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# Bioeconomic Analysis and Risk Assessment of Integrated Forestry and Wood Pellet Production for Post-Mining Land Use in East Kalimantan

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**Abstract.** Coal mining in East Kalimantan, Indonesia, has spurred economic growth but inflicted severe environmental degradation, necessitating innovative PMLU strategies for ecosystem restoration and sustainable development. This study evaluates the financial viability and risks of an integrated wood forestry and wood pellet factory using *Acacia mangium* plantations on 10,500 hectares of degraded land, aligning with SDGs 7, 15, and 8. Employing a bioeconomic model, we constructed a base case financial framework with proforma statements, free cash flow calculations, and Monte Carlo simulations (50,000 iterations) to assess NPV, IRR, and DPP under uncertainty. Results indicate baseline feasibility with an NPV of USD 2.2 million, IRR of 12.08% (exceeding 9% WACC), and DPP of 19 years, transitioning to positive cash flows by year 5. Simulations reveal a mean NPV of USD 6.146 million and DPP of 14.87 years, but high variability (coefficient of variation up to 1.60) and risks from pellet price fluctuations (over 70% variance contribution) and cost growth, where a 5% adverse pellet price change reduces NPV by 72%. These findings underscore the project's potential for bioenergy production and land rehabilitation, while highlighting the need for market stabilization strategies.

## 1 Introduction

Coal mining in East Kalimantan, Indonesia, has driven economic growth but caused severe environmental damage, including land degradation, biodiversity loss, and reduced soil fertility. These impacts leave large areas unproductive, posing challenges for local communities and ecosystems[1], [2], [3]. On the other hand, Indonesian regulations, such as Law No. 4/2009 on Mineral and Coal Mining, require reclamation to restore mined lands, yet many sites remain underutilized due to poor soil quality and high restoration costs [4], [5]. As a result, sustainable post-mining land use (PMLU) solutions are essential to recover ecosystems and support economic development while aligning with global sustainability goals [6].

A promising alternative for post mining land usage is integrating wood forestry with a wood pellet factory, dedicated to produce bioenergy products, such as wood pellets, for global

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markets. Fast-growing tree species, like Acacia or Eucalyptus, can rehabilitate degraded mine sites by stabilizing soil and restoring vegetation [7], [8], while a pellet factory processes biomass into renewable energy products to meet demand in regionals like East Asia and Europe [9]. This strategy supports Indonesia's commitment to the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) by promoting renewable energy and SDG 15 (Life on Land) by restoring degraded ecosystems. However, the financial viability and risks of this approach in East Kalimantan's post-mining context remain underexplored due to unique ecological and market challenges.

Bioeconomic modelling provides a framework to evaluate this integrated system by combining biological growth with economic analysis. These models, widely used in forestry, optimize resource management by integrating tree growth functions with financial metrics like costs and revenues [10]. While effective in general forestry, bioeconomic models are rarely applied to tropical post-mining landscapes like East Kalimantan, where soil degradation complicates reforestation efforts [11]. This gap highlights the need for a tailored model to assess the proposed forestry-pellet system in this specific context.

Existing research identifies gaps that this study addresses. Post-mining reclamation studies discuss restoration strategies, such as reforestation, but rarely explore integrated forestry-pellet systems as a cohesive solution. Wood pellet economics, as examined by Manouchehrinejad et al. [12], [13] and also Nunes et al. [12], [13], focus on production costs but lack emphasis on tropical post-mining settings with distinct ecological and market constraints. Financial feasibility studies in bioenergy are common, yet few incorporate advanced risk assessments, such as Monte Carlo simulations, in Southeast Asian contexts. These gaps underscore the need for a context-specific analysis to support sustainable land use and bioenergy production.

This study contributes to SDGs by promoting renewable energy and ecosystem restoration in East Kalimantan. By evaluating the financial viability and risks of a forestry-pellet system, it provides practical insights for stakeholders, including policymakers, mining companies, and investors, to advance SDG 7 and SDG 15. The research also aligns with SDG 8 (Decent Work and Economic Growth) by exploring economic opportunities in post-mining regions, fostering sustainable livelihoods through bioenergy production and land rehabilitation.

