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Green Economy in The Mining Industry: CCS Synergy for Sustainable Natural Resource Management

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Abstrak

Penelitian ini mengeksplorasi potensi integrasi teknologi Penangkapan dan Penyimpanan Karbon (PPK) di sektor pertambangan Dompu, Nusa Tenggara Barat, sebagai bagian dari transisi ekonomi hijau yang lebih luas. Dengan menggunakan pendekatan studi kasus kualitatif, data dikumpulkan melalui wawancara, analisis kebijakan, dan sumber statistik sekunder. Temuan menunjukkan bahwa meskipun PPK belum diterapkan secara lokal, penerapannya menghadirkan peluang signifikan untuk mengurangi emisi industri, terutama jika dikombinasikan dengan energi terbarukan seperti tenaga surya atau panas bumi. Pemodelan ekonomi menunjukkan bahwa efisiensi biaya jangka panjang dapat dicapai melalui sistem hibrida PPK-energi terbarukan, terutama dengan mekanisme penetapan harga karbon yang suportif. Namun, tantangan utama meliputi keterbatasan penilaian geologi, kesenjangan regulasi, biaya investasi awal yang tinggi, dan kurangnya kesadaran publik. Studi ini menyimpulkan bahwa PPK dapat menjadi jalur strategis untuk pengelolaan sumber daya alam berkelanjutan di Dompu, dengan syarat kerangka kerja kelembagaan, keuangan, dan berbasis masyarakat diperkuat. Rekomendasi yang diberikan meliputi inisiasi proyek percontohan, mengintegrasikan PPK dalam rencana pembangunan daerah, dan membangun kemitraan publik-swasta untuk inovasi iklim.

***Kata kunci**: Ekonomi Hijau; Industri Pertambangan; Penangkapan dan Penyimpanan Karbon; Energi Terbarukan; Pengelolaan Sumber Daya Berkelanjutan.*

Abstract

This research explores the potential integration of Carbon Capture and Storage (CCS) technology in the mining sector of Dompu, West Nusa Tenggara, as part of a broader green economy transition. Using a qualitative case study approach, data were collected through interviews, policy analysis, and secondary statistical sources. The findings indicate that although CCS has not yet been implemented locally, it presents a significant opportunity to

reduce industrial emissions, especially when combined with renewable energy such as solar or geothermal. Economic modeling suggests that long-term cost efficiency is achievable through hybrid CCS-renewable systems, especially under supportive carbon pricing mechanisms. However, key challenges include limited geological assessments, regulatory gaps, high initial investment costs, and a lack of public awareness. The study concludes that CCS can serve as a strategic pathway for sustainable natural resource management in Dompu, provided that institutional, financial, and community-based frameworks are strengthened. Recommendations include initiating pilot projects, embedding CCS in regional development plans, and establishing public-private partnerships for climate innovation.
***Keywords**: Green Economy; Mining Industry; Carbon Capture and Storage; Renewable Energy; Sustainable Resource Management.*

INTRODUCTION

Indonesia as a country rich in natural resources has a mining sector as one of the main pillars driving the national economy. In areas such as Dompu, West Nusa Tenggara, mining activities not only contribute to the Gross Regional Domestic Product (GRDP), but also create jobs and encourage infrastructure development. However, intensive exploitation of natural resources has various ecological and social impacts, including environmental degradation, air pollution, and agrarian conflicts. In the context of the global climate crisis, the mining industry faces demands to transform towards more sustainable practices.

The concept of a green economy is one of the strategic approaches that can bridge economic growth and environmental preservation. In the mining sector, the application of green economy principles requires energy efficiency, measurable waste management, and significant reductions in carbon emissions (Ahleyani, 2025). One of the technological innovations that supports the decarbonization agenda in the mining sector is Carbon Capture and Storage (CCS), namely the process of capturing, transporting, and storing carbon dioxide (CO_2) from industrial activities so that it is not released into the atmosphere.

