The Harmful Effects of Rare-Earth Mining: A Case Study of the Bayan Obo Rare-Earth Mine

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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STS Research Question

The Harmful Effects of Rare-Earth Mining: A Case Study of the Bayan Obo Rare-Earth Mine: *How does the Bayan Obo rare-earth mine impact its surrounding communities and environment?*

I. Introduction

As the world shifts towards electrification in the name of sustainability, it is important for this shift to be done in a way that truly protects the environment and improves upon the current technology. While innovations in electrification, such as battery technology and renewable energy, have solved many problems, there is still one that remains unsolved and continually exacerbated: the increasing demand for pollution-heavy rare-earth metals. A few notable industries rely heavily on the metals in pursuit of electrification, including electric cars, large turbines, and defense applications (ANI News, 2023; International Energy Agency, 2022; Turra, 2018). Accordingly, the rare-earth industry is estimated to see large growth between now and 2030 (P&S Intelligence, 2022).

It is important to understand where these metals come from, in order to understand the problem and its context. China's Bayan Obo mine accounts for 35% of the world's total rare-earth production (Bai et al., 2022; U.S. Department of the Interior, 2023). As Bayan Obo is world's preeminent mine, it is the worthy target of the case study conducted by this paper. This study asks the question "How does the Bayan Obo rare-earth mine impact its surrounding communities and environment?"

II. Background & Context

Significant deposits of iron and rare-earth elements were discovered in the Inner Mongolia region of China in 1927 and 1935, respectively (NS Energy, 2020). The rare-earth mine first became active in 1957. When mining began in Bayan Obo, the area was a vast and fertile farming region (Bontron, 2012). Contaminated by mining waste and chemicals, the land has been left derelict and desolate. The population is unable to farm there anymore due to the impacts on the land, and many suffer from significant, health problems. This is due to the long history of the mine. , since mining has been going on there for so long, and went on while China was underdeveloped and developing, mining continued mostly unregulated and unmitigated for a significant part of the history of the Bayan Obo mine.

Rather than taking the contamination at its word, it is helpful to understand the basics of the mining process. There are two primary processes that are used to mine rare-earths. The first involves removing layers of soil and transporting them to a leaching pond (Standaert, 2019). A leaching pond is a manmade pond where acids and chemicals are used to separate the valuable metals from clay, rock, and dirt. The second process requires inserting polyvinyl chloride (PVC) pipes into the ground, and shooting a mixture of water and acidic chemicals into it, and flushing out a slurry of the rare-earth metals, water, dirt, acid, and other chemicals, which is then also transported to a leaching pond. Injecting these chemicals into the ground, without using any sort of containment, poisons the soil for future use, and contaminates the groundwater substantially.

China has become a significant provider of rare-earth metals due to their low regulations. Their low regulations have allowed them to sell their metals for comparatively cheap, and have put many cleaner and more ethical mining operations out of business. Many operations went out of business in the United States in the late 1980s and early 1990s because they could no longer compete and turn a profit (Turra, 2018). This essentially allowed China to monopolize the rare-earth industry for a significant period of time, and one that could be argued they still maintain.

There are many vested actors and actants in this complicated problem network. First and foremost, the local peoples and their communities have a great stake, as these problems affected their land and caused great loss and harm for themselves and their communities. Second, mining companies have a stake, in having a responsibility to remediate the land, a necessity to provide these strategic resources and meet quotas, and maximize their profits. The Chinese government has a responsibility to ensure that their country has such strategic resources, but also to ensure the wellbeing of its citizens and the ethicality of their corporations. Governments of the world have a significant stake in Chinese rare-earth mining, as much of the world purchases rare-earth metals from China. For example, the EU imported approximately 98% of its rare earth metals from China in 2021 (Chatterjee, 2023). Due to the strategic and infrastructural applications of rare-earth elements, countries have a national security interest in maintaining a supply chain of rare earth metals. For example, China cut off supply of rare-earth metals to Japan for 40 days, due to a territorial dispute in 2010 (Bradsher, 2010). International governing bodies also have a stake in China's mining operations. The World Trade Organization (WTO) has intervened in the past when China has attempted to restrict exports of their product, which China has argued was used to lower production and lessen environmental impacts (Lee & Wen, 2017).

