# Balancing Economic Growth and Environmental Responsibility in Australia's and Canada's Mining Sector: Policy Models and Sustainable Solutions

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**Abstract:** Abstract: Australia's and Canada's mining industry has been a critical driver of economic growth, contributing significantly to national income, infrastructure development, and employment. However, this prosperity has come at a substantial environmental cost, with widespread land, water, and air degradation, as well as a proliferation of abandoned mines. This paper examines the economic benefits and environmental impacts of Australia's mining sector through the lens of two models: the Mine Rehabilitation Model (MRM) and the Mine Policy Model (MPM). These models provide a framework for assessing the cost-effectiveness of mine rehabilitation and the optimization of policies aimed at maximizing social welfare.Our findings reveal limitations within the current regulatory approach, such as the inadequacy of environmental bonds and land damage taxes, and identify loopholes that allow mining companies to evade rehabilitation responsibilities. To address these issues, this study recommends a comprehensive policy strategy that includes strengthening financial requirements, implementing rigorous compliance audits, promoting economic diversification, raising environmental awareness, and integrating advanced technological solutions for real-time monitoring and site rehabilitation.The paper concludes by highlighting the need for a balanced approach that integrates economic growth with environmental stewardship, ensuring that Australia's mining industry can continue to contribute to the economy without compromising the natural environment. These policy recommendations offer a pathway for Australia to achieve sustainable development and secure long-term economic and environmental resilience.

**Keywords:** mining industry, economic growth, environmental degradation, mine rehabilitation, policy model, sustainable development, Australia

## 1 Introduction

Australia's mining industry has long been a cornerstone of its economy, with the discovery of vast mineral resources driving economic growth since the 1800s. The famed gold rush of the 1840s marked a pivotal moment, during which Australia produced 40% of the world's gold, positioning the nation as a global leader in mineral wealth (Healey, 2016). This abundant resource base fueled rapid economic development and attracted both foreign and domestic investment, contributing to

Australia's high standards of living and making it one of the countries with the highest quality of life globally (US News, n.d.). During the mining boom, Australians experienced a 13% increase in real disposable income per capita, as mining significantly boosted wages across various sectors (Tulip, 2014).

Similarly, Canada's mining sector has been integral to its economic development, particularly in regions like Ontario, Quebec, and British Columbia. The Canadian mining industry, often dubbed the "bedrock" of the Canadian economy, contributes significantly to the country's GDP. In 2022, mining and quarrying represented approximately 5% of Canada's total GDP, with the sector generating $80 billion in revenue (Natural Resources Canada, 2023). Like Australia, Canada has vast reserves of minerals such as gold, copper, nickel, and diamonds, and has maintained a position as a global leader in mineral production. For instance, Canada is one of the world's top producers of potash, uranium, and nickel, and is the third-largest gold producer globally (Natural Resources Canada, 2022). The mining industry has been a significant driver of economic growth and employment, with the sector employing over 400,000 Canadians and providing substantial revenue to provincial governments (Canadian Mining Association, 2021).

Despite these economic benefits, both Australia and Canada face significant challenges in managing the environmental impact of mining. In Australia, mining's environmental costs have raised considerable concerns. The extraction processes that support the Australian economy cause substantial ecological harm, impacting air, water, and soil quality. Mining releases harmful gases, devastates ecosystems, and, because of the non-renewable nature of resources like coal and oil, poses long-term sustainability challenges (Chepkemoi, 2017). As mineral deposits are depleted, companies often abandon mines, leaving significant rehabilitation costs that fall upon the government and, ultimately, taxpayers. Current estimates suggest that there are approximately 60,000 abandoned mines across Australia, each requiring costly rehabilitation efforts potentially reaching millions of dollars (Campbell, Lindqvist, Browne, Swann, & Grudnoff, 2017).