This study addresses two research questions: Is an integrated wood forestry and pellet factory project financially viable under baseline conditions in East Kalimantan's post-mining landscape? What are the key risk factors affecting its success? To answer these, the study will: (1) evaluate financial feasibility using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period; (2) conduct risk analysis through sensitivity analysis using Monte Carlo simulation methods. The methodology uses data from local sources, such as government reports and field surveys, to ensure context-specific results. The paper is structured as follows: Section 2 details the methodology, Section 3 presents results, Section 4 discusses findings, and Section 5 concludes with recommendations.

## 2 Methodology

The research was conducted following a logical flow of work. Starting with data collection for market data, biological data, technical data, and financial data related to *Acacia mangium* plantation and wood pellet production. These data were then used to determine the initial values of the input parameters which are required to build the base case financial model where revenue and cost schedules were constructed to calculate the values for the proforma financial statements. The initial valuation of net present value and discounted payback period required a calculation of free cash flow which can be derived from the proforma financial statements. The base case valuation indicated the project's financial feasibility.

The Monte Carlo simulation was used to simulate changes in the input parameters' values, simultaneously. The simulation was conducted using Oracle Crystal Ball ® add-ins in Microsoft Excel. It was run for 50,000 iterations, which was considered sufficient due to the consistency and convergence of the output. The simulation's results can be used to determine the impact of changes in input parameters' values on the feasibility of the project. The input parameters with significant impact towards the feasibility values were then considered as risk factors which must be carefully managed should the project is pursued as the PMLU.

# 3 Results and Discussion

The wood forestry with an integrated wood pellet factory comprised two main activities: plantation management and wood pellet production. The forestry was intended to be the sole raw material supplier for the wood pellet factory. The final product of this project is the wood pellet to be used as a biomass energy source.

## 3.1 General assumptions

The financial model for wood forestry and wood pellet factory was constructed based on a set of assumptions. Wood forestry would cover 10,500 hectares with an annual planting rate of 2,100 hectares. The planting process would require five years to complete. The coppicing harvesting method was assumed to be used which left a stomp that would enable the regrowing of the tree. **Table 1** summarized the general assumptions used in the model.

**Table 1.** General Assumptions.

| Data Group | Data Point | Value | Unit |
|---|---|---|---|
| Raw Material | Annual Plant Area | 2,100 | hectare |
| | Yield | 15 | m3 / ha / year |
| | Density | 0.66 | ton/m3 |
| | Fresh moisture content | 60% | |
| | Target moisture content | 15% | |
| Sales | Pellet Price | 115 | USD / ton |
| | Price growth | 2% | per year |
| Production Capacity | Installed Capacity | 10 | ton / hour |
| | Daily operation | 24 | hours |
| | Annual operational | 360 | days |
| | Annual installed capacity | 86,400 | ton / year |
| | Production Efficiency | 95% | |
| | Expected production capacity | 82,080 | ton / year |
| Financial data | Cost of funds for equity | 6% | per year |
| | Cost of funds for bank loan | 10% | per year |
| | Hurdle rate | 3% | |
| | Cost growth | 3% | per year |
| | Exchange rate USD to IDR | 16,500 | IDR / USD |

The selected species to be planted is the *Acacia mangium.* The wood trees would be grown for five years before harvesting. The harvest cycle would allow the cut trees to be regrown for another five years before re-harvesting. At five years old, the wood yield is estimated at 75 $m^3$ per hectare. The *Acacia mangium* has an estimated density of 660 $kg/m^3$ [14].

The base case for the wood pellet selling price was set at USD 115 per ton, which falls within the global price range [15]. The price growth was set at a conservative rate of 2% per year considering the close gap between demand and supply of the product in the global market.

### 3.2 Planting and Production

The planting process is assumed to begin in 2025 with an annual planting rate of 2,100 hectares as shown in Table 2. The seeds would be planted at least three meters apart, so around 1,000 seeds would be planted in each hectare. After five years of growing, each hectare of the plantation would yield 49.5 tons of wood as the raw material for pellet production. The amount of wood ready to be supplied during each harvest cycle could reach almost 104 thousand tons. However, the harvested woods have a relatively high moisture content that must be dried before being processed into pellets.