III. Methods

This paper will conduct a case study on the Bayan Obo rare-earth mine in Bayan Obo, China. Sources for this case study have been gathered from many different angles of the system.

First, case studies, specifically of a statistical nature, have been conducted before on the Bayan Obo mine. Finding those studies and borrowing from their points and statistical analyses has been especially helpful. What these case studies often lack, though, is an understanding of the broader sociotechnical system that the mine exists in, and how expansive these problems are in the world. These issues have been supplemented in many ways, both by data and analysis. All analysis and data is cited from peer-reviewed studies conducted in the region, and on rare-earth mines generally. In regards to data, many sources have been used that reflect further the severity of the problems. Examples of this include studies of the health of the locals, such as a urine and drinking water study conducted by Liang et. al. and a bone density study conducted by Liu et. al. Information on the process of rare earth mining, how harmful it is, and how it pollutes the surrounding environment, were also found, in order to paint an accurate picture of the problem at hand. In this vein, many environmental studies were sought to quantitatively prove that the problem exists. Supporting information, such as the US Geological Survey's *Mineral Commodity* Summary, and the *Nomenclature of Inorganic Chemistry* by the International Union of Pure and Applied Chemistry (IUPAC) have also been helpful in learning about the industry. Overall, statistical studies and data, and their analyses, have been especially beneficial to the conducting of this case study.

In order to dive a bit deeper into the sociotechnical problems, various other types of sources were sought. A couple of interviews conducted by The Guardian have also been particularly insightful. The locals who have lived with the harmful effects for tens of years provide insights and share personal information that cannot simply be captured by studies. Through these interviews, much has been learned about how the pollution of their home has affected various aspects of everyday life, especially related to jobs, health and wellbeing, and livestock and crops, just to name a few areas. These interviews will be heavily relied on to paint a first-hand picture of the severity of the environmental degradation and the injustice it has caused. Information about the global rare-earth economy has also been sought, which is especially important to frame the context of this situation. Since the Bayan Obo mine is the largest in the world, by far, global trade and diplomatic relations have been and continue to be affected by the mine, making its environmental regulation especially pertinent.

IV. Evidence & Discussion

There are many different facets of this sociotechnical system which must be examined. First, the environmental impacts will be examined. Then, information on the health impacts on the local residents will be presented. Health impacts not only include medical information, but how the food, water, and environment influence the health of the locals. Finally, the geopolitical environment will be examined, helping contextualize the problem on the global scale.

IV.I Environmental Implications

It will be helpful to cover the mining process a little more in-depth to truly demonstrate the pollution. The picture below shows the geography of the Bayan Obo mine.

Figure 1

Bayan Obo Rare Earth Mine, from above

Note. Taken from Google Earth. Images dated 3/7/2021 and 3/13/2021. Annotated by the author. The large impressions in the ground closer to the top of the image are open-pit strip mines. The water surfaces seen in the picture are tailings ponds, and the large, dark mounds towards the right side of the picture are tailings piles. From the leftmost edge of the strip mines to the small pond on the right is a distance of 12 miles. The distance from the small pond towards the bottom left, to the top edge of the strip mine is 5.5 miles. The tailings piles are about 1.6 miles long. The bottom pile is 0.6 miles wide, and the top one is 0.4 miles wide.

The map of the Bayan Obo mining district (Figure 1) depicts a desolate land, one that has been abused and worn from its former beauty (Bontron, 2012). As can be seen in Figure 1, the tailings piles and ponds span the greater part of a few kilometers (Google, 2021). As the ore is mined and initially refined, it releases cadmium, lead, uranium, nitrogen compounds, sulfuric acid, hydrogen fluoride, ammonia, and hydrochloric acid, among others, into the environment (Lee & Wen, 2017). The process is also very energy-intensive, and relies on coal power (Google, 2021).

