MEASURING GREEN EFFICIENCY IN THE MINING INDUSTRY THROUGH AN INTEGRATED INDICATOR-BASED APPROACH FROM NAVOI MINING AND METALLURGICAL COMPANY

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Abstract:

This article develops an integrated indicator-based approach for measuring green efficiency in the mining industry using the case of Navoi Mining and Metallurgical Company. The study combines resource productivity, environmental load, energy value efficiency and green technology contribution into an Integrated Green Efficiency Index. The results show that green efficiency increased steadily between 2020 and 2025, while resource and environmental load declined. The proposed framework demonstrates that green modernization in mining should be treated not only as an environmental obligation but also as a measurable economic efficiency mechanism.

Keywords:

green efficiency, mining industry, integrated indicators, resource productivity, environmental load, energy efficiency, Navoi Mining and Metallurgical Company.

Introduction

The mining industry occupies a paradoxical position in the contemporary green transition. On the one hand, it supplies the minerals required for renewable energy systems, digital infrastructure, electric mobility and high-technology manufacturing. On the other hand, mining remains one of the most resource-intensive industrial sectors, placing substantial pressure on energy, water, land and waste management systems. This contradiction requires a new approach to measuring performance. Traditional indicators such as output volume, profit, production cost and profitability remain important, but they are no longer sufficient for evaluating the long-term sustainability of mining enterprises [1].

In resource-intensive sectors, efficiency must be interpreted not only as the ability to produce more, but also as the ability to generate greater economic value with lower resource use and reduced environmental pressure. This is particularly relevant for large-scale mining and metallurgical enterprises, where energy intensity, water consumption, waste generation and ecological risks directly influence production costs, investment attractiveness and international competitiveness [2]. In this context, green efficiency becomes an integrated category that connects economic value creation with resource productivity and environmental responsibility.[1]

The case of Navoi Mining and Metallurgical Company is especially relevant for such an assessment.[2] As one of the largest gold-producing industrial enterprises in Central Asia, the company combines extraction, processing and metallurgical production within a complex industrial chain. Its performance cannot be fully understood through financial indicators alone. A broader analytical framework is needed to show whether production growth is accompanied by more efficient resource use, lower environmental load and stronger technological modernization.

This article aims to develop and apply an integrated indicator-based approach for measuring green efficiency in the mining industry. The proposed framework combines five indicators: Green Value Added Efficiency, Resource Load Index, Energy Value Efficiency, Green Technology Contribution Index and Integrated Green Efficiency Index. The study argues that such an approach makes it possible to transform green modernization from a qualitative policy statement into a measurable economic management tool.

Literature Review

The theoretical foundation of green efficiency is closely related to the economics of exhaustible resources, green growth, eco-efficiency, circular economy and innovation-driven competitiveness. Dasgupta and Heal emphasized that the use of non-renewable resources should be evaluated through the logic of intertemporal efficiency, because current extraction decisions influence future economic opportunities [3]. This perspective is highly relevant to mining, where resource depletion and environmental damage may generate long-term hidden costs.

The green growth approach developed by the OECD links economic expansion with improved resource productivity and reduced environmental pressure [4]. In this framework, growth is not rejected, but its quality becomes central. An enterprise may increase output, but if this increase is achieved through excessive energy use, water losses and growing waste volumes, such growth cannot be considered sustainable. Therefore, green growth requires indicators that connect economic value with resource and environmental performance.

The World Bank's climate-smart mining approach also highlights that mineral extraction must adapt to the requirements of the global energy transition [5]. Mining companies are expected not only to supply critical minerals but also to reduce emissions, improve water stewardship, manage waste responsibly and integrate cleaner technologies. This creates a demand for measurable indicators that allow firms, regulators and investors to evaluate whether green technologies actually improve performance.

Porter and van der Linde argued that environmental requirements can stimulate innovation and improve competitiveness when firms redesign production processes and reduce resource inefficiencies [6]. In mining, this argument can be extended to energy-saving equipment, closed water circulation systems, digital monitoring, waste recycling and cleaner processing technologies. Such innovations may initially require capital investment, but they can reduce operating costs and strengthen long-term competitiveness.

The circular economy literature also provides an important conceptual basis. Stahel's performance economy emphasizes the extension of resource value through reuse, repair, remanufacturing and recycling [7]. In mining, this logic can be adapted through the reprocessing of tailings, recovery of valuable components from metallurgical residues, reuse of water and transformation of waste into

[1] The term "green efficiency" in this article refers to the ability of a mining enterprise to generate economic value while reducing resource intensity, energy burden and ecological pressure.

