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THE ISSUE OF GREEN ENERGY AND RARE METALS: HEADING TOWARDS A NEW ECOLOGICAL CRISIS

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Abstract:

This article analyzes the new environmental and social challenges arising from the dependence of renewable energy technologies on rare earth elements. In the process of achieving decarbonization goals, the demand for strategic raw materials such as lithium, cobalt, nickel and rare earth elements is increasing sharply. However, the extraction and processing of these metals has environmentally disastrous consequences and is creating a new imbalance between developing countries located in the mining areas and developed countries, which are the centers of consumption. The study analyzes the material flows of green energy based on the theoretical concepts of "ecologically unequal exchange" and "inter-societal just transition". The article highlights China's monopoly position in the rare earth metals market, social tragedies associated with cobalt mining in the Congo, and the prospects for the development of processing technologies. The author argues that in order to avoid environmental injustice in the process of implementing a "green economy", the author argues that it is necessary to close the material cycle, introduce geographical diversification and international fair trade mechanisms.

Keywords: green energy, rare earth elements, environmental injustice, just transition, cobalt, lithium, global inequality, recycling, raw material independence, ecologically unequal exchange.

INTRODUCTION

The transition to renewable energy sources is the most important agenda today in order to combat global climate change and reduce carbon emissions. According to the International Energy Agency, the volume of renewable energy technologies must increase several times to achieve carbon neutrality by 2050. However, this "green transition" has its own dark side: modern energy technologies are overly dependent on rare metals and mineral raw materials. Materials such as lithium, cobalt, nickel and rare earth elements (REE) are needed to produce solar panels, wind turbines and electric vehicle batteries. For example, one electric vehicle uses about 1 kg of rare earth elements, and a wind turbine uses up to 600 kg of rare earth magnets. The demand for these materials is expected to double by 2030.

But the problem is that the process of extracting and processing these metals itself has serious environmental and social consequences. This process, carried out under the guise of "green" energy, is causing environmental destruction and human rights violations in many regions. In addition, the geographical distribution of rare metals is extremely uneven, with mining mainly in developing countries, while consumption and industrial production are concentrated in developed countries. The purpose of this article is to reveal the connection between green energy and rare metals mining, analyze the issues of global inequality and environmental injustice that arise in this process, and consider ways to eliminate existing imbalances.

LITERATURE REVIEW AND THEORETICAL BACKGROUND

In recent years, the concept of "Just Transition Minerals" has emerged in the scientific literature. This term refers to essential raw materials that are essential for building decarbonization infrastructure, but which pose complex socio-ecological challenges. The concept emerged from the convergence of two important social movements: the labor movement's demand for fair working conditions and the environmental justice movement's concern that environmental burdens should not be shifted to disadvantaged communities. The core idea of the Just Transition Minerals concept is that material flows in the path to climate sustainability should not become sources of new global inequalities. This requires a rethinking not only of the impact of

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extractive industries on local communities, but also of power relations in global supply chains.

The theory of "ecological unequal exchange" developed by Tanguy Bonnet (2025) is important in analyzing the imbalance between core and periphery countries. According to this theory, countries in the periphery (mainly developing countries) bear the heavy socio-ecological costs associated with mining activities, resulting in a disproportionate flow of materials to the rich core countries through global trade flows. In Bonnet's study, China is analyzed as a semi-periphery and the United States as a core country. China has occupied the upper stages of the rare earth value chain by controlling not only production but also processing capacities. This creates a more complex relationship than the traditional core-periphery model. Dana Abuzinadah (2025) draws on Wallerstein's world systems theory to show that the trade in rare earth metals exacerbates global wealth inequality. The researcher believes that countries with mineral wealth can be pushed to the periphery of economic, social and technological development by countries with high geopolitical influence. The author identified patterns of power and weakness in mineral trade through cluster analysis and proposed a more complex classification against the traditional binary model of "winners and losers".

The rare earth industry has undergone dramatic changes over the past three decades. In the 1990s, the United States was one of the leading producers, relying on the Mountain Pass mine in California. However, after an environmental scandal and lawsuits over a wastewater leak in 1997, domestic production declined sharply, creating the conditions for rapid growth in China. China has increased its production from about 31,000 tons in 1994 to 270,000 tons by 2024. Today, China controls not only mining, but also about 90 percent of the world's rare earth metals. China accounted for 70 percent of U.S. rare earth imports in 2020-2023. This article is a qualitative study based on analysis of secondary sources. The following methods were used in the study:

1. Content analysis – study of reports of international organizations, scientific journals and materials published in the media;
2. Comparative analysis – comparison of rare earth mining practices in different regions and countries, their environmental and social impacts;
3. Systematic analysis – study of material flows, power relations and resource allocation along the rare earth value chain;
4. Statistical data analysis – processing of data from the United States Geological Survey (USGS), the International Energy Agency and other sources.
5. The theoretical basis of the study is the concepts of ecological economics, world systems theory and environmental justice.