Table 1. Audiences for CCS cost estimates (Herzog, 2011)

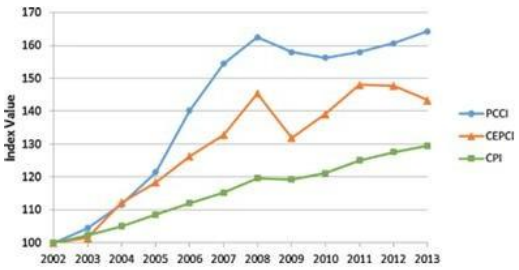
Government	Industry	NGOs
-Policymakers -Analysts -Regulators -R&D agencies	-Operators -Vendors -A&E firms -Venture capital -Tech developers -R&D organizations	-Environmental -Media -Academia -Foundations

CCS is considered a transitional solution in an effort to reduce carbon emissions from the extractive industry which is still very dependent on fossil fuels. In addition, CCS can be combined with the use of renewable energy as a simultaneous step towards a clean energy transition. In the Dompu region, which has geothermal and solar power potential, the integration of CCS with renewable energy opens up new opportunities to create a more environmentally friendly energy production system. This approach also supports Indonesia's target of achieving Net Zero Emission by 2060.

Although the potential for CCS application is quite promising, its implementation requires large investments, regulatory readiness, and fiscal policy support. Therefore, an in-depth economic study is needed to assess the feasibility and long-term impact of this technology on regional growth (Olsson, 2019). The combination of CCS and renewable energy in the mining sector is also expected to be able to create economic added value, such as energy diversification, long-term cost efficiency,

and increasing the reputation of mining companies as green industry players.

Figure 1. Cost indices normalized to 100 in year 2002

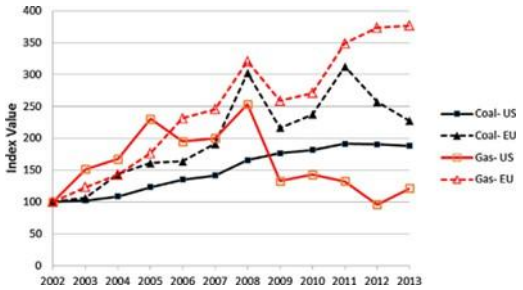


Sumber: (BLS, 2014)

This approach is not only important from a technical and environmental perspective, but also from a natural resource economic perspective. There needs to be a clear measurement of the contribution of low-carbon technology to the sustainability of the regional economy (Sovacool, 2014). The perspective of sustainable natural resource economics emphasizes the use of resources efficiently, fairly, and maintaining the carrying capacity of the ecosystem. Therefore, this study will assess how CCS technology can be part of the sustainability strategy of the mining industry in Dompu.

Previous studies have mostly discussed CCS in the global context or developed countries, while specific studies at the local level such as Dompu are still very limited. In fact, local potential and geological characteristics of the region greatly determine the success of CCS implementation. This study is expected to contribute to enriching the literature on the green economy in the mining sector with a region-based approach, as well as providing policy input for local governments and industry players.

Figure 2. Fuel cost indices for coal and natural gas used by power plants in the US and Europe, normalized to 100 in year 2002



Sumber: (IEA, 2014)

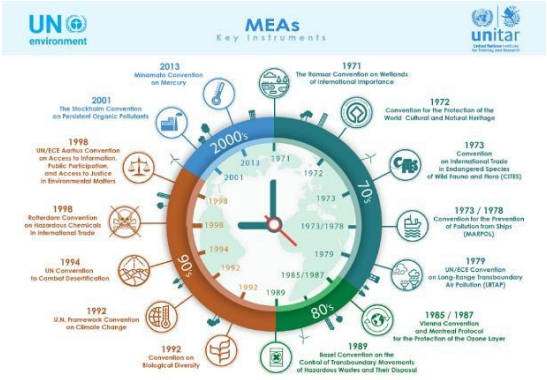
In the context of regional development planning, it is important for the Dompu government to make the energy transition and green economy part of the medium and long-term strategic development plan. In addition to environmental aspects, attention also needs to be paid to the social and economic aspects of the community around the mine. New technologies such as CCS must be ensured not to cause social exclusion or inequality in the distribution of benefits.

Therefore, this study will not only discuss the technical potential of CCS, but will also examine the economic, policy, and potential aspects of community empowerment through a green transition approach. Based on this background, this paper aims to explore the potential synergy of CCS in encouraging green economic transformation in the Dompu mining industry as a sustainable strategy in natural resource management.

The concept of a green economy was popularized by the United Nations Environment Programme (UNEP) as a development model that promotes human well-being and social equity while significantly reducing environmental risks and ecological scarcities. In the context of the mining sector, it emphasizes resource efficiency, clean energy use, and environmental

preservation. (Pearce, Markandya, and Barbier, 1989) conceptualized sustainable natural resource economics as intergenerational equity the principle that current resource use must not compromise the ability of future generations to meet their needs. For the mining industry, this entails ensuring resource exploitation is accompanied by effective rehabilitation and low-emission technologies.

