

STRATEGIC BARRIERS TO GREEN INNOVATION ADOPTION IN MINING ENTERPRISES OF RESOURCE-BASED ECONOMIES

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Abstract: This thesis examines strategic barriers to green innovation adoption in mining enterprises of resource-based economies. The study focuses on the mining sector as a resource-intensive industry where environmental modernization is economically necessary but institutionally and technologically difficult to implement. Using the case logic of a large gold mining and metallurgical enterprise, the thesis identifies five major groups of barriers: capital intensity, technological inertia, energy and water dependence, organizational fragmentation, and delayed financial return. The findings suggest that green innovation adoption requires not only new equipment but also coordinated project management, digital monitoring, ESG-oriented governance and long-term investment planning.

Keywords: green innovation, mining enterprises, resource-based economies, strategic barriers, energy efficiency, ESG, technological modernization.

Introduction

Mining enterprises in resource-based economies face a difficult strategic dilemma. On the one hand, they remain central to national industrial development, export earnings, employment and regional economic stability. On the other hand, they are increasingly exposed to environmental pressure, energy constraints, water scarcity, carbon regulation, ESG requirements and global market expectations [1]. This creates a new management reality: mining companies must continue producing strategic mineral resources while reducing ecological damage, energy intensity and resource losses.

Green innovation appears to be the most promising response to this challenge. It includes energy-efficient equipment, renewable energy integration, closed-loop water systems, tailings recovery, automated environmental monitoring, digital production

control, low-carbon technologies and circular resource management¹. However, in practice, green innovation adoption in mining enterprises is not a simple technical transition. It is a complex strategic process influenced by capital requirements, old technological infrastructure, organizational culture, uncertainty of payback periods and external institutional pressure [2].

Resource-based economies often depend heavily on mining revenues. This dependence can create two opposite effects. First, it provides a strong motivation to modernize mining enterprises because their efficiency affects national economic stability. Second, it may slow down green innovation because enterprises are cautious about interrupting production, changing established processes or investing in technologies with delayed returns. Therefore, understanding the barriers to green innovation adoption is essential for designing effective industrial policy and enterprise-level modernization strategies.

The purpose of this thesis is to identify and analyze the main strategic barriers that restrict the adoption of green innovation in mining enterprises of resource-based economies. The study argues that these barriers are not only technological. They are financial, organizational, infrastructural and managerial. Green innovation succeeds only when these barriers are recognized as a system rather than as separate problems.

Theoretical Background

Green innovation in mining can be defined as the introduction of technologies and management solutions that reduce resource intensity and environmental pressure while increasing economic efficiency [3]. This definition is important because it connects ecological modernization with productivity. A green innovation is not simply a technology that reduces emissions. It is a technology or practice that changes the relationship between resource input, ecological impact and economic output².

In mining enterprises, green innovation adoption differs from other sectors because of three specific features. First, mining processes are capital-intensive. New technologies usually require large investment in equipment, infrastructure, digital systems and training. Second, mining operations are continuous and technologically interdependent. Changing one process can affect extraction, transportation, processing, energy use and waste management. Third, environmental risks in mining are long-term.

¹ In this thesis, green innovation refers to technologies and management practices that reduce environmental pressure while improving resource productivity and economic efficiency in mining enterprises.

² Resource input includes energy, water, raw materials, equipment capacity, land use and other production factors directly involved in mining operations.

Tailings, land disturbance, water use and emissions can create obligations that extend far beyond the production cycle [4].

For this reason, the adoption of green innovation should be analyzed as a strategic transformation process. It involves not only the purchase of new equipment, but also the redesign of production logic, investment planning, digital monitoring, ESG reporting and resource flow management. If these components are not coordinated, green innovation remains fragmented and produces limited economic impact [5].

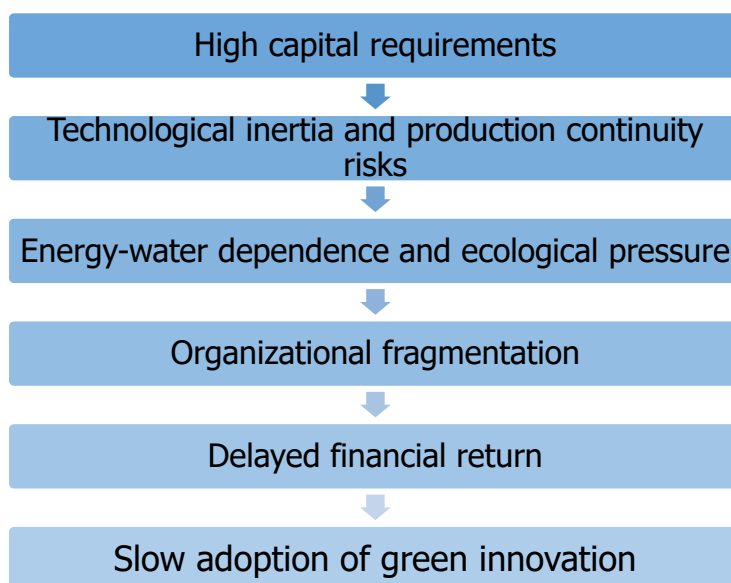


Figure 1. Strategic logic of green innovation barriers in mining

This figure shows that green innovation barriers form a chain. If high capital costs are not supported by long-term investment logic, technological modernization slows down. If technological change is not coordinated, production risks increase. If energy, water and waste systems are not integrated, ecological modernization remains partial. As a result, green innovation becomes slower, more expensive and less effective.