In Canada, similar environmental concerns persist, particularly regarding resource extraction in ecologically sensitive areas like the Alberta oil sands and northern mining regions. Mining operations in these areas have been criticized for their adverse effects on local ecosystems, water resources, and Indigenous lands. The Canadian government has implemented various regulatory measures to address these concerns, such as the Federal Impact Assessment Act, which requires thorough environmental assessments for large-scale mining projects (Government of Canada, 2021). Despite these policies, there have been challenges in enforcing and ensuring compliance, with ongoing debates about the effectiveness of current regulations in mitigating environmental harm (Martin, 2022).

To address these environmental and economic challenges, both the Australian and Canadian governments have implemented policies such as environmental bonds, land damage taxes, and stricter mine reclamation standards. Environmental bonds are intended to ensure that companies restore mining sites, while land damage taxes aim to hold companies accountable for the environmental degradation they cause. However, the limited scope and enforcement of these policies have often allowed companies to avoid their restoration obligations. Mining firms sometimes exploit policy loopholes, declaring sites "under maintenance" until their leases expire, effectively shifting the responsibility for site rehabilitation to the government (Ngugi & Kusy, 2015). This policy shortcoming exemplifies a classic market failure: while mining companies profit from resource extraction, the environmental and financial burdens of site rehabilitation are disproportionately placed on the public (Tuovila, 2022).

This paper seeks to explore the economic and environmental impacts of Australia's and Canada's mining sectors, using the Mine Rehabilitation Model (MRM) and the Mine Policy Model (MPM) to assess the efficacy of current policies and identify potential improvements. By examining these models and the challenges of implementing effective regulations, this study aims to provide a more sustainable policy framework that balances the substantial economic benefits of mining with the need for environmental responsibility. Such a balanced approach is critical for both countries' sustainable development trajectories, ensuring that mining continues to support economic growth while safeguarding the environment for future generations.

## 2 Literature review

### 2.1 Economic Contributions of the Mining Sector

The Australian mining sector has been a primary driver of national economic growth for over a century, profoundly shaping the country's financial and social landscapes. Mining activities have not only brought wealth through resource exports but have also contributed significantly to employment and infrastructure development, particularly in remote areas. The financial influx from mining has supported the construction of infrastructure such as roads, hospitals, and schools in rural areas, thereby enhancing the quality of life for remote communities. According to historical data, the early discovery of minerals, such as gold in the 1840s, marked a transformative period in Australia's economy, with the nation accounting for approximately 40% of the world's gold production at that time (Healey, 2016). The economic impact of mining has continued through subsequent decades, with Australia's abundant reserves of coal, iron ore, and natural gas attracting foreign investment and driving economic expansion.

In recent years, the impact of the mining boom has been particularly notable. From 2003 to 2013, Australia experienced a 13% increase in real disposable household income per capita, largely attributed to mining-related economic growth (Tulip, 2014). This economic boom spurred wage increases across various sectors, benefiting not only those directly employed in mining but also those in industries indirectly linked to resource extraction. As mining operations expanded, they stimulated demand for goods and services, thereby contributing to a cycle of prosperity that supported broader economic stability and raised Australia's quality of life (US News, n.d.).

Similarly, Canada's mining sector has played a pivotal role in its national economy, contributing to both economic growth and the development of infrastructure. The Canadian mining industry is a major economic driver, particularly in provinces like Ontario, Quebec, and British Columbia. In 2022, mining and quarrying contributed about 5% to Canada's GDP, generating $80 billion in revenue and providing jobs for over 400,000 Canadians (Natural Resources Canada, 2023). Canada is home to vast mineral reserves, including gold, nickel, copper, and potash, making it a leading global player in resource extraction. The Canadian mining sector has also spurred significant investments in regional infrastructure. For example, the financial inflows from mining activities have been pivotal in supporting public services and infrastructure development in resource-rich provinces, helping to improve transportation networks, educational facilities, and healthcare systems, much like in Australia (Canadian Mining Association, 2021).