RESULTS AND DISCUSSION

Rare earth elements (REEs) are 17 elements in the periodic table, consisting of the lanthanide series (15 elements) and yttrium and scandium. Despite their name, they are actually relatively common in the Earth's crust, but rarely occur in economically exploitable concentrations. The geographic concentration of rare earth metals is extremely high. This creates vulnerabilities in supply chains. In particular, China's monopoly position in the processing of rare earth metals is a geopolitically important factor. China's export restrictions against Japan in 2010 and the restrictions on the export of gallium and germanium in 2023 demonstrate the strategic importance of these raw materials. Renewable energy technologies require more materials than conventional energy. According to the International Energy Agency, electric vehicles require six times more mineral resources than conventional cars. Wind power, on the other hand, requires nine times more materials than gas-fired power plants.

Electric vehicle batteries require lithium, cobalt, nickel and manganese. Lithium-ion batteries require high concentrations of lithium, cobalt and nickel, which makes the transition to a more environmentally friendly form of energy. Permanent magnets for wind turbines rely on rare earth elements such as neodymium and dysprosium. Solar panels require materials such as silicon, silver and tellurium. Demand for rare earth metals is expected to double by 2030, requiring a dramatic expansion of existing mining capacity. The process of extracting and processing rare earth metals is extremely environmentally damaging. The production of one ton of rare earth metals produces twice as much toxic waste. Some of these emissions contain gases that accelerate global warming, while volatile particles from the production process cause various permanent harm to humans, animals, and plants.

In the case of ion-adsorption rare earth metal mines in southern China, mining operations have led to deforestation, soil erosion, and water pollution. Heavy metal pollution in these areas is causing chronic kidney disease and other health problems. Similar problems are being observed in rare earth metal mining areas in Myanmar's Kachin State. According to a report by EarthRights International, mining activities in this region

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are causing widespread environmental degradation and human rights abuses. Cobalt mining in the Democratic Republic of the Congo is one of the most striking examples. According to UNICEF data from 2022, 40,000 child laborers are employed in cobalt mines in Congo alone. While the battery life of phones and computers depends on cobalt, we rarely think about the harsh working conditions of these children.

Photographer Sebastiano Salgado's photographs of the Serra Pelada gold mine in Brazil in the 1980s vividly illustrate this situation: "Thousands of children, mostly young men, with flesh the color of dirt, working the rocks and stones like giant ants, literally working themselves to death." These images are being replicated today in Congo and other countries. This phenomenon, known as "green colonialism," shows that the ecological transition of developed countries is being achieved at the expense of the ecological and social destruction of developing countries. Cheap labor, lax environmental requirements, and weak legal protections attract transnational companies to these very regions. China's position in the rare earth metals market is not only economic but also geopolitical. The country has dominated the NTE market since the 1980s. The export restrictions it imposed on Japan in 2010 have clearly demonstrated the world's dependence on these elements.

The main advantage of China's strategy is that it controls not only mining, but also processing capacity. The separation and purification of rare metals is a complex and capital-intensive process, and China has built up huge capacities in this area in recent decades. Today, about 90 percent of the world's rare metal processing capacity is located in China. The United States and the European Union are developing various strategies to reduce dependence on China. The United States is investing in the restoration of production at the Mountain Pass mine in California - by 2024, production was increased to 46 thousand tons. The European Union, having adopted the Critical Raw Materials Act, aims to cover 10 percent of strategic raw materials by domestic extraction and 40 percent by processing by 2030. However, the effectiveness of these strategies is limited, since the development of new mines and the construction of processing capacities takes decades. However, these efforts cannot completely eliminate the shortage of rare metals. One of the most promising ways to solve the problem of rare metals is the transition to a circular economy. The so-called "urban mining" method allows the recovery of precious metals from consumer products. For example, used batteries, electronic waste and old wind turbines can be considered as "secondary ore sources".

Currently, the recycling rate of rare metals is very low - less than 1 percent. The main reason for this is the complexity and economic inefficiency of processing technologies. However, with the development of technologies and the increase in the price of primary raw materials, recycling is becoming economically feasible. Expanding the geography of rare metal mining and processing is an important measure against the Chinese monopoly. Projects for the development of new deposits are being developed in Australia, the USA, Canada and various countries in Africa. In particular, the Australian corporation Lynas is gaining importance as the largest producer of rare metals outside China. However, the diversification process takes a long time and requires significant investments. At the same time, it is important to keep the environmental and social impacts of new mines to a minimum.

International mechanisms are needed to regulate trade in rare earth metals and ensure fair distribution. "Mandatory due diligence legislation" is an important first step to ensure that materials are sourced without conflict financing or harsh labor practices. According to the "ecologically unequal exchange" theory, peripheral countries bear the social and environmental costs of mining activities, resulting in global trade flows that allow materials to flow disproportionately towards rich core countries. International fair trade mechanisms, technology transfer and environmental compensation funds are proposed to address this imbalance. Scientific research is developing new technologies that can reduce the need for rare earth metals. For example, sodium-ion batteries are being developed as an alternative to lithium-ion batteries. Solid-state batteries could significantly reduce the need for cobalt. Research is also underway to reduce the proportion of rare earth elements in magnets or replace them with other materials. However, commercial implementation of these innovations will require much more time and investment.