Figure 3. UN Environment programme focus in the year



Studies by (Dasgupta and Mäler , 2004) highlight the importance of internalizing environmental costs in resource extraction to reflect true economic value. The failure to account for ecological degradation often leads to overexploitation and long-term economic loss. The implementation of green economy principles in mining is gaining traction globally. According to the International Council on Mining and Metals (ICMM, 2020), mining companies are increasingly adopting energy efficiency strategies, waste minimization, and biodiversity protection to align with Environmental, Social, and Governance (ESG) standards.

A key technological innovation supporting green mining is Carbon Capture and Storage (CCS), which involves capturing CO_2 emissions from industrial sources and storing them underground to prevent atmospheric release. CCS has been recognized as a transitional strategy to reduce emissions in carbon-intensive sectors. The Intergovernmental Panel on Climate Change (IPCC, 2022) asserts that CCS plays a crucial role in achieving net-zero targets, especially in sectors where emissions are hard to abate, such as mining, cement, and steel production. However, the economic feasibility of CCS remains a challenge, particularly in developing regions.

Research by (Rubin et al., 2015) examined the cost components of CCS, including capture, compression, transport, and storage, and found that cost reductions are possible through policy incentives, technology scaling, and regional infrastructure planning. The application of CCS in developing countries like Indonesia is still at an early stage. According to the (Ministry of Energy and Mineral Resources, 2023), pilot projects and feasibility studies are ongoing, with a focus on integrating CCS into existing fossil-based industries to support the national Net Zero Emission roadmap by 2060.

In regions such as Dompu, with abundant natural resources and geothermal potential, CCS can be synergized with renewable energy initiatives. This hybrid approach known as CCS-RE integration has been explored in studies like those by (Gibbins & Chalmers, 2008), showing its potential to accelerate decarbonization. From an economic standpoint, the integration of CCS into the mining sector must consider cost-benefit analysis, return on investment, and long-term operational sustainability (Zhang, 2022).

Moreover, adopting low-carbon technologies in mining can open access to green financing mechanisms, carbon credits, and ESG-oriented investments. According to the (World Bank, 2021), there is a growing pool of green finance for sustainable infrastructure and clean technology, which mining companies can tap into. Public-private partnerships (PPPs) are also crucial for enabling CCS

adoption. As suggested by (Olsson & Johansson, 2019), collaborative frameworks involving government, industry, and academia can reduce financial burdens and share technological risks.

Despite its promise, CCS faces skepticism related to its long-term storage reliability, environmental safety, and social acceptance. Studies like those by (Krause et al., 2011) emphasize the need for transparent stakeholder engagement and community inclusion in CCS planning. In the Indonesian context, regulatory frameworks to support CCS deployment are still under development. However, Presidential Regulation No. 98/2021 on carbon pricing and climate resilience provides a starting point for integrating CCS into national energy and resource policies.

Academic literature also stresses the importance of localizing CCS solutions to suit regional geologies, energy infrastructures, and economic capacities. Case studies from Norway, Canada, and Australia provide useful benchmarks for adapting CCS to Indonesian mining contexts. In summary, the synergy between CCS and green economy principles in the mining sector is well-supported by existing research, but requires contextual adaptation, inclusive policy support, and sustained investment to ensure its viability in regions like Dompu, NTB.

METHOD

This study adopts a qualitative descriptive approach with a case study design focusing on the mining industry in Dompu, West Nusa Tenggara (NTB), Indonesia. The objective is to analyze the potential application of CCS technology as part of a green economy strategy in a natural resource-rich region (Yulius, 2019). The rationale for using a case study method lies in its strength to explore complex phenomena within real-life contexts. The Dompu mining sector offers a representative case for examining the intersection of environmental innovation, economic sustainability, and regional development planning.

Figure 4. Dompu regency map

Data were collected through three primary methods: (1) in depth interviews with key stakeholders, (2) document analysis of policies and industry reports, and (3) secondary data review of regional economic statistics and emissions inventories. (Oktaviani, 2021) Semi-structured interviews were conducted with government officials from the Energy and Mineral Resources Office of NTB, environmental NGOs, mining company executives, and academic researchers working on sustainable energy and climate policy.

