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GREEN TECHNOLOGICAL TRANSFORMATION AND RESOURCE PRODUCTIVITY IN A LARGE-SCALE GOLD MINING ENTERPRISE BASED ON EVIDENCE FROM UZBEKISTAN

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Abstract: This article examines green technological transformation and resource productivity in a large-scale gold mining enterprise based on evidence from Uzbekistan. Unlike traditional studies focused mainly on financial efficiency, the article analyzes how modernization, energy-saving technologies, localization, digital monitoring and renewable energy contribute to resource productivity. Using the case of Navoi Mining and Metallurgical Company, the study shows that green transformation is not merely an environmental obligation but a mechanism for reducing costs, increasing added value and strengthening industrial competitiveness.

Keywords: green transformation, resource productivity, gold mining, energy efficiency, localization, added value, Uzbekistan.

Annotatsiya: Maqolada O‘zbekiston tajribasi asosida yirik oltin qazib oluvchi korxonada yashil texnologik transformatsiya va resurs unumdorligi tadqiq etilgan. Tadqiqotda modernizatsiya, energiya tejamkor texnologiyalar, mahalliylashtirish, raqamli monitoring va qayta tiklanuvchi energiya resurs unumdorligiga qanday ta’sir qilishi tahlil qilingan. Navoiy KMK misolida yashil transformatsiya ekologik majburiyatgina emas, balki xarajatlarni kamaytirish, qo‘shilgan qiymatni oshirish va sanoat raqobatbardoshligini kuchaytirish mexanizmi ekani asoslangan.

Kalit so‘zlar: yashil transformatsiya, resurs unumdorligi, oltin qazib olish, energiya samaradorligi, mahalliylashtirish, qo‘shilgan qiymat, O‘zbekiston.

Аннотация: В статье исследуются зеленая технологическая трансформация и ресурсная производительность на примере крупного золотодобывающего предприятия Узбекистана. Анализируется влияние модернизации, энергосберегающих технологий, локализации, цифрового мониторинга и возобновляемой энергетики на ресурсную производительность. На примере Навоийского ГМК обосновано, что зеленая трансформация является не только экологическим обязательством, но и механизмом снижения затрат, роста добавленной стоимости и укрепления промышленной конкурентоспособности.

Ключевые слова: зеленая трансформация, ресурсная производительность, золотодобыча, энергоэффективность, локализация, добавленная стоимость, Узбекистан.

Introduction

Large-scale gold mining enterprises are under increasing pressure to combine production growth with lower resource intensity. Gold mining remains one of the most economically valuable segments of the global mining industry, but it is also associated with high energy consumption, significant water use, large-scale processing infrastructure and long-term environmental liabilities. In this context, the central question is no longer whether mining enterprises can increase output, but whether they can create more value with fewer resources, less downtime and lower ecological pressure.

The case of Uzbekistan is important because mining and metallurgy play a strategic role in national industrial development. Navoi Mining and Metallurgical Company is one of the country's key industrial enterprises and provides a useful example of how green technological transformation can be linked with resource productivity.[1] The company's scale, production complexity and modernization trajectory make it possible to observe how technological renewal affects energy saving, added value, localization and environmental management. The dissertation materials emphasize that NMMC's resource efficiency has direct implications for national industrial stability and that its production scale creates a unique platform for evaluating the practical outcomes of green transformation .[2]

In many mining enterprises, green transformation is still interpreted as an environmental compliance agenda. However, this article argues that it should be understood as an industrial productivity agenda. Energy-saving technologies, modernized mills, renewable energy, localization of spare parts, automated environmental monitoring and digital control systems affect the economic structure of production. They reduce unnecessary losses, improve equipment availability, lower dependence on imported components, stabilize production schedules and increase value added.

The purpose of this article is to analyze how green technological transformation influences resource productivity in a large-scale gold mining enterprise.[3] The study does not repeat the integrated green efficiency indicator methodology discussed in the previous article. Instead, it focuses on the transformation channels through which green technologies become economically productive. The main research question is: how does green technological transformation convert resource saving into measurable industrial competitiveness?