In a quest for greater profits and productions, simple environmental protections, such as lining trailing ponds with impervious liners, were disregarded (Standaert, 2019). Simple measures, such as this, would have mitigated damage to the surrounding land, caused by leaching of the aforementioned chemicals into the ground. As a result, those chemicals have leached into the environment for upwards of 30 years.

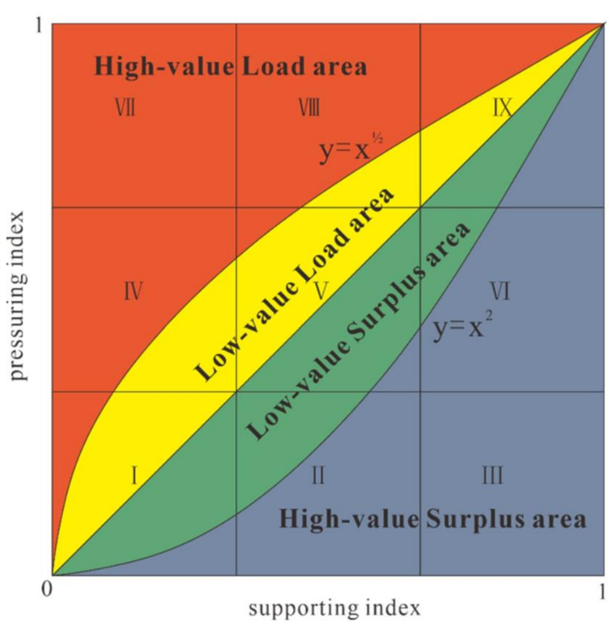
In a peer-reviewed case study conducted by the Chinese Academy of Sciences, researchers Yuxue Pan and Haitao Li investigated the creation of mining brownfields in the Bayan Obo mining region. Brownfields are simply derelict land (Pan & Li, 2016). As of 2015, China had about 3 million hectares (ha) of derelict land, expanding at a rate of 46,700 ha per year. This expansion is due to the continued leaching of chemicals further and further from the mine. The researchers specifically outline an “extremely high potential ecological risk” due to the cadmium concentrations, stating a “significant potential risk to environmental quality, the ecosystem, and human health.”

Work must be done to stop the rapid expansion of mining brownfields in China (Pan & Li, 2016). Already, such brownfields have severely impacted the local population, forcing many to cease living off of it, and become more reliant on government providence. Further, this expansion threatens China’s drinking water, as it inches ever-closer to the Yellow River, at a rate of 20-30 meters per year (Kaiman, 2014).

In another study conducted by multiple researchers from the Inner Mongolia University of Science and Technology, in Baotou, China, examines the resource and environmental carrying capacity (RECC) and pressure. Their RECC index is complied of 30 indicators, from the areas of climate conditions, resource endowment, environmental governance, and economic development, ecological damage loss, environmental pollution loss, and social pressure (Bai et al., 2022). The pressure index seeks to quantify the pressures placed on the mine, whether environmental, societal, etc. The support index characterizes the resources the mine can take advantage of, as well as the health of the surrounding environment, and measures taken to mitigate harm. The figure below helps explain the use of the parameters.

Figure 2

Diagram of support and pressure indices



Note. This diagram comes from the study *Evaluation of resource and environmental carrying in rare earth mining areas in China*, by Bai, Xu, Duan, Zhang, Wang, Wang, and Zheng. It shows the use of the support and pressure indices, as well as the overall RECC index.

The indices are then produced by summing each value's performance measure, times a weighting function. The individual indices come out on values from 0 to 1. Pressure index values closest to 1 signify large amounts of pressure on the mine and its operations. Supporting index values closest to 1 signify large amounts of support. As concluded by the paper, the Bayan Obo mine is facing substantial increases in pressures, with slight decreases in support, leading to unsustainable operation of the mine, and increasingly irreparable damage to the environment.