**Table 2.** Planting density and yield.

| Planting Phase | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 |
|---|---|---|---|---|---|
| Start planting | 2025 | 2026 | 2027 | 2028 | 2029 |
| Area (ha) | 2,100 | 2,100 | 2,100 | 2,100 | 2,100 |
| Quantity of seeds per ha (pcs) | 1,100 | 1,100 | 1,100 | 1,100 | 1,100 |
| Harvest cycle (years) | 5 | 5 | 5 | 5 | 5 |
| First harvest | 2030 | 2031 | 2032 | 2033 | 2034 |
| Yield (m3/ha) | 75 | 75 | 75 | 75 | 75 |
| Density (ton/m3) | 0.66 | 0.66 | 0.66 | 0.66 | 0.66 |

The plantation plan and harvest cycle would result in an estimated annual harvest of around 157,500 $m^3$ of wood volume. Multiplying the volume with the density would yield a wood mass of 103,950 tons annually. The harvested wood is assumed to have 60% moisture that needs to be dried to 15% before being converted into wood pellets. The drying process would reduce the moisture content and impact the total wood mass. The amount of final mass after the mass loss during the drying process can be calculated by using Eq. (1).

$$M_f = M_i \times \frac{1 + MC_f}{1 + MC_i} \quad (1)$$

Here in Eq. (1), $M_f$ is the final mass (tons), and $M_i$ represent the initial mass (tons). On the other hand, $MC_f$ and $MC_i$ are the final moisture content (%), and the initial moisture content (%), respectively.

Moreover, for the present project, the final mass calculation is as follows:

$$M_f = 103{,}950 \times \frac{1 + 15\%}{1 + 60\%} = 103{,}950 \times \frac{115\%}{160\%} = 74{,}714\ tons$$

Additionally, the drying process is typically conducted in two stages: natural drying, which involves exposing the material to sunlight, and mechanical drying, using a specialized machine in the pellet production line. Therefore, it is also presumed that the entire mass will be effectively transformed into wood pellets once it has been dried. The annual wood production is assumed to be constant throughout the projection horizon. The data would be used to calculate the annual revenue of the project.

### 3.3 Profit and loss statement

The data in **Table 3,** indicated that there will be a gradual decrease in profitability over the projected timeframe, with both EBITDA and net income margins showing a declining pattern. The average EBITDA Margin is calculated at around 16.45%. The decreasing trend in EBITDA values specifically indicated a decrease in operating profitability. This decrease results from operational costs increasing annually at a faster rate (3%) than revenue growth (2%). This indicates that although the business is still producing positive EBITDA, its capacity to maintain strong operating profits diminishes at later stage of the projection.

Similarly, the net income margin, with an average of 10.94%, highlights the difficulties the project encounters in sustaining profitability. The persistent decrease in this margin indicates that net profits are being negatively affected, potentially as a result of rising expenses that are not being balanced by revenue expansion. These downward trends must be anticipated as they may be directly correlated to the project's profitability and feasibility. Should this project be selected, then the management actions are required to address how to reduce the costs or improve the revenues.

**Table 3.** Profit and loss statement.

| **Year** | **2030** | **2031** | **…** | **2054** |
|---|---:|---:|---|---:|
| Revenue | 9,676,119 | 9,869,642 | … | 15,563,431 |
| Production cost | (6,316,781) | (6,482,094) | … | (11,814,183) |
| Gross Profit | 3,359,339 | 3,387,548 | … | 3,749,248 |
| Operating Cost | (1,237,853) | (1,265,312) | … | (2,105,687) |
| EBITDA | 2,121,486 | 2,122,236 | … | 1,643,561 |
| Deprecations & amortization | (192,000) | (192,000) | … | - |
| Earnings before interest and tax | 1,929,486 | 1,930,236 | … | 1,643,561 |
| Interest payment | - | - | … | - |
| Earnings before tax | 1,929,486 | 1,930,236 | … | 1,643,561 |
| Tax payment | (578,846) | (579,071) | … | (493,068) |
| Net Income | 1,350,640 | 1,351,165 | … | 1,150,493 |

### 3.4 Free cash flow calculation and base case financial modelling valuation results

The summary of the free cash flow calculations in each period are displayed in **Table 4**Error! Reference source not found.. The data suggest that the first five years will be exposed to a series of significant negative free cash flow (FCF) due to the intense capital investment. These periods' data show the project's strategic decision to spend resources to establish the plantations, as evidenced by the substantial cash outflows from 2025 (year 0) to 2029. The substantial investment in 2029 is due to the wood pellet factory setup. However, these investments are necessary for the project, which would enable it to generate revenue in a longer timeframe. These investments need to be repaid by future cash flows to make the project considered financially feasible.