[2] Navoi Mining and Metallurgical Company is used as a case because of its strategic role in Uzbekistan's mining and metallurgical industry and the availability of indicator-based internal analytical data.

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secondary raw materials. In this sense, waste becomes not only an ecological problem but also a potential economic asset.

Existing studies on mining performance often use separate indicators such as energy intensity, water consumption, emissions, waste generation, output growth or profitability [8]. However, separate indicators provide fragmented information. A company may improve energy efficiency while environmental load remains high, or it may increase added value while resource pressure also increases. Therefore, an integrated indicator system is required to evaluate the overall direction of green efficiency.

Methodology

The study uses a systematic indicator-based methodology. The core idea is that green efficiency in mining should be measured through the interaction of economic value, resource use, environmental load, energy efficiency and technological contribution. The proposed system includes five indicators.

Table 1. Integrated indicators for measuring green efficiency in mining

Indicator	Full name	Analytical meaning	Expected direction
GVAE	Green Value Added Efficiency	Economic value created per resource input	Higher is better
RLI	Resource Load Index	Environmental and resource pressure per production activity	Lower is better
EVE	Energy Value Efficiency	Economic value created per energy-related cost	Higher is better
GTCI	Green Technology Contribution Index	Contribution of green technologies to resource saving	Higher is better
IGEI	Integrated Green Efficiency Index	Composite measure of green economic efficiency	Higher is better

The methodological logic is straightforward. If a mining enterprise creates more value from each unit of resource, reduces environmental load, improves energy value efficiency and increases the contribution of green technologies, then its overall green efficiency should rise. Conversely, if output grows but resource and environmental pressure also increase, the growth cannot be interpreted as green efficiency. The Integrated Green Efficiency Index can be expressed conceptually as follows:

IGEI = f(GVAE, RLI, EVE, GTCI)

In this relationship, GVAE, EVE and GTCI are positive contributors, while RLI is a pressure indicator whose reduction improves the final index. The model therefore reflects both value creation and burden reduction.[3]

[3] GVAE, RLI, EVE, GTCI and IGEI are interpreted in this article as methodological indicators for integrated green performance assessment rather than as standard accounting indicators.

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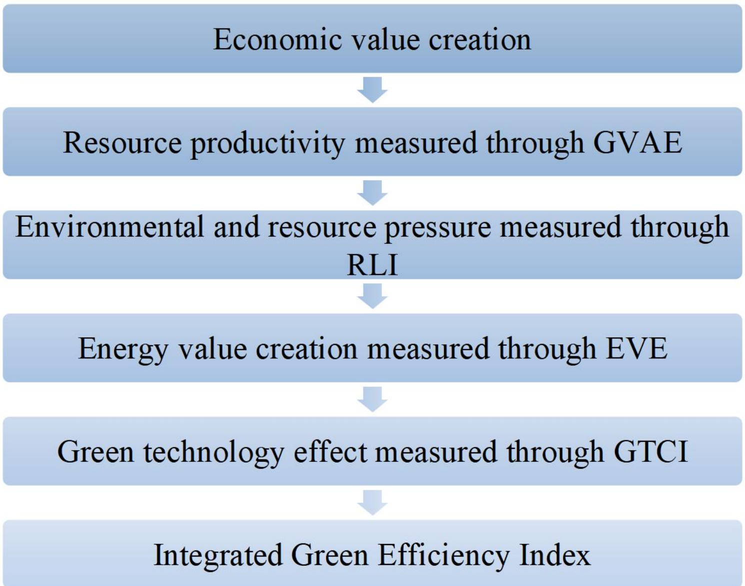

Figure 1. Conceptual model of integrated green efficiency measurement

The empirical part of the study uses the 2020–2025 indicator dynamics of Navoi Mining and Metallurgical Company. The selected period is sufficient to observe the transition from initial green modernization to more systematic efficiency effects. The analysis is based on dynamic comparison rather than cross-sectional benchmarking, because the aim is to identify internal transformation trends within a large mining enterprise.[4]

Results

The results show a clear improvement in the green efficiency performance of Navoi Mining and Metallurgical Company between 2020 and 2025. The most important finding is the simultaneous increase in GVAE, EVE and GTCI together with the decline in RLI. This indicates that the company not only generated more economic value from resources but also reduced resource and environmental load.