Literature Review

The relationship between technological change and productivity has long been central to economic theory. Schumpeter viewed innovation as a force that transforms production systems and creates new combinations of resources, technologies and organizational methods [1]. In the mining industry, this idea is particularly relevant because productivity growth depends not only on labor and capital but also on the ability to extract, process and convert mineral resources more efficiently.

Drucker interpreted innovation as a disciplined management process rather than a random technological event [2]. From this perspective, green transformation in mining should not be treated as a set of isolated environmental projects. It should be managed as a strategic portfolio of technological and organizational changes. A solar power unit, a digital monitoring platform, a

[1] In this article, "green technological transformation" refers to the modernization of mining production through energy-saving equipment, renewable energy, digital monitoring, localization and environmental control systems.
[2] Navoi Mining and Metallurgical Company is selected as a case because it is one of Uzbekistan's largest industrial enterprises and a major gold mining and metallurgical producer.
[3] "Resource productivity" is interpreted as the ability of the enterprise to create greater economic value from a given volume of energy, material, technological and natural resource inputs.

modernized grinding mill or a localization program becomes innovative only when it changes the economic behavior of the enterprise.

Porter and van der Linde argued that environmental requirements can stimulate innovation and strengthen competitiveness [3]. This idea is especially applicable to mining. Energy-saving technologies, water circulation systems and waste reduction tools may initially require investment, but they can later reduce operating costs and increase resource productivity. Thus, environmental modernization can become an economic advantage rather than a burden.

The OECD green growth framework emphasizes that industrial development should be decoupled from excessive resource use and environmental degradation [4]. For mining enterprises, this means increasing output or value added without proportional growth in energy, water and material consumption. In this sense, resource productivity becomes a core indicator of industrial modernization.

The World Bank's climate-smart mining concept also highlights the need to produce minerals in ways that support the energy transition while reducing environmental and social risks [5]. This is highly relevant for gold mining enterprises because even though gold is not always discussed as a critical mineral in the same way as lithium or cobalt, gold mining companies face similar sustainability expectations from investors, regulators and global markets.

Circular economy literature adds another layer to this discussion. Stahel's approach stresses that value should be retained within the economic system through repair, reuse, remanufacturing and resource recovery [6]. In mining, this logic can be applied to tailings, technological residues, spare parts, water circulation and equipment life-cycle management.

Recent ESG frameworks show that mining companies increasingly need to demonstrate measurable progress in environmental performance, governance transparency and resource efficiency [7]. For large-scale gold producers, such indicators are not only reputational. They influence access to investment, green finance, international partnerships and long-term market positioning.

Methodology

This article uses a qualitative-analytical case study approach supported by dynamic interpretation of selected quantitative results. The case study method is appropriate because green technological transformation in mining is a complex process involving technology, management, finance, energy, environment and localization. It cannot be explained by one variable alone.[4]

The methodological framework is based on four transformation channels:

[4] The adaptation stage means that newly installed technologies require time to become fully integrated into maintenance, monitoring and production routines.

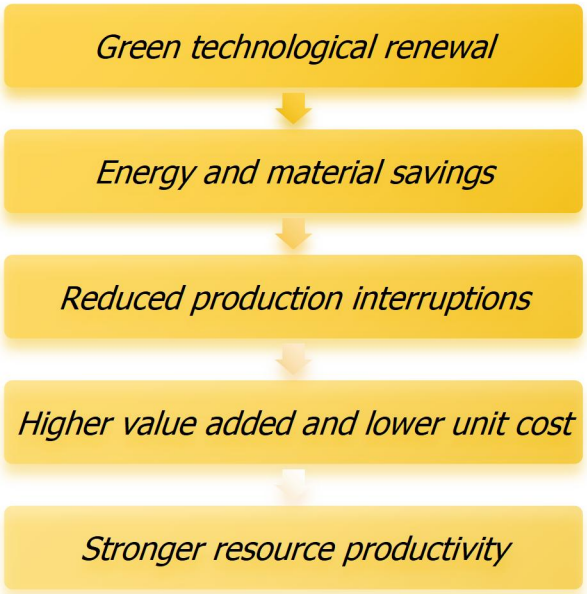


Figure 1. Transformation channels from green technology to resource productivity

The first channel is energy productivity. This refers to the ability of the enterprise to generate more output or value with lower electricity and fuel consumption. The second channel is technological reliability. Modernized equipment reduces downtime and improves production continuity. The third channel is localization. Domestic production of spare parts and components reduces import dependence and foreign currency outflow. The fourth channel is environmental and digital control. Monitoring systems reduce ecological risk and support data-based decision-making.