The changes in resource and environment carrying capacity index show that cleanup and mitigation is not happening in an efficacious manner. More is continuing to be demanded of the resource, putting increasing strain on the mine and the region as a whole. Due to the methodology of how the study accounts for rare-earth resource reserves, the study's conclusions and data are conservative, as the Bayan Obo mine has, by far, the world's largest reserves.

IV.II Health Implications

These environmental effects do not come without resulting health effects on the local populations, by means of exposure to toxic chemicals and decreasing nutrition. Nutrition is inhibited by harming the land's ability to sustain healthy crops and animals. Numerous studies and interviews examine the impact of rare-earth mining on the local populations.

In regards to food, a study produced by several researchers in Chinese government and academia examines the concentration of rare-earth elements in fruits and vegetables from mining areas. In this study, the researchers found a statistically-significant increase in the concentration of rare-earth elements in vegetables, increasing by a factor of about 1.5 for vegetables (Shi et al., 2022). An increase of a factor of close to 2 was present for leafy vegetables from mining to control areas. Though they concluded that the estimated daily intakes were below the allowable, the study calls for a further examination of sustained exposure. It is significant to note that this study assumes a standard diet, which may not be representative of their subjects, especially due to the prevalence of farming in the region. Another study, by a team of 6 authors come to a similar conclusion about the drinking water. The study shows detectable amounts of lanthanum and cerium, but since it provides for intake below the daily allowable limit, the study concluded that drinking water might not be the cause of pollution's effects on the general population. Both of these studies still necessitate research on sustained exposure study and on vulnerable groups, such as pregnant women and children (Liang et al., 2018).

Further work must also be done on Lanthanum exposure. From the water study, it is notable that lanthanum was detected significantly in human urine (Liang et al., 2018). Many studies have been conducted on both acute and chronic toxicity due to Lanthanum. A study cited in the discussion of the urine study, examined the harmful effects of lanthanum in the liver of mice. Lanthanum accumulated in the mice's livers, causing harm, and even genetic damage. Given these effects in mice, a study on lanthanum exposure in humans may prove especially telling.

Though the food itself may not be acutely harming the population, the rare-earth elements can still harm plants and crop yields. From a review of a slew of rare-earth-related studies on food, Christian Turra shows that overall crop health and yield can be hurt significantly by high rare-earth exposure. Also important to note, Turra's extensive review find that not all plants are equal in their uptake of rare-earth elements. Some plants take up especially high amounts of rare-earth elements when exposed to them, such as pecans, hickory trees, and ferns, while others less.

While the food and water are potentially unable to be blamed for direct effects on human health, pollution from mining and exposure to rare-earth elements still has harmful effects on the human body. A study conducted by researchers from 3 different Chinese medical institutions, concluded that “long term environmental and occupational exposure leads to rare-earth element accumulation, and a low level of iron and calcium” (Liu et al., 2021). This happens due to competition between the necessary nutrients and rare-earth elements in binding in chemical reactions in bone metabolism. The low-nutrient effects further induce bone metabolism disorders, and reduce bone mass density.

Studies are powerful in the pictures that they paint, but testimony from interviews conducted with those affected also helps demonstrate the effects of the rare-earth mining industry in China, and make the proofs of the study more real. In a pair of interviews conducted by The Guardian and Le Monde, Jonathan Kaiman and Cécile Bontron talk to the locals about the way they’ve seen their health and community change over the years. Wang Jianguo, speaks of how, when rare-earth production kicked into full gear in the 1990s, his sheep died and his cabbage crops withered (Kaiman, 2014). Most of his friends moved away as a result. Those that stayed haven’t faired much better, as seven, out of a small population of about 300, have died of cancer, and his own teeth are yellow and crooked, and jut out from his blackened gums (Bontron, 2012; Kaiman, 2014). Another, unnamed villager tells Mr. Kaiman that, at a nearby sheep market, many of the sheep have two rows of teeth, with some so long that they cannot even close their mouths (Kaiman, 2014). Ms. Bontron shares the story of Li Guirong, who shares much about his home. Towards the end of the 1980s, Li says, “Plants grew badly. They would flower all right, but sometimes there was no fruit or they were small or smelt awful" (Bontron, 2012). By the end of the 1990s, most villagers had accepted that vegetables simply would not grow any longer, and many farmers let their fields overrun, or only planted wheat and corn. Ms. Bontron makes note of the strong solvent vapors in the air, as well as the visible coal dust in the air between the houses. In 2007, Li shares that he had to get rid of the last of his sick pigs, the remainder of a collection of livestock killed off by the toxic environment. Another villager interviewed by Ms. Bontron, He Guixiang, speaks of rampant diabetes, osteoporosis, and chest problems. She states, "All the families are affected by illness."