The projections indicate a transition from negative to positive FCF beginning in 2030, the period of production started and revenues inflow generated. The project's operational efficiencies and revenue-generating capabilities are increasing, as evidenced by the consistent improvement in cash flows over the subsequent years. This period of consistent positive FCF underscores the project's capacity to generate adequate cash from its core operations, enabling it to pay for the expenses in terms of production and operational costs. The most notable characteristic is the substantial increase in FCF in the terminal year 2054 (year 29) due to a substantial terminal cash flow. The terminal cash flow recaptured the cash spent for establishing the plantation as the costs could not be amortized.

**Table 4.** Free cashflow & NPV.

| Year | Free Cashflow | Present Value (i= 9.00%) | Cumulative PV |
|---:|---:|---:|---:|
| 0 | (1,186,500) | (1,186,500) | (1,186,500) |
| 1 | (1,190,595) | (1,092,289) | (2,278,789) |
| 2 | (1,194,813) | (1,005,650) | (3,284,439) |
| 3 | (1,199,157) | (925,969) | (4,210,408) |
| 4 | (3,423,632) | (2,425,387) | (6,635,796) |
| 5 | 1,158,640 | 753,037 | (5,882,759) |
| 6 | 1,159,165 | 691,172 | (5,191,587) |
| 7 | 1,158,825 | 633,917 | (4,557,670) |
| 8 | 1,157,577 | 580,949 | (3,976,721) |
| 9 | 1,155,375 | 531,967 | (3,444,754) |
| 10 | 1,152,173 | 486,690 | (2,958,064) |
| 11 | 1,147,921 | 444,857 | (2,513,207) |
| 12 | 1,142,570 | 406,223 | (2,106,984) |
| 13 | 1,136,067 | 370,561 | (1,736,423) |
| 14 | 1,128,357 | 337,657 | (1,398,766) |
| 15 | 1,394,784 | 382,921 | (1,015,845) |
| 16 | 1,384,490 | 348,711 | (667,134) |
| 17 | 1,372,813 | 317,220 | (349,914) |
| 18 | 1,359,691 | 288,246 | (61,668) |
| 19 | 1,345,059 | 261,600 | 199,933 |
| 20 | 1,328,849 | 237,108 | 437,040 |
| 21 | 1,310,991 | 214,607 | 651,647 |
| 22 | 1,291,412 | 193,946 | 845,594 |
| 23 | 1,270,037 | 174,987 | 1,020,581 |
| 24 | 1,246,788 | 157,600 | 1,178,181 |
| 25 | 1,272,583 | 147,579 | 1,325,760 |
| 26 | 1,245,340 | 132,495 | 1,458,255 |
| 27 | 1,215,971 | 118,688 | 1,576,943 |
| 28 | 1,184,386 | 106,060 | 1,683,003 |
| 29 | 6,400,493 | 525,830 | 2,208,832 |

The data show the present value (PV) calculation for each year by discounting the time value of money at a 9% annual rate. The first five years' values are negative because no revenue has yet been generated by the project as the project was still in the establishment phase. In this phase, the cash flow represents the amount of investments spent for plantation and factory setup. Consequently, the cumulative negative PV reaches nearly USD -6.64 million by Year 4. The financial strain that was experienced during the initial investment phase is underscored by this period.

The cumulative deficit gradually reduces as the FCF becomes positive from Year 5 onward. The cumulative PV finally shifts from negative to positive between Years 18 and 19, signaling that the project has recovered its initial investment and has started generating value. This is a pivotal moment. The discounting impact is apparent, as the present values of future cash flows are significantly lower than their nominal quantities. For instance, the terminal year (Year 29) estimated a substantial FCF of USD 6.4 million; however, its PV is only USD 525,830 due to the long discounting period from the present. Furthermore, it turns out that this analysis generally suggests that it will eventually yield if only a large initial investment is made, and that the first few years of the journey will be fraught with financial difficulties or challenges. These subsequent years produce the highest value, culminating in a positive cumulative PV in Year 19 and thus signaling a strong end to Year 29.