The article relies on the following analytical categories:

Table 1. Analytical categories of green technological transformation

Category	Meaning in a mining enterprise	Expected productivity effect
Energy-saving modernization	Replacement or upgrade of energy-intensive equipment	Lower unit cost and higher energy productivity
Renewable energy integration	Use of solar and other low-carbon energy sources	Reduced grid dependence and stable long-term energy costs
Localization	Domestic production of spare parts and components	Lower import dependence and stronger supply resilience
Digital monitoring	Real-time control of equipment, energy and ecological parameters	Lower downtime and faster corrective decisions
Environmental control	Dust-gas systems, CO_2 monitoring and ecological stations	Lower ecological risk and better ESG readiness

The analysis is based on selected data from the dissertation materials, including modernization effects, energy savings, added value dynamics, localization results and 2025 green economy measures for NMMC.

Results

The results show that green technological transformation in NMMC developed through several interconnected stages. The first stage was adaptation. During 2021–2022, the number of

modernized blocks increased to 26, but the reduction in technical stoppages remained limited to 25 percent. This suggests that modernization initially created quantitative technological capacity, while full productivity effects required adaptation of maintenance standards, digital monitoring and technological control systems .

The second stage was financial realization. During 2022–2023, energy savings increased by 6.5 percent and generated 2.2 million US dollars in foreign currency savings. This was linked to new-generation mills that consumed less energy, had a higher grinding coefficient and longer service life. The localization of spare parts at the Navoi Machine-Building Plant reduced import costs and strengthened the economic security role of the enterprise .

The third stage was operational stabilization. During 2023–2024, technical stoppages decreased by 35 percent. This indicates that production processes became more continuous and predictable. Energy savings reached 7.5 percent, which contributed to lower production costs and increased the competitiveness of gold output in global markets .

The fourth stage was technological independence. During 2024–2025, the reduction of foreign currency savings to zero in some modernization segments was interpreted not as a decline in efficiency, but as a sign that major mills, spare parts and core components were increasingly produced locally. This indicates a transition from import substitution to technological self-sufficiency .[5]