The studies provided only corroborate the claims of the Bayan Obo villagers. The bone density study justifies He Guixiang's claims of rampant osteoporosis (Bontron, 2012; Liu et al., 2021). Christian Turra's review of the impact of rare-earth elements on crops explains the increase of mining brownfields, and the demise of the region's strong agriculture (Bontron, 2012; Pan & Li, 2016; Turra, 2018). The study on mice may also help explain the effects of the rare-earth mine on Li Guirong's livestock (Bontron, 2012; Liang et al., 2018). Overall, the powerful testimony provided by the villagers is corroborated by the numerous studies on plant, animal, and human health.

IV.III Political and Societal Implications

This issue spans all levels of government, from the local municipal arms of the Chinese government, to the national People's Republic of China, and the international governing bodies like the World Trade Organization.

On the local level, the community suffers from great poverty. What used to be a thriving community of farmers, is now reduced to industrial buildings and derelict mining land (Bontron, 2012). When the problems started to arise, the municipal environmental agency conducted a study. The study showed that the new rare-earth mining was the cause of their problems, not only because of the elements themselves, but also because of the new factories and processing facilities. He Guixiang says, "I've been knocking on government doors for nearly 20 years. To begin with, I'd go every day, except Sundays." Their pressure has brought some promise of financial compensation, but much that was promised has yet to be fulfilled. The government demands the locals pay to live in housing towers that were built with money paid by a Chinese company as compensation. Some locals even tried selling the mining waste, but the central government soon made this illegal as well.

On the national level, there are a few factors at play. Starting with an industrial greed, Ma Jun, director of the Institute of Public and Environmental Affairs, says "In China, the cost of environmental violations and damage is way too low" (Kaiman, 2014). China is known for producing at a low cost. The United States and many other countries were players early in the rare-earth industry, but other mines were forced to close in the late 1980s and early 1990s, because they could no longer compete and turn a profit (Turra, 2018). Class problems also affect the people of Bayan Obo. Many are registered as farmers, and are thus "treated like second-class citizens and mercilessly exploited" (Bontron, 2012).

In regards to international government and politics, China's stranglehold on the rare-earth industry has come to the detriment of the West. China claims that they have tried to mitigate the pollution by reducing production and exports, but the World Trade Organization ruled that their restrictions were unlawful (Lee & Wen, 2017). As rare-earth metals are essential for the defense industry, among others, the West is at the mercy of China's policies, and China's motives have long been believed to be disruptive and malicious. This is exemplified in a couple stories. First, in 2010, China withheld exports of rare-earth metals over the imprisonment of a Chinese fishing boat fishing in territory the world largely recognizes as Japan's, but China claims (ANI News, 2023). China continued to withhold rare-earth elements from Japan until the captain was released. Japan was, at that time, China's largest consumer of rare-earth elements. China also threatened the US with the same export ban over former-President Donald Trump's treatment of Huawei. In response, the United States has started to produce more of its own alloys, with both Trump and President Joe Biden promoting the rare-earth industry in the US. An example of this is the F-35, which previously relied on a Chinese rare-earth alloy, but the US will now start making the alloy at home, to limit the American military's reliance on Chinese goods, that could be withheld on a whim. Accordingly, as shown by the *Mineral Commodity Survey*, other nations around the world have started producing rare-earths, reducing China's previously-monopolizing market share, but China still holds a large share of the market (U.S. Department of the Interior, 2023). The US has, for example, tripled production since 2018.