The weighted average cost of capital (WACC) is set at 9%, which already includes a 3% hurdle rate. The average EBITDA in the base case model is found at around USD 1.63 million, which indicates the ability of the project to cover the operating costs. The discounted payback period can be observed in year 19, and the total net present value of the alternative is around USD 2.2 million. The internal rate of return is found at 12.08% which is higher than the WACC. These valuation values indicated that the project is financially feasible.

### 3.5 Risk simulation using Monte Carlo Simulation

The Monte Carlo simulation (MCS) was the chosen method to simulate the risk or uncertainties instead of the more popular three-point scenarios, which utilized three static points of assumptions set, i.e., best, normal, and worst scenario. The MCS offered a more realistic simulation model as the values of the assumption parameters can be simultaneously varied in each iteration. The availability of MCS software as add-ins in the spreadsheet software has helped to reduce simulation time despite the large number of iterations. The 50.000 iterations for each alternative took approximately six minutes to complete. The descriptive statistics of the MCS results are shown in **Table 5.**

**Table 5.** Descriptive statistics of MCS results.

| **Forecasts** | **Avg. EBITDA (million USD)** | **NPV (million USD)** | **DPP (years)** |
|---|---|---|---|
| # of iteration | 50,000 | 50,000 | 50,000 |
| Base Case | 1.63 | 2.208 | 19 |
| Mean | 1.939 | 6.146 | 14.87 |
| Median | 2.027 | 6.634 | 10 |
| Standard Deviation | 1.890 | 9.837 | 8.79 |
| Skewness | -0.22 | -0.361 | 0.955 |
| Kurtosis | 3.30 | 3.49 | 2.18 |
| Coeff. of Variation | 0.97 | 1.60 | 0.5907 |

Monte Carlo Simulation results reveals a stark contrast between the baseline figures ($50 million for EBITDA and NPV, 50-year DPP) and simulated means ($1.939 million, $6.146 million, 14.87 years), suggesting initial overestimations. High variability, indicated by standard deviations ($1.890 million for EBITDA, $9.837 million for NPV) and coefficients of variation (0.97 and 1.60), highlights significant uncertainty, requiring sensitivity analyses to address risks. Negative skewness for EBITDA and NPV (-0.22, -0.361) signals underperformance risks, while a 10–14.87-year DPP warrants cautious financial planning. Additionally, the kurtosis values exceeding 3 for EBITDA and NPV indicate a distribution with heavier tails, increasing the potential for extreme outcomes that must be stress-tested.

The variance of the NPV and DPP values is caused by the variations in the input parameters in each iteration. It would be beneficial to learn further about the input parameters that significantly lead to the variance of the NPV and DPP. The parameters with a high contribution to variance could then be considered risk factors that should be carefully examined and mitigated to ensure the achievement of favorable NPV and DPP. The identification process was done using the sensitivity analysis report, which was also obtained via the MCS.

Only two risks were identified for the wood forestry and pellet factory alternative, namely pellet price and cost growth. These factors can be classified into two categories: revenue factors and cost factors. Pellet prices are classified as revenue factors because they have a direct impact on the project's revenue. Fluctuations in pellet prices can have a significant impact on the venture's profitability. On the other hand, cost growth, which includes inflation, has an impact on the cost factors, affecting the factory's operating expenses. Both of these factors are classified as external risks, which means they are largely beyond the company's control. This external nature makes them difficult to manage internally, as the company has little control over market prices or broader economic conditions. To mitigate the potential impact of these risks on the project, strategies such as long-term contracts, hedging, or careful financial planning will likely be required.

The pellet price significantly contributes (more than 70%) to the variance for both the discounted payback period and the net present value indicating that the pellet price fluctuation should be the major concern in executing the alternative. The 2023 global wood pellet market size is valued at around 18.9 billion USD and is expected to reach 19.5 billion USD in 2024. The market size is estimated to grow at a compounded annual growth rate of 6.8% until 2034. However, the demand for wood pellets is only 1% greater than the supply, which indicates that the producer has anticipated the demand growth and managed to grow the supply accordingly. This would suggest that the pellet price will likely stabilize in the near future.