Main Strategic Barriers

The first barrier is **capital intensity**. Green innovation in mining often requires high initial investment. Energy-efficient mills, automated control systems, dust-gas cleaning equipment, water recycling systems, renewable energy facilities and digital monitoring platforms are expensive. For a large mining enterprise, modernization cannot be limited to one department or one machine. It usually requires system-level investment across multiple production stages [6].

This creates a financial challenge. Even when a green technology promises long-term savings, decision-makers may hesitate because the initial capital burden is high and the payback period is not always immediate. In resource-based economies, mining enterprises may also face competing investment priorities: capacity expansion, exploration, infrastructure, safety, export logistics and social obligations. As a result, green innovation can be postponed despite its long-term economic benefits.

The second barrier is **technological inertia**. Mining enterprises often operate with complex production chains that have been developed over many years. Existing equipment, maintenance routines, energy systems and production schedules are adapted to established technologies. Introducing green innovation may require changes in technical standards, staff skills, spare parts supply, maintenance planning and data systems. This creates resistance even when the technology itself is economically justified.

Technological inertia is especially visible in energy-intensive processes such as crushing, grinding, pumping, ventilation and metallurgical processing. These processes cannot be stopped easily. Any technological change must be carefully tested, integrated and stabilized. Therefore, the barrier is not only outdated equipment; it is the difficulty of changing a functioning industrial system without reducing production continuity³.

The third barrier is **energy and water dependence**. Mining enterprises consume large volumes of electricity, fuel and water. Energy costs may represent a significant share of production costs, while water use is often linked to regional ecological constraints [7]. In dry regions, water recycling and closed-loop systems become strategically necessary. However, implementing them requires infrastructure, monitoring and process redesign.

The problem is that energy and water efficiency projects are often treated separately. Energy departments focus on electricity and fuel, environmental departments focus on water and emissions, and production departments focus on output. If these systems are not integrated, resource-saving measures lose their strategic effect. Green innovation requires a unified view of energy, water, waste and production cost.

The fourth barrier is **organizational fragmentation**. In large mining enterprises, innovation projects involve many units: production, finance, ecology, technical services, digital systems, procurement, safety and strategic planning. If coordination is

³ Production continuity is especially important in mining because unplanned stoppages may increase unit cost, reduce ore processing efficiency and disrupt downstream metallurgical operations.

weak, green innovation becomes fragmented. One department may introduce an energy-saving measure, another may develop environmental monitoring, while another manages investment planning. Without a central coordination mechanism, these efforts do not become a unified transformation strategy [8].

This is why project management becomes important. A project management office or similar institutional mechanism can help select innovation projects, evaluate their economic and environmental impact, coordinate departments, monitor implementation and assess results. Without such a mechanism, even good projects may be delayed, duplicated or poorly evaluated.

The fifth barrier is **delayed financial return**. Green innovations often produce cumulative effects rather than immediate profit. For example, renewable energy may reduce energy costs gradually. Digital monitoring may first require investment and training before reducing losses. Water recycling may not immediately increase revenue but may reduce long-term risk. Tailings recovery may require testing before generating additional value [9].

This delayed return creates a perception problem. Managers may view green innovation as a cost rather than an investment. To overcome this barrier, enterprises need clear economic models that show how green technologies affect cost reduction, resource saving, production continuity, ESG performance and investment attractiveness. Without such models, green innovation remains vulnerable to short-term financial thinking.

Results and Analytical Interpretation

The analysis shows that barriers to green innovation adoption should not be interpreted separately. They interact with each other and form a strategic resistance system. For example, high investment cost becomes more serious when payback is delayed. Technological inertia becomes more dangerous when there is no digital monitoring. Organizational fragmentation becomes stronger when departments do not share common indicators. Therefore, overcoming the barriers requires a systemic management model.

Table 1. Strategic barriers and possible managerial responses

Strategic barrier	Practical manifestation	Managerial response
Capital intensity	High initial cost of green technologies	Long-term investment planning and phased implementation

Technological inertia	Difficulty of changing established production systems	Pilot testing and gradual scaling
Energy and water dependence	High resource intensity and regional constraints	Integrated energy-water-resource management
Organizational fragmentation	Weak coordination between departments	Project management office and cross-functional teams
Delayed financial return	Green innovation perceived as cost	Economic models showing savings, risk reduction and added value

The comparison demonstrates that green innovation requires a change in management philosophy. The enterprise must move from a “production-first” model to a “value-and-resource-efficiency” model. This does not mean reducing production. It means increasing production quality through lower energy intensity, lower water pressure, fewer interruptions and stronger ecological control.

Conclusion

Green innovation adoption in mining enterprises of resource-based economies is restricted by a system of strategic barriers. These barriers include high capital intensity, technological inertia, energy and water dependence, organizational fragmentation and delayed financial return. They are not separate problems; they reinforce each other and slow down the transition toward resource-efficient and environmentally responsible mining.

The main conclusion is that green innovation should be managed as a strategic transformation process. It requires financial planning, technological adaptation, digital monitoring, organizational coordination, ESG transparency and long-term economic evaluation. For mining enterprises, green innovation is not merely an ecological obligation. It is a path toward lower production costs, reduced resource risks, stronger investment attractiveness and long-term competitiveness.

Resource-based economies need mining enterprises that can produce not only more output but also more value with less resource pressure. This requires moving from traditional extraction logic to a green innovation model based on efficiency, circularity and strategic management. Such a transition is difficult, but it is becoming unavoidable in the context of global ESG standards, energy constraints and sustainable industrial development [12].

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