Additionally, the mining sector has been critical to the Canadian government's revenue through royalties and taxes, similar to Australia's model. These revenues are often reinvested into public infrastructure and social services, supporting both local communities and national programs. Like Australia, Canada's mining regions benefit from these revenues through improvements in transportation, healthcare, and education, helping to elevate the standard of living in remote and resourcedependent areas.

However, as with Australia, the long-term sustainability of Canada's mining sector has come under scrutiny, particularly in light of environmental concerns. While Canada's vast resources have supported economic growth, the extraction process has raised significant environmental issues, including the degradation of ecosystems, water pollution, and habitat destruction. The challenge for Canada lies in balancing the economic benefits derived from mining with the need for environmental stewardship. The finite nature of mineral resources in both countries, coupled with growing concerns about climate change and ecological preservation, complicates the debate over the future of mining.

This complex trade-off between immediate economic gains and long-term environmental preservation is central to the ongoing discourse in both Australia and Canada. Both countries are grappling with the consequences of mining on ecosystems, climate, and Indigenous communities, especially as the global demand for resources continues to rise.

In sum, the economic contributions of the mining sector in both Australia and Canada are substantial, encompassing job creation, improved income levels, foreign investment, and enhanced public infrastructure. However, these benefits come with significant environmental costs and raise critical questions about the sector's future sustainability. This review thus underscores the importance of evaluating current policies to ensure that the mining industry can continue to support the economy without compromising environmental and social welfare in the long term. A balanced approach to mining policy is essential for both nations, as they strive to promote economic growth while safeguarding the planet's ecological health..

## 2.2 Environmental Impacts of the Mining Industry

The environmental consequences of mining activities in Australia have become increasingly pressing as the sector continues to expand. While mining contributes significantly to the economy, the extraction processes involved cause considerable ecological damage. The environmental footprint of mining operations extends across multiple domains, including land degradation, air and water pollution, and long-term habitat destruction. The extraction of minerals such as coal and iron ore requires invasive methods that disrupt natural landscapes, leading to substantial soil erosion, loss of vegetation, and biodiversity reduction (Chepkemoi, 2017). Additionally, harmful by-products such as particulate matter and toxic gases are released into the atmosphere, exacerbating air pollution and impacting nearby communities.

The water resources in mining regions are also significantly affected. Mining operations often consume vast amounts of water and generate wastewater containing pollutants that can seep into local water systems. This contamination poses a risk to both human populations and aquatic ecosystems, making water quality management a critical challenge for regulatory authorities (Ngugi & Kusy, 2015). These environmental hazards associated with mining activities threaten to destabilize ecosystems, disrupt natural processes, and jeopardize the health of surrounding communities.

The issue of abandoned mines further amplifies the environmental impact of the industry. As mineral reserves in specific areas are depleted, mining companies frequently abandon sites without restoring them to their natural state. The costs and responsibility for rehabilitating these abandoned mines often fall on the government, resulting in a significant financial burden for taxpayers. Currently, it is estimated that there are around 60,000 abandoned mines across Australia, each requiring extensive and costly rehabilitation efforts (Campbell, Lindqvist, Browne, Swann, & Grudnoff, 2017). These sites can remain hazardous for decades, as unrehabilitated land continues to degrade, leading to the erosion of soil, contamination of groundwater, and ongoing ecological harm.

To mitigate these issues, the Australian government has introduced policies aimed at holding companies accountable for environmental restoration. Environmental bonds, for example, require companies to set aside funds for site rehabilitation before commencing mining activities. However, the efficacy of these measures has been limited, as some mining firms find ways to avoid fulfilling their rehabilitation obligations by exploiting regulatory loopholes. Consequently, many abandoned sites remain unaddressed, posing ongoing risks to the environment and public health (Ngugi & Kusy, 2015).

