to PLN electricity. The objectives include evaluating the long-term financial feasibility of transitioning using the Levelized Cost of Electricity (LCOE) framework and assessing the environmental benefits, particularly in terms of emission reduction, associated with the shift from off-grid to PLN electricity.

A review of relevant literature is conducted to establish a foundation, emphasizing off-grid and on-grid systems, levelized cost of energy (LCOE), financial metrics such as net present value (NPV) and internal rate of return (IRR), carbon dioxide (*CO2*) emissions, and prior research on LCOE. Two sets of parameters are established: Economic Parameters, which encompass capital cost estimation, LCOE calculation, and electricity tariff comparisons, and Environmental Parameters, which concentrate on *CO2* emission reduction and broader environmental impacts.

This study's methodology integrates three analytical dimensions (economic, technical, and environmental) to evaluate the off-grid diesel to on-grid transition in mining which is illustrated in the following conceptual framework. The framework uses a step-by-step method to calculate LCOE, NPV, and emission reduction, combines the information, and then produces results to determine if the transition is feasible.

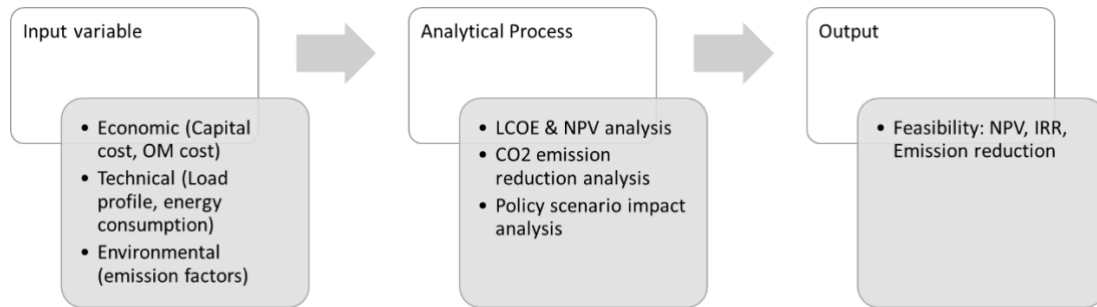


Figure 2 Conceptual Framework

4. RESULT AND DISCUSSION

Techno-Economic

Company A, as the case study in this research, is a mining company that uses PLTD as a power plant. company A will make the transition from off-grid or PLTD to on-grid (PLN). Financial analysis is performed to assess the feasibility. it can be said to be feasible if the internal rate of return (IRR) exceeds the expected return, with a positive NPV and a quick payback period. Cash flows are projected and calculated using estimates of the plant's revenue and O&M costs.

For this case, project revenue is calculated through the potential savings of electricity generation resulting from the off-grid (PLTD) compared to on-grid (PLN). To assess the feasibility of transition, two main components are evaluated: capital costs and operational costs (O&M costs). Capital costs are associated with the initial investment during the predevelopment and construction phases. Capital costs include expenses incurred for the physical construction of the plant, including equipment procurement, labor costs for mechanical, civil, and electrical work, as well as the procurement of supporting buildings. O&M costs include both routine and non-routine expenses incurred during the operational phase.

In this analysis, several key basic assumptions are established to ensure a robust financial evaluation of the project. Depreciation is calculated using the straight-line method. Key assumptions include an exchange rate of IDR 16,500/USD, a discount rate of 8.72%, and a project duration of 10 years. The financial feasibility is further supported by a projection of revenues based on potential savings in electricity generation compared to using diesel generators.

Table 2. Summary Result

Option	Off-grid	On-Grid
Investment Cost (million)	11.51	9.67
LCOE (USD/kWh)	0.50	0.17

The capital investment for the off-grid option totaled USD 11.51 million, and for the on-grid option totaled USD 9.67 million. The off-grid option had a levelized cost of energy (LCOE) of 0.50 USD/kWh, and the on-grid option showed improved performance with an

LCOE of 0.17 USD/kWh, an IRR of 32.34%, and a Net Present Value (NPV) of USD 14.46 million.

The financial analysis provides strong evidence supporting the economic feasibility of shifting from diesel-based off-grid power to PLN's on-grid electricity. On-grid electricity demonstrates a 66% lower LCOE, driven by the avoidance of volatile diesel fuel costs and reduced maintenance needs.