The annual cost growth of the project has a substantial effect on all costs associated with its operation, including labor costs, plantation maintenance costs, and supporting overhead costs, which tend to increase annually. Despite the fact that annual cost growth accounts for less than 20% of the variance in the valuation value, it is still a critical factor that necessitates meticulous monitoring. These increasing costs, particularly when annual revenues are expected to stay constant due to the capacity cap and unchanging selling price, might account for decreasing profits over time. If costs continue unchecked, they may surpass the income, resulting to lower margins; hence the investment could become less profitable. The data hints that there are needs for a sound strategic planning and proper management of finances. The plan should be able to mitigate the impact of inflation or any other factor which likely to push costs up, thus ensuring the sustainability of the project in the longer run.

**Table 6.** Impact of 5% change in risk factor values.

| Risk Factors | 5% worse | NPV | DPP |
|---|---|---|---|
| Pellet Price | 109.25 | 404,878 | 29 |
| Cost Growth | 0.0315 | 1,658,486 | 20 |

**Table 6** displays the impact of a 5% worse condition for the two risk factors (pellet price decreased, cost growth increased) on the NPV and DPP. A 5% drop in pellet price would cause a 72% reduction in the value of the NPV while extending the payback period by ten

years. This data re-emphasizes the venture's dependency on the price stability of the final product in the global market. A 5% increase from the base case in cost growth would reduce the NPV by 25% and delay the investment repayment by one year. This indicates that rising costs, though challenging, maybe more manageable than declining revenue.

## 4 Conclusions

This study evaluates the financial viability and associated risks of an integrated wood forestry and wood pellet factory as a sustainable post-mining land use (PMLU) strategy in East Kalimantan, Indonesia, addressing the pressing need for ecosystem restoration and renewable energy production amid coal mining's environmental legacy. Key findings demonstrate that the project is financially feasible under baseline conditions, with a net present value (NPV) of approximately USD 2.2 million, an internal rate of return (IRR) of 12.08% exceeding the 9% WACC, and a discounted payback period (DPP) of 19 years, aligning with the first research objective by confirming positive economic outcomes despite initial capital-intensive phases. Monte Carlo simulation (MCS) further reveals an average NPV of USD 6.146 million and a mean DPP of 14.87 years across 50,000 iterations, underscoring viability but highlighting high variability (coefficients of variation up to 1.60), negative skewness indicating underperformance risks, and kurtosis suggesting potential extreme outcomes. Pertaining to the second objective, sensitivity analysis identifies pellet price fluctuations and annual cost growth as primary risk factors, with pellet price contributing over 70% to NPV and DPP variance; a 5% adverse change in pellet price could reduce NPV by 72% and extend DPP by 10 years, emphasizing the need for market stabilization strategies like long-term contracts or hedging to mitigate external uncertainties.

These results directly support the research objectives by providing a tailored bioeconomic model for tropical post-mining contexts, advancing Indonesia's commitments to Sustainable Development Goals (SDGs) 7 (Affordable and Clean Energy) through bioenergy production, 15 (Life on Land) via land rehabilitation with *Acacia mangium* plantations, and 8 (Decent Work and Economic Growth) by fostering local livelihoods. The integrated system not only rehabilitates degraded lands but also positions East Kalimantan as a contributor to global wood pellet markets, projected to grow at 6.8% annually until 2034, while addressing gaps in existing literature on context-specific financial assessments.

However, this research has limitations, including reliance on assumed parameters (e.g., 2% price growth, 3% cost escalation) derived from secondary data, which may not fully capture real-time ecological variabilities such as soil degradation dynamics or climate-induced yield reductions in tropical settings. A different growth setup may lead to a different value of viability, even it could reverse the decision. The model also excludes non-financial aspects like detailed environmental impact assessments or socio-political factors. For future research, incorporating stochastic elements for biological growth under climate scenarios, conducting empirical field trials to validate assumptions, and comparing this PMLU option with alternatives like agroforestry or ecotourism could enhance robustness. Additionally, expanding the analysis to include carbon credit monetization or supply chain optimizations would provide deeper insights for stakeholders in pursuing sustainable transitions in post-mining regions.