Table 2. Green efficiency indicators of Navoi Mining and Metallurgical Company

Year	GVAE	RLI	EVE	GTCI	IGEI
2020	2.2190	0.1144	3.2627	0.0027	0.1737
2021	2.4335	0.1062	3.5517	0.0043	0.3481
2022	2.8142	0.0958	4.0800	0.0055	0.6614
2023	3.2394	0.0852	4.6422	0.0075	1.3169
2024	3.8613	0.0753	5.5146	0.0091	2.5805
2025	4.6048	0.0672	6.5464	0.0107	4.7752

The GVAE indicator increased from 2.2190 in 2020 to 4.6048 in 2025. This means that the economic value generated relative to resource input more than doubled. Such growth suggests that resource productivity improved not as a marginal effect but as a structural tendency. In practical terms, the enterprise became more capable of producing value without proportionally increasing resource use.

The RLI indicator decreased from 0.1144 to 0.0672 over the same period. This is important because green efficiency cannot be confirmed only by rising value indicators. The decline in RLI means that resource and environmental pressure per unit of activity decreased. In mining, this may

[4] The 2020–2025 indicator values are based on the analytical calculations presented in the dissertation materials prepared for article development.

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reflect better water management, reduced resource losses, improved technological control and more systematic environmental planning.[5]

The EVE indicator increased from 3.2627 in 2020 to 6.5464 in 2025. This indicates that energy-related expenditures generated greater economic value over time. Since mining and metallurgical processes are energy-intensive, this improvement has direct implications for production costs and competitiveness. Energy efficiency is therefore not only an environmental criterion but also a cost management instrument.

The GTCI increased from 0.0027 to 0.0107. Although the absolute values are relatively small, the trend is significant because it shows the growing contribution of green technologies to overall performance. In the initial period, green technologies had limited measurable impact. By 2025, however, they became a more visible component of the company's economic and environmental efficiency.

The IGEI increased from 0.1737 in 2020 to 4.7752 in 2025. This is the most important result of the analysis. It suggests that the combined effect of resource productivity, lower environmental load, energy value efficiency and green technology contribution produced a strong upward trend in integrated green performance.[6]

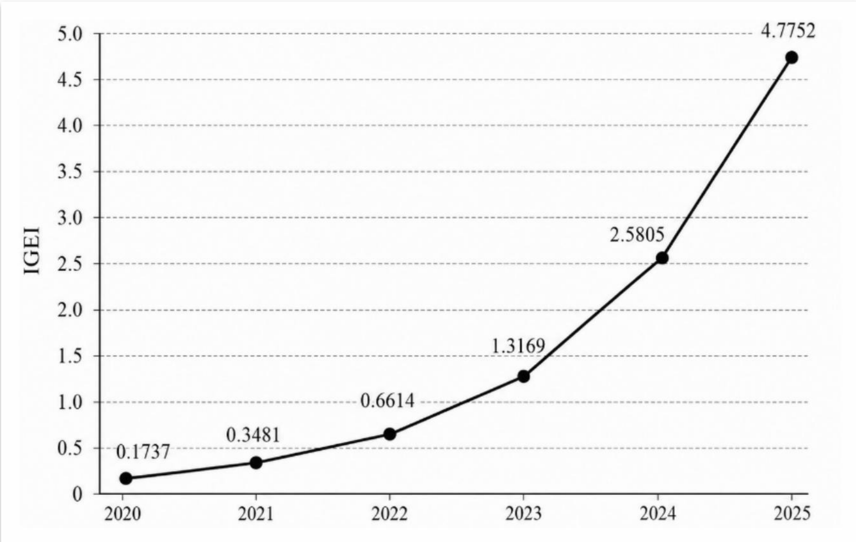

Figure 2. Dynamics of IGEI during 2020–2025[7]

The results show that the period can be divided into three stages. The first stage, 2020–2021, represents the initial formation of green efficiency. The second stage, 2022–2023, represents acceleration, when green technologies began to produce visible economic effects. The third stage, 2024–2025, represents consolidation, when integrated green efficiency became a major component of the company's overall performance.

Discussion

The findings confirm that mining efficiency should be measured through integrated indicators rather than isolated financial metrics. If only profitability or production volume is considered, management may overlook resource load, energy intensity and ecological liabilities. By contrast, the

[5] A decrease in RLI is interpreted as a positive result because it reflects a reduction in resource and ecological load.

[6] The IGEI value should be interpreted dynamically. Its analytical importance lies not only in the absolute level of the index but also in the direction and speed of change over time.

[7] Source: developed by the author

proposed indicator framework shows how economic value is connected to resource-saving and green technology.

The case of Navoi Mining and Metallurgical Company demonstrates that green transformation can generate economic value rather than simply increase compliance costs. The growth of GVAE shows that resource productivity improved. The decline of RLI shows that ecological and resource pressure decreased. The growth of EVE indicates that energy efficiency contributed directly to economic performance. The rise of GTCI confirms that green technologies became increasingly relevant for production efficiency. Together, these indicators explain the rapid increase in IGEI.