CO₂ Emission Reduction

The results of the analysis's emission calculations, there is a significant environmental benefit to using on-grid electricity. Off-grid or diesel generators would use roughly 5,135,873 liters of diesel, resulting in 13,764 tons of CO₂ emissions (at 2.68 kg CO₂/liter), based on Company A's yearly energy consumption of 19,516,316 kWh. On the other hand, switching to on-grid PLN (emission factor: 0.6 kg CO₂/kWh) shows a potential reduction of 2,054 kg per year (15% decrease).

Policy Scenarios Impact Analysis

The economic feasibility of shifting from off-grid diesel to on-grid electricity is markedly improved under several policy scenarios currently being considered or implemented by Indonesia. In a scenario involving a carbon tax of IDR 30 per kg CO₂, this aligns with Law No.7 of 2021 About the Harmonization of Tax Regulations (Indonesia, 2021) the off-grid LCOE adds only \$0.0013/kWh to diesel costs, resulting in minimal change to the economic analysis. However, potential policy scenarios could significantly alter the transition economics.

5. CONCLUSION

According to the findings of the study, switching from off-grid diesel power to on-grid PLN electricity offers considerable economic benefits. These benefits include a reduction of LCOE by 66% (from 0.50/kWh to 0.17/kWh), as well as a predicted net present value of \$14.46 million with an internal rate of return of 32.34% with the transition. In addition to this, it has positive effects on the environment, a 15% reduction in emissions (1,053 tons per year), outperforming diesel-dependent mines in Sub-Saharan Africa (Mulenga et al., 2023) but lagging behind Chile's 40–60% emission cuts (Pouresmaieli et al., 2023) due to Indonesia's coal-heavy grid. This highlights a critical divergence: while emerging economies universally benefit from cost savings, emission outcomes depend on the grid decarbonization pace.

The findings of this study demonstrate that transitioning from off-grid diesel power to on-grid PLN electricity presents substantial economic and environmental advantages for mining operations. From an economic point of view, the change results in impressive cost efficiencies, the most notable of which is a 66% drop in the Levelized Cost of Electricity (LCOE) for On-grid PLN-supplied power, which goes from 0.50/kWh to 0.17/kWh. The elimination of unpredictable diesel fuel charges, as well as cheaper maintenance requirements for grid infrastructure in comparison to diesel generators, are the primary

factors that have led to this significant reduction. The impressive investment indicators, which include a predicted Net Present Value (NPV) of \$14.46 million and an Internal Rate of Return (IRR) of 32.34%, further substantiate the existence of this transition as a financially viable option. The compelling business case for electrification is brought to light by these numbers, particularly for large-scale mining operations that have substantial energy requirements.

The switch to on-grid power has the potential to bring about significant reductions in emissions from an environmental point of view; however, the extent to which these benefits are realized is strongly dependent on the energy generation mix of PLN. In comparison to activities that rely on diesel, the transition results in a reduction of CO_2 emissions by 15% annually, which is equivalent to 1,053 tons per year of carbon dioxide being released into the atmosphere. On the other hand, this is dependent on the energy generation composition of PLN.

Our analysis reveals critical scale dependencies in mining electrification economics that directly inform Indonesia's Just Energy Transition Partnership (JETP) implementation. The case study of Company A (19.5 GWh annual consumption) demonstrates favorable grid transition economics at medium scale, with LCOE reductions of 66% while smaller operations face lower NPW due to disproportionate connection cost 8 – 10 GWh viability threshold identified by Ortega-Arriaga et al. (2021). This scalability framework aligns with JETP's dual objectives of achieving 50% CO_2 reductions by 2030 through power sector decarbonization (IESR, 2022) and maintaining energy access equity. For mines below the economic threshold, we propose a phased JETP implementation strategy: immediate deployment of modular hybrid systems (solar + battery + diesel) as stopgap solutions, synchronized with PLN's rollout of mining-specific renewable tariffs combining time-of-use pricing and capacity payments.

Policymakers should prioritize three JETP-aligned interventions: (1) targeted grid corridors for >10GWh mines, (2) subsidy reallocation from diesel to hybrid grants for smaller operations, and (3) adaptive tariff structures that reward load shifting - collectively advancing Indonesia's NDC target of 31.89% emission reductions (NDC Indonesia, 2022), while preventing energy exclusion of remote mines.