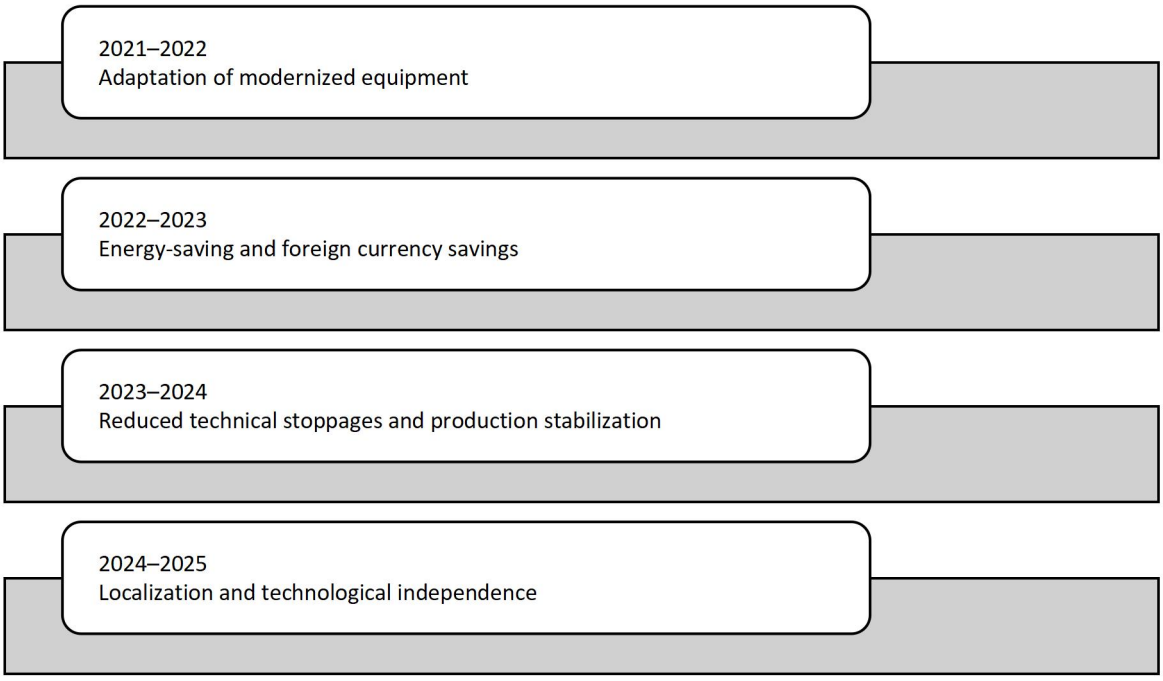


Figure 2. Stages of green technological transformation in NMMC

The added value dynamics provide another important result. According to the dissertation materials, the company's value added increased from 38.5 trillion UZS in 2020 to 63.5 trillion UZS in 2025, which represents an increase of almost 65 percent. This growth was not explained only by higher production volume, but also by resource-saving technologies, energy efficiency and deeper

[5] Localization is treated not only as import substitution but also as a productivity factor because it reduces downtime, foreign currency exposure and supply-chain vulnerability.e

processing. The materials note that the acceleration in 2022–2025 indicates that modernization and green transformation started to generate visible economic effects .

Table 2. Transformation effects observed in NMMC

Transformation area	Observed result	Economic interpretation
Modernized processing blocks	26 blocks by 2021–2022	Capacity expansion required adaptation before full effect
Technical stoppages	25% reduction, later 35% reduction	Higher continuity and better production planning
Energy saving	6.5%, later 7.5%	Lower unit cost and stronger global competitiveness
Foreign currency saving	2.2 million USD during 2022–2023	Lower import dependence and stronger economic security
Added value	38.5 trillion UZS to 63.5 trillion UZS	Resource productivity and deeper processing improved
Localization	349.8 billion UZS in localized products in Q1 2025	Import substitution and domestic industrial linkage strengthened

Discussion

The NMMC case demonstrates that green technological transformation should be understood as a structural change in the production model. The enterprise did not simply introduce separate "green" measures. Instead, modernization gradually affected energy costs, technical reliability, import dependence, added value and environmental readiness.

A key implication is that resource productivity in gold mining is not determined only by ore quality or production volume. It is shaped by the technological system that converts mineral resources into economic value. If equipment is outdated, energy-intensive and frequently interrupted, resource productivity remains low even when production volume is high. If equipment is modern, digitally monitored and supported by localized components, the same resource base can generate greater economic value.

The adaptation phase is particularly important. The 2021–2022 experience shows that modernization does not immediately produce maximum results. New equipment, maintenance routines and digital control systems require time to become fully integrated. This is common in large-scale mining enterprises, where technological change affects multiple departments at once. Therefore, productivity analysis should distinguish between the installation of technology and the operational assimilation of technology.

Conclusion

This article examined green technological transformation and resource productivity in a large-scale gold mining enterprise based on evidence from Uzbekistan. The findings show that green transformation in NMMC developed through adaptation, financial realization, operational stabilization and technological independence.

The study shows that modernization of processing equipment, energy-saving technologies, localization of components, digital monitoring, environmental control and renewable energy integration together formed a productivity-enhancing mechanism. Added value increased from 38.5

trillion UZS in 2020 to 63.5 trillion UZS in 2025, while energy saving, reduced technical stoppages and localization strengthened the company's industrial competitiveness.

The main conclusion is that green transformation in gold mining should not be viewed as an external environmental requirement. It is an internal productivity strategy. A large-scale mining enterprise becomes more competitive when it creates higher value with lower energy intensity, fewer technical interruptions, reduced import dependence and stronger environmental control. The NMMC case demonstrates that green technological transformation can become a practical mechanism for improving resource productivity in resource-rich economies.

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