The interviews aimed to capture stakeholders' perceptions, institutional readiness, and strategic planning concerning CCS deployment and the transition to green mining practices in Dompu. Document analysis involved reviewing national and regional regulations, including Indonesia's Presidential Regulation No. 98/2021 on carbon economic value, the National Energy Grand Strategy (GSEN), and Dompu's Medium-Term Development Plan (RPJMD).

Industry data such as Environmental Impact Assessments (AMDAL), company sustainability reports, and emissions audits were also examined to assess the current environmental performance of local mining operations (Rejeki, 2018). For secondary data, we utilized datasets from the Central Bureau of Statistics (BPS),

the Ministry of Energy and Mineral Resources (ESDM), and international institutions like the IEA and World Bank to contextualize Dompu's emission trends and energy composition (Dasgupta, 2015).

Data triangulation was employed to ensure the validity and reliability of findings. This included cross-verifying interview data with official documents and statistical trends, as well as member-checking with selected informants. The analytical framework for this study integrates three perspectives: (1) technological readiness of CCS (based on IPCC and IEA frameworks), (2) economic viability (using simplified cost-benefit estimation and literature review), and (3) policy alignment (through a regulatory and institutional mapping).

The study applies thematic analysis to categorize data into recurring themes such as: policy gaps, financial challenges, community engagement, energy transition potential, and innovation adoption. To contextualize CCS within Dompu's development, geographic and geological assessments were also included, focusing on potential storage sites such as deep saline aquifers and depleted gas fields, based on national geological maps (Abadi, 2020).

The research also considers socio-political dynamics, including local acceptance of industrial innovation, environmental awareness among the population, and previous experiences with resource governance in the region (Gibbins, 2015). Ethical considerations were observed throughout the study. Consent was obtained from all interview participants, and sensitive data were anonymized. The study also adhered to local research protocols and academic ethical standards (Gunawan, 2021).

Limitations of this study include the relatively early stage of CCS development in Indonesia, limited access to proprietary industrial data, and evolving policy frameworks that may change post-study. Despite these limitations, the study offers grounded insights into how CCS could be integrated into green economic strategies in resource-dependent regions like Dompu, paving the way for further empirical and implementation-focused research (Zulkarnain, 2022).

RESULTS AND DISCUSSION

The findings reveal that the mining sector in Dompu is currently dominated by medium scale operations with high dependence on fossil fuel based energy, particularly diesel-powered machinery and logistics. As a result, emissions intensity remains significantly high per unit of mineral output. Interviews with mining companies indicate that while awareness of climate-related regulations is increasing, most operators lack technical knowledge and institutional support to adopt low-carbon technologies such as CCS. Only two out of seven companies surveyed had environmental innovation embedded in their strategic plans.

Figure 5. Implementing Energy Efficiency Management for Enviromental Protection at Hu'u Project Dompu Regency

A key enabler for green transformation is the existence of renewable energy resources in Dompu, especially solar and geothermal. However, the integration between mining operations and local renewable energy infrastructure remains minimal due to a lack of investment incentives and cross-

sector coordination (Atmadja, 2022). From a policy perspective, local governments in NTB have expressed strong commitment to sustainable development through RPJMD documents and environmental zoning, but CCS is not yet explicitly addressed in regional energy or industrial roadmaps. This indicates a policy vacuum for advanced climate technologies at the sub-national level.

Economically, preliminary cost modeling based on international CCS projects suggests that implementing CCS in Dompu would require an estimated investment of USD 70–100 per ton of CO_2 avoided. This cost is not feasible for most domestic companies without substantial subsidies or carbon pricing mechanisms. Nonetheless, economic modeling shows that combining CCS with renewable energy especially using solar PV for capture and compression processes can reduce operational costs over a 10-year period, especially if carbon trading or offset markets are introduced regionally.

Stakeholders identified several challenges: limited geological studies for CO_2 storage in Dompu, lack of pilot projects, absence of clear regulations on liability and monitoring, and the perceived risks of underground storage among local communities. Despite this, stakeholder interviews suggest a moderate-to-high level of social acceptance for green mining initiatives provided they are accompanied by clear communication, benefit sharing mechanisms, and community involvement in environmental oversight.

The analysis also identified opportunities for positioning Dompu as a testbed for green economy transition in resource-rich rural regions, especially through public-private partnerships. Local universities and vocational institutions could be engaged for capacity-building in CCS technologies and sustainability practices. International experience offers relevant benchmarks. For instance, Australia's Gorgon CCS project and Norway's Sleipner field demonstrate that CCS can be viable when supported by strong policy, clear liability frameworks, and multi-actor collaboration. These cases offer institutional lessons for Indonesia.