Policymakers should take note of these findings because they highlight the critical need to expedite the deployment of renewable energy sources and alter tariff structures to encourage the use of clean energy in the mining industry. It is demonstrated that economic and environmental goals can be linked by careful planning and engagement with energy providers, which is demonstrated by the results, which provide a clear framework for evaluating energy transition strategies for mining businesses.

According to the findings of this study, not only does it prove the financial and environmental benefits of grid-based electrification for Indonesia's mining industry, but it also underlines the essential role that policy support and investment in renewable energy play in ensuring that these benefits are fully realized. It is possible that the methods and insights that have been offered here can serve as a beneficial reference for other energy-intensive companies in emerging markets that are confronting comparable issues related to decarbonization.

We propose stakeholder-specific strategies to translate findings into actionable outcomes, addressing both technical and coordination challenges. PLN's development of mining-specific renewable tariffs that integrate time-of-use pricing with capacity payments presents systemic advantages. Conversely, mining companies can promptly implement modular hybrid systems (solar + battery + diesel) to deliver essential stopgap solutions during grid delays.

6. REFERENCES

- Adebanji, B., Atoki, O., Fasina, T., Adetan, O., & Abe, A. (2021). Comparative study of off-grid and grid-connected hybrid power system: issues, future prospects and policy framework. *Indonesian Journal of Electrical Engineering and Computer Science*, 22(2), 752–759. <https://doi.org/10.11591/ijeecs.v22.i2.pp752-759>
- Alstone, P., Gershenson, D., & Kammen, D. M. (2015). Decentralized energy systems for clean electricity access. In *Nature Climate Change* (Vol. 5, Issue 4, pp. 305–314). Nature Publishing Group. <https://doi.org/10.1038/nclimate2512>
- Arjunan, K. (2022). *A New Method to Estimate NPV and IRR from the Capital Amortization Schedule and the Advantages of the New Method*.
- Blum, N. U., Sryantoro Wakeling, R., & Schmidt, T. S. (2013). Rural electrification through village grids - Assessing the cost competitiveness of isolated renewable energy technologies in Indonesia. In *Renewable and Sustainable Energy Reviews* (Vol. 22, pp. 482–496). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2013.01.049>
- Cruz-Soto, J. de la, Azkona-Bedia, I., Velazquez-Limon, N., & Romero-Castanon, T. (2022). A techno-economic study for a hydrogen storage system in a microgrid located in baja California, Mexico. Levelized cost of energy for power to gas to power scenarios. *International Journal of Hydrogen Energy*, 47(70), 30050–30061. <https://doi.org/10.1016/j.ijhydene.2022.03.026>
- Dufo-López, R., Bernal-Agustín, J. L., Yusta-Loyo, J. M., Domínguez-Navarro, J. A., Ramírez-Rosado, I. J., Lujano, J., & Aso, I. (2011). Multi-objective optimization minimizing cost and life cycle emissions of stand-alone PV-wind-diesel systems with batteries storage. *Applied Energy*, 88(11), 4033–4041. <https://doi.org/10.1016/j.apenergy.2011.04.019>
- Emblemsvåg, J. (2020). On the levelised cost of energy of windfarms. *International Journal of Sustainable Energy*, 39(7), 700–718. <https://doi.org/10.1080/14786451.2020.1753742>
- Gharibi, M., & Askarzadeh, A. (2019). Size and power exchange optimization of a grid-connected diesel generator-photovoltaic-fuel cell hybrid energy system considering reliability, cost and renewability. *International Journal of Hydrogen Energy*, 44(47), 25428–25441. <https://doi.org/10.1016/j.ijhydene.2019.08.007>
- Guidelines for National Greenhouse Gas Inventories*. (2006).
- IESR. (2022). *Indonesia Energy Transition Outlook 2023: Tracking Progress of Energy Transition in Indonesia: Pursuing Energy Security in the Time of Transition*.
- Igogo, T., Awuah-Offei, K., Newman, A., Lowder, T., & Engel-Cox, J. (2021). Integrating renewable energy into mining operations: Opportunities, challenges, and enabling approaches. *Applied Energy*, 300. <https://doi.org/10.1016/j.apenergy.2021.117375>
- Indonesia. (2021). *Undang-undang No. 7 tahun 2021 Tentang Harmonisasi Peraturan Perpajakan*.
- Jasuan, A., Nawawi, Z., & Samaulah, H. (2018). *Comparative Analysis of Applications Off-Grid PV System and On-Grid PV System for Households in Indonesia*.