SUMMARY

The transition to green energy is crucial in the fight against climate change, but this process itself is creating new environmental and social problems. The sharp increase in demand for rare earth metals, their uneven geographical distribution and the severe environmental consequences of mining are deepening global inequality and environmental injustice. The results of the study show that the current "green transition" model mainly serves the interests of developed countries, while the environmental and social

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costs are borne by developing countries. China's monopoly position in the rare earth metals market, child labor in the Congo, and environmental disasters in mining areas - all these are the dark sides of the "green economy".

To overcome these problems, an integrated approach is needed:

1. Development of the circular economy - creation of a secondary resource base through the recycling of post-consumer products;
2. Geographic diversification - expansion of rare metal mining and processing areas, creating a balance against the Chinese monopoly;
3. International fair trade mechanisms - protection of the interests of communities in mining areas and introduction of an environmental compensation system;
4. Technological innovation - development of new technologies that reduce the need for rare metals;
5. Mandatory due diligence - monitoring compliance with human rights and environmental standards in supply chains.

The main idea of the concept of "Just Transition" is that efforts to achieve climate sustainability should not become a source of new global inequalities. Green energy should be a means not only of reducing carbon emissions, but also of ensuring social justice. This can only be achieved through a fundamentally new philosophy of managing material flows – an environmentally responsible, socially just and geopolitically balanced approach. Future research should focus on the economic viability of rare earth metal processing technologies, the potential of "urban mining" and the legal framework for international fair trade mechanisms. It is also important to develop inclusive governance models that take into account the needs and interests of local communities in mining areas.

The transition to renewable energy sources has become one of the most important agendas today in order to combat global climate change and reduce carbon emissions. According to the International Energy Agency, the deployment of renewable energy technologies must increase several times to achieve carbon neutrality by 2050. However, this "green transition" has its own dark side: modern energy technologies are overly dependent on rare metals and mineral raw materials. Materials such as lithium, cobalt, nickel and rare earth elements are needed to produce solar panels, wind turbines and electric vehicle batteries. The demand for these materials is expected to double by 2030. The process of mining and processing rare metals has serious environmental and social consequences. The production of one ton of rare metals produces twice as much toxic waste. This process, carried out under the guise of "green" energy, is causing environmental destruction and human rights violations in many regions. The most striking example is cobalt mining in the Democratic Republic of Congo. According to 2022 UNICEF data, 40,000 child laborers are employed in cobalt mines in Congo alone. Cobalt, which is needed to produce batteries for phones and electric vehicles, is mined under harsh working conditions.

In addition, the geographical distribution of rare earth metals is extremely uneven, with mining concentrated mainly in developing countries, while consumption and industrial production are concentrated in developed countries. China controls not only mining, but also about 90 percent of the world's processed rare earth metals. In 2020-2023, China accounted for 70 percent of US rare earth imports. The process of mining and processing rare earth metals is extremely environmentally harmful. In the case of ion-adsorption rare earth metal deposits in southern China, the mining processes have led to deforestation, soil erosion, and pollution of water sources. Heavy metal pollution in these areas is causing chronic kidney disease and other health problems.

Similar problems are observed in rare earth mining areas in Kachin State, Myanmar. According to a report by EarthRights International, mining activities in this region are causing widespread environmental degradation and human rights abuses. This phenomenon, known as "green colonialism," shows that the ecological transition of developed countries is being achieved at the expense of environmental and social destruction in developing countries. Cheap labor, lax environmental requirements, and weak legal protections attract transnational companies to these regions. One of the most promising ways to solve the problem of rare metals is to move to a circular economy. A method called "urban mining" can recover precious metals from post-consumer products. For example, used batteries, electronic waste, and old wind turbines can be considered "secondary ore sources." Currently, the recycling rate of rare metals is very low – less than 1 percent. The main reason for this is the complexity and economic inefficiency of processing technologies. However, with the development of technologies and the increase in prices of primary raw materials, recycling is becoming economically feasible.

Expanding the geography of rare earth mining and processing is an important measure against the Chinese monopoly. New mine development projects are

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being developed in Australia, the United States, Canada and various countries in Africa. The United States is investing in the restoration of production at the Mountain Pass mine in California - by 2024, production will reach 46 thousand tons. The European Union, having adopted the Critical Raw Materials Act, aims to cover 10% of strategic raw materials with domestic extraction and 40% with processing by 2030. However, the effectiveness of these strategies is limited, as it takes decades to develop new mines and build processing capacities. International mechanisms need to be created to regulate the trade in rare earth metals and ensure fair distribution. "Mandatory due diligence legislation" is an important first step in ensuring that materials are sourced without conflict financing or heavy labor violations. According to the theory of "ecological unequal exchange", peripheral countries bear the socio-ecological costs of extractive activities, resulting in global trade flows that allow materials to flow disproportionately towards rich central countries. To address this imbalance, it is proposed to create international fair trade mechanisms, technology transfer, and environmental compensation funds.

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