The research further discusses how CCS aligns with Indonesia's commitment under the Enhanced Nationally Determined Contributions (NDC), which aims to reduce emissions by 31.89% unconditionally and up to 43.2% with international support by 2030. Integrating CCS in Dompu's mining sector would not only support national climate targets but also stimulate green employment, promote technology transfer, and increase investor confidence in the region's extractive industries.

However, the success of this integration depends heavily on institutional coordination between national agencies (such as the Ministry of Energy and Mineral Resources), local governments, and industry actors to formulate a feasible regulatory and financing model.

The findings also highlight the need for regionally adapted CCS frameworks that consider local geologies, risk perceptions, and governance capacities. Standardized national guidelines must allow for local variation in implementation pathways.

In this context, a proposed transition pathway includes four strategic steps: (1) initiate geological feasibility studies; (2) integrate CCS into regional planning and environmental permitting; (3) develop fiscal incentives such as tax credits or carbon offset schemes; and (4) establish pilot projects with local monitoring systems. Overall, the research confirms that while technological and economic barriers to CCS adoption in Dompu exist, the long-term environmental and economic benefits justify serious consideration of CCS as a pillar in the region's green economy transformation strategy.

CONCLUSION

This study has examined the feasibility and strategic role of Carbon Capture and Storage (CCS) as a key instrument in accelerating the green economy transition in Dompu's mining sector. The findings highlight both the opportunities and challenges of aligning extractive industries with climate resilience goals. The research shows that although CCS remains underdeveloped in Indonesia, especially at the regional level, it holds substantial potential when synergized with Dompu's renewable energy landscape and green economy aspirations.

One major conclusion is that policy frameworks at both the national and regional levels must evolve to incorporate CCS not only as an emission reduction mechanism, but also as a tool for natural resource management and economic diversification. The case of Dompu illustrates that regional planning must be tailored to local contexts geological, economic, and institutional. A one-size-fits-all model of CCS adoption would likely fail without customization based on resource profiles and governance capacity.

CCS can become a long-term solution for reducing emissions from Dompu's mining sector, especially when paired with solar energy to reduce operational carbon footprints and energy costs during CO_2 compression and storage processes. However, the current lack of local geological assessments, pilot projects, and community awareness campaigns presents serious obstacles. These gaps must be addressed through coordinated, multi-stakeholder efforts involving government, academia, industry, and civil society.

An integrated transition framework is necessary one that begins with knowledge sharing and capacity building and progresses toward regulatory reform, technology investment, and adaptive financing models suited to local conditions. Dompu's local government has an opportunity to position itself as a pioneer of green transformation in rural mining regions. Such positioning could attract climate finance, improve investor confidence, and increase bargaining power in national policy dialogues.

From a macroeconomic perspective, incorporating CCS into regional industrial strategies aligns with Indonesia's Enhanced NDC targets and the global momentum toward decarbonization. This alignment may also yield international collaboration opportunities. The socio-political dimension cannot be overlooked. Local communities must be included not just as passive observers but as active stakeholders in shaping, monitoring, and benefiting from green innovation initiatives like CCS.

Institutions of higher learning in NTB should be encouraged to establish interdisciplinary research centers focused on sustainable mining, energy transitions, and low-carbon technology adoption thereby ensuring a steady pipeline of local expertise. The financial burden of CCS remains a key constraint. Therefore, policy instruments such as tax breaks, green bonds, or carbon offset schemes should be considered to create enabling conditions for investment.

It is recommended that a regional task force be established to oversee CCS feasibility, policy integration, and infrastructure development ensuring alignment with both the regional RPJMD and national green energy strategies. The

mining companies operating in Dompu are advised to begin baseline emissions assessments, improve environmental transparency, and explore technology partnerships that facilitate CCS and renewable energy integration.

Further research is needed to examine public perceptions of CCS in rural communities, long-term cost-benefit analysis in Indonesian settings, and institutional reform pathways for regional decarbonization strategies. In conclusion, while the road toward green transformation through CCS in Dompu is filled with technical, economic, and governance hurdles, it also presents a timely and strategic opportunity to redefine natural resource management toward sustainability, resilience, and shared prosperity.

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