This result supports Porter and van der Linde's argument that environmental modernization can strengthen competitiveness [6]. In mining, this competitiveness is created through lower resource intensity, reduced production costs, improved sustainability profile and stronger investment attractiveness. The findings also support the circular economy logic because resource-saving measures help reduce waste and transform ecological burdens into potential economic value [7].

From a managerial perspective, the proposed framework can be used as a decision-making tool. GVAE helps managers understand whether resource inputs are generating sufficient value. RLI shows whether ecological pressure is decreasing. EVE measures whether energy efficiency projects are economically justified. GTCI evaluates whether green technologies are becoming productive assets. IGEI summarizes the overall direction of green transformation.

Table 3. Managerial interpretation of the indicator system

Management question	Indicator	Practical meaning
Are resources generating more value?	GVAE	Measures resource productivity
Is ecological pressure decreasing?	RLI	Measures resource and environmental load
Is energy use economically efficient?	EVE	Measures energy-value relationship
Do green technologies create measurable benefits?	GTCI	Measures technological contribution
Is the overall system becoming greener and more efficient?	IGEI	Provides an integrated strategic signal

The framework can also support ESG reporting and green finance. Mining companies increasingly need credible quantitative indicators to demonstrate progress in environmental performance. An integrated green efficiency index can provide a concise but meaningful signal for investors, regulators and stakeholders. However, it should not replace detailed environmental reporting. Instead, it should complement technical, ecological and financial data.

The main limitation of this article is that it focuses on one company case. While the indicator logic is transferable, the specific numerical dynamics reflect the conditions of Navoi Mining and Metallurgical Company. Future studies may apply the same framework to other mining enterprises in Central Asia or compare gold, copper, uranium and coal mining companies. Another direction for future research is to test the statistical relationship between green efficiency indicators and financial outcomes such as profitability, cost reduction, export competitiveness and investment attraction.

Conclusion

This article developed an integrated indicator-based approach for measuring green efficiency in the mining industry. The proposed framework combines GVAE, RLI, EVE, GTCI and IGEI indicators to evaluate economic value creation, resource pressure, energy efficiency and green technology contribution in a unified system.

The case of Navoi Mining and Metallurgical Company shows that integrated green efficiency improved significantly during 2020–2025. IGEI increased from 0.1737 in 2020 to 4.7752 in 2025, indicating a major shift from early-stage green transformation toward consolidated green efficiency. GVAE and EVE increased steadily, RLI declined, and GTCI rose, showing that resource-saving technologies and green innovation increasingly contributed to economic performance.

The study concludes that green efficiency in mining should be understood not as a purely environmental concept but as an economic-management category. A mining enterprise becomes genuinely efficient when it creates more value with lower resource pressure, higher energy productivity and stronger green technology contribution. Therefore, integrated green efficiency indicators can serve as a useful methodological tool for mining companies, policymakers, investors and sustainability analysts.

References

1. OECD. (2021). Mining and green growth in the EECCA region. OECD Publishing.
2. World Bank. (2020). Minerals for climate action: The mineral intensity of the clean energy transition. World Bank Group.
3. Dasgupta, P. S., & Heal, G. M. (1979). Economic theory and exhaustible resources. Cambridge University Press.
4. OECD. (2011). Towards green growth. OECD Publishing.
5. World Bank. (2019). Climate-smart mining: Minerals for climate action. World Bank Group.
6. Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment–competitiveness relationship. Journal of Economic Perspectives, 9(4), 97–118.
7. Stahel, W. R. (2019). The circular economy: A user's guide. Routledge.
8. Global Reporting Initiative. (2024). GRI 14: Mining sector standard. Global Sustainability Standards Board.
9. International Council on Mining and Metals. (2022). Mining principles: Performance expectations. ICMM.
10. Stern, N. (2007). The economics of climate change: The Stern review. Cambridge University Press.
11. Barbier, E. B. (2011). The policy challenges for green economy and sustainable economic development. Natural Resources Forum, 35(3), 233–245.
12. International Energy Agency. (2021). The role of critical minerals in clean energy transitions. IEA.
13. Schumpeter, J. A. (1934). The theory of economic development. Harvard University Press.
14. Tidd, J., & Bessant, J. (2020). Managing innovation: Integrating technological, market and organizational change (7th ed.). Wiley.
15. "Navoiy kon-metallurgiya kombinati" AJ. (2024). Korxona faoliyati va innovatsion rivojlanish boʻyicha analitik maʼlumotlar. NKMK AJ.