## References

1. J. A. Ordonez, M. Jakob, J. C. Steckel, and A. Fünfgeld, Coal, power and coal-powered politics in Indonesia. Environ Sci Policy. **123**, pp. 44–57, Sep. (2021). doi: 10.1016/j.envsci.2021.05.007.

2. H. Aimon, A. P. Kurniadi, S. U. Sentosa, and N. A. Rahman, Production, Consumption, Export and Carbon Emission for Coal Commodities: Cases of Indonesia and Australia. Int. J. Energy Econ. Policy. **13**, no. 5, pp. 484–492, Sep. (2023). doi: 10.32479/ijeep.14798.
3. I. E. Setiawan, Z. Zhang, G. Corder, and K. Matsubae, Evaluation of environmental and economic benefits of land reclamation in the indonesian coal mining industry. Resources. **10**, no. 6, Jun. (2021). doi: 10.3390/resources10060060.
4. N. Listiyani, M. Y. Said, and A. Khalid, Strengthening Reclamation Obligation through Mining Law Reform: Indonesian Experience. Resources. **12**, no. 5, May (2023). doi: 10.3390/resources12050056.
5. S. Maryati, Land Capability Evaluation of Reclamation Areain Indonesia Coal Mining using LCLP Software. Procedia Earth Planet. Sci. **6**, pp. 465–473 (2013). doi: 10.1016/j.proeps.2013.01.061.
6. I. M. Ronyastra, L. H. Saw, and F. S. Low, A review of methods for integrating risk management and multicriteria decision analysis in financial feasibility for post-coal-mining land usage selection. Resour. Policy. **86**, Oct. (2023). doi: 10.1016/j.resourpol.2023.104260.
7. R. Päivinen, M. Lindner, K. Rosén, and M. J. Lexer, A concept for assessing sustainability impacts of forestry-wood chains. Eur. J. For. Res, **131**, no. 1, pp. 7–19, Jan. (2012). doi: 10.1007/s10342-010-0446-4.
8. L. Šebelíková *et al.*, Spontaneous revegetation versus forestry reclamation—Vegetation development in coal mining spoil heaps across Central Europe. Land Degrad. Dev. **30**, no. 3, pp. 348–356, Feb. (2019). doi: 10.1002/ldr.3233.
9. R. Jonsson and F. Rinaldi, The impact on global wood-product markets of increasing consumption of wood pellets within the European Union. Energy. **133**, pp. 864–878 (2017). doi: 10.1016/j.energy.2017.05.178.
10. E. Petersen, E. Susanti, R. Oktaviani, C. Jones, and A. Diedrich, Bio-Economics of Tropical Spiny Lobster Farming in Indonesia. Aquac. Fish. Stud. **2**, no. 2, Apr. (2020)
11. E. Rocha-Nicoleite, M. L. Campos, G. T. Colombo, G. E. Overbeck, and S. C. Müller, Forest restoration after severe degradation by coal mining: lessons from the first years of monitoring. Rev. Bras. Bot. **41**, no. 3, pp. 653–664, Sep. (2018). doi: 10.1007/s40415-018-0486-4.
12. M. Manouchehrinejad, E. M. T. Bilek, and S. Mani, Techno-economic analysis of integrated torrefaction and pelletization systems to produce torrefied wood pellets. Renew. Energy. **178**, pp. 483–493, Nov. (2021). doi: 10.1016/j.renene.2021.06.064.
13. L. J. R. Nunes, J. C. O. Matias, and J. P. S. Catalão, Wood pellets as a sustainable energy alternative in Portugal. Renew. Energy. **85**, pp. 1011–1016, Jan. (2016). doi: 10.1016/j.renene.2015.07.065.
14. W. D. Nugroho *et al.*, Radial variations in the anatomical characteristics and density of the wood of Acacia mangium of five different provenances in Indonesia. J. Wood Sci. **58**, no. 3, pp. 185–194 (2012). doi: 10.1007/s10086-011-1236-4.
15. J. Oh and D. H. Suh, Exploring the import allocation of wood pellets: Insights from price and policy influences under the renewable portfolio standard. For. Policy Econ. **161**, p. 103180, Apr. (2024). doi: 10.1016/j.forpol.2024.103180.