- Lucheroni, C., & Mari, C. (2018). Optimal integration of intermittent renewables: A system LCOE stochastic approach. *Energies*, 11(3). <https://doi.org/10.3390/en11030549>
- Marchioni, A., & Magni, C. A. (2018). Investment decisions and sensitivity analysis: NPV-consistency of rates of return. *European Journal of Operational Research*, 268(1), 361–372. <https://doi.org/10.1016/j.ejor.2018.01.007>
- Matsuo, Y. (2022). Re-Defining System LCOE: Costs and Values of Power Sources. *Energies*, 15(18). <https://doi.org/10.3390/en15186845>
- Mellichamp, D. A. (2019). Profitability, risk, and investment in conceptual plant design: Optimizing key financial parameters rigorously using NPV%. *Computers and Chemical Engineering*, 128, 450–467. <https://doi.org/10.1016/j.compchemeng.2019.04.016>
- Mulenga, E., Kabanshi, A., Mupeta, H., Ndiaye, M., Nyirenda, E., & Mulenga, K. (2023). Techno-economic analysis of off-grid PV-Diesel power generation system for rural electrification: A case study of Chilubi district in Zambia. *Renewable Energy*, 203, 601–611. <https://doi.org/10.1016/j.renene.2022.12.112>
- NDC Indonesia. (2022). *ENHANCED NATIONALLY DETERMINED CONTRIBUTION REPUBLIC OF INDONESIA 2022*.
- Ortega-Arriaga, P., Babacan, O., Nelson, J., & Gambhir, A. (2021). Grid versus off-grid electricity access options: A review on the economic and environmental impacts. In *Renewable and Sustainable Energy Reviews* (Vol. 143). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2021.110864>
- Palit, D., & Bandyopadhyay, K. R. (2016). Rural electricity access in South Asia: Is grid extension the remedy? A critical review. In *Renewable and Sustainable Energy Reviews* (Vol. 60, pp. 1505–1515). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2016.03.034>
- Peng, J., Zhao, Y., Jiao, L., Zheng, W., & Zeng, L. (2012). CO2 Emission Calculation and Reduction Options in Ceramic Tile Manufacture-The Foshan Case. *Energy Procedia*, 16, 467–476. <https://doi.org/10.1016/j.egypro.2012.01.076>
- Perkins, G. (2018). Techno-economic comparison of the levelised cost of electricity generation from solar PV and battery storage with solar PV and combustion of bio-crude using fast pyrolysis of biomass. *Energy Conversion and Management*, 171, 1573–1588. <https://doi.org/10.1016/j.enconman.2018.06.090>
- PLN. (2024). *STATISTIK PLN 2024 Data Operasional (Unaudited)*.
- Pouresmaieli, M., Ataei, M., Nouri Qarahasanlou, A., & Barabadi, A. (2023). Integration of renewable energy and sustainable development with strategic planning in the mining industry. *Results in Engineering*, 20. <https://doi.org/10.1016/j.rineng.2023.101412>
- Renewable Energy Agency, I. (2024). *RENEWABLE POWER GENERATION COSTS IN 2023 2 R E N E W A B L E P O W E R G E N E R A T I O N C O S T S I N 2023*. www.irena.org
- Rodríguez-Gallegos, C. D., Gandhi, O., Bieri, M., Reindl, T., & Panda, S. K. (2018). A diesel replacement strategy for off-grid systems based on progressive introduction of PV and batteries: An Indonesian case study. *Applied Energy*, 229, 1218–1232. <https://doi.org/https://doi.org/10.1016/j.apenergy.2018.08.019>
- Tost, M., Bayer, B., Hitch, M., Lutter, S., Moser, P., & Feiel, S. (2018). Metal mining's environmental pressures: A review and updated estimates on CO2 emissions, water use, and land requirements. *Sustainability (Switzerland)*, 10(8). <https://doi.org/10.3390/su10082881>

Tran, N., Ta, Q. T. H., & Nguyen, P. K. T. (2022). Transformation of carbon dioxide, a greenhouse gas, into useful components and reducing global warming: A comprehensive review. *International Journal of Energy Research*, 46(13), 17926–17951. <https://doi.org/https://doi.org/10.1002/er.8479>