The political and societal implications are very interesting on all three levels. It is apparent that the Chinese government, on the local and national level, is aware of the problems at hand. As many of the locals are classified as farmers on government paperwork, and thus treated as second-class citizens, they are treated poorly and are afraid to speak out. Li Guirong is one of the few with a voice, as the local secretary general of the Chinese Communist Party (Bontron, 2012). The persistence and power of citizens, despite the threat of retaliation for criticism of the government, shows through by the example of He Guixiang. If the locals had not continued to speak out, they certainly never would have been heard or helped. Though they have started to receive the necessary aid, much is still left to be desired with the government's response.

Change is slowly occurring in China's rare-earth industry, and the world's. Now that China has had to increase regulation and mitigate clean-up costs, their prices are increasing. As their prices increase, the world's market is beginning to diversify, with new players in the game. More rare-earth mines are opening in the West. For example, Sweden just found a large deposit of rare-earth elements (Chatterjee, 2023). Europe currently operates no rare-earth mines, and imports much of theirs from China, as noted previously. Other countries, like the US, Brazil, and Australia are increasing production. Another important note about production in the West is that it is typically better-regulated, resulting in a cleaner, more environmentally-friendly product, especially when contrasted against China's product. Authors Jason Lee and Zongguo Wen even propose that the World Trade Organization's ruling may actually be helpful to China, and force action towards more effective action towards sustainability in the industry (Lee & Wen, 2017). Merely reducing production doesn't change the nature and pollution of the production.

In a time where China appears to be increasingly at-odds with the West, it is important that the West to transition away from reliance on China for something so critical as rare-earth metals. This shift is far from over, and will take a substantial amount of time. Much infrastructure needs to be developed to become independent of Chinese rare-earth elements. The West must continue on this quest for independence, not only in the interest of national and international security, but in the interest of justice to the environment, and a cleaner product, with better mitigated and reduced environmental costs of business.

V. Conclusion

The crucial rare-earth industry has a lot of power and importance in the world. The toxic process, the effects of which have been realized over years of unprotected mining, have done irreparable damage to the lives of many, as well as the environment, especially in the Bayan Obo region. Unsustainable mining has continued, even after the harmful effects have become known, in order to gain short-term profit, at the expense of the people, the land, and long-term profit. As mentioned in the background, and exemplified through the discussion, the rare-earth mining industry, and specifically the industry surrounding the Bayan Obo mine, is an especially complex sociotechnical system, that fits into an even larger, more complex web of actors and actants. As the world accelerates towards electrification, in its quest for freedom from fossil fuels, and in search of cleaner and reduced emissions, the rare-earth industry, and the Bayan Obo mine and region, will continue to be taxed substantially. If electrification is achieved, at the cost of cutting environmental corners, the world will only be worse off than before, and the Bayan Obo mine is one of the cornerstones of this revolutions. It is crucial that the China pushes to clean up its act in the rare-earth industry, not just in the Bayan Obo region, but in all of their mines. The West must seek to sustainably-source their own rare-earth elements, and break from reliance on such cruel practices. Further, where the West has run companies in other countries, the West should help fund the clean-up. The governments and corporations that run the mines are ultimately responsible, but the West must make good on any place where is has exploited. Many new, promising technologies are being developed to clean up rare earth mining practices, such as proteins and bacteria (McCormick, 2021). Continued innovation and funding is necessary in the search for cleaner rare-earth mining practices. Overall, the rare-earth industry, in its current state is extremely harmful for the environment, but with continued effort and mitigation, the rare-earth industry, which is essential for a cleaner future, can be brought up to speed, and can be a catalyst in the world's electrification.

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