In Canada, similar policies have been implemented to manage the environmental impacts of mining, such as the requirement for mining companies to post financial guarantees for mine reclamation. The Canadian government mandates that companies set aside funds for the cleanup and rehabilitation of mining sites before they are permitted to begin operations. Despite these efforts, enforcement remains a challenge, particularly in remote areas where monitoring is difficult. Critics argue that some companies in Canada exploit these gaps, delaying the restoration process or shifting responsibility to the public sector when they abandon sites (Martin, 2022). For instance, the abandonment of old mines in regions like the Yukon and British Columbia has left significant environmental liabilities, similar to the situation in Australia, raising concerns about the adequacy of current policies in preventing long-term ecological damage (Natural Resources Canada, 2023).

In conclusion, while Australia’s and Canada’s mining sectors play vital roles in their respective economies, the environmental impact of mining operations presents significant challenges. The industry’s activities lead to substantial degradation of land, water, and air, and the problem of abandoned mines continues to pose long-lasting ecological and public health risks. Both countries face similar hurdles in ensuring that mining companies fulfill their environmental responsibilities and that abandoned sites are properly rehabilitated. Addressing these concerns is crucial for the sustainable future of the mining industry and the communities it affects. This review underscores the urgent need for more effective and enforceable policy measures that balance economic gains with environmental preservation in both nations.

## 3 Model basis

The Mine Rehabilitation Model (MRM) is grounded in cost-minimization principles to optimize fund allocation for mine site restoration, while the Mine Policy Model (MPM) aims to balance social welfare impacts with corporate interests, providing a nuanced framework for sustainable policy design.

### 3.1 Mine rehabilitation Model

While Australia had enormous mining areas to restore, it was impossible to restore these areas all at once. Therefore, the government identified five sites that should be considered for rehabilitation based on four constraints (public and environmental safety risks; end use of the land and cost-effectiveness of restoration or remediation works). However, the most significant consideration was how the costs required to rehabilitate the mine could be used with maximum efficiency. In other words, how to achieve the goal at the least cost became a priority. The Mine rehabilitation Model (MRM) provided a model for allocating funds, which considered how various variables should allocate restoration costs.

$$\underbrace{\sum_{i=1}^{I}[X_{i,0}K_i + D(V_{i,0}, C_{i,0})]}_{\text{part1}} + \underbrace{\sum_{t=1}^{T}\delta^t\left\{\sum_{i=1}^{I}[(X_{i,t}-X_{i,t-1})K_i] + (1-X_{i,t-1})D_i(V_{i,t}, C_{i,t})\right\}}_{\text{part2}}$$

As illustrated above, the whole model could be roughly divided into two parts. Part 1 was the initial damage value of the land before the whole remediation started, where xi,0 indicated whether to remediate this land or not, which meant 0=no remediation; 1=remediation. The latter part of Ki indicated the restoration cost required to restore this piece of land for i. The second half of part1 was the equation for the initial damage, which concerned two variables, namely the initial contamination ( vi,0) and the initial average contamination ( ci,0). Part 2 was the sum of the damage incurred when restoring the land and the damage caused by the unrestored land, where the δt at at the front of the equation represented the discount factor converted from the discount rate. The discount rate was an interest rate that converts future values to present values (Hayes, 2022) and, in part 2, represented the future damage of the impaired land calculated to its present value. The subsequent xi,t represented whether the site I was cleaned up. When xi,t was equal to 1, it meant the land had been cleaned up and would not cause further contamination in the future, while the remediation cost was still ki. The second half of part 2 denoted the damage that occurred during the rehabilitation of the mine. Once it was cleaned up, all the damage became zero. Where Di( vi,t, ci,t) was the contaminated damage incurred at t equal to different times, which was distinguished from the initial damage equation of part 1. Finally, the value of part 2 at different timest was summed up with part 1 to form the whole MRM, and the minimum value obtained was the choice that maximizes the efficiency of the limited funds.

$$\sum_{i=1}^{I}[X_{i,0}K_i] + \sum_{t=1}^{T}\delta^t\left\{\sum_{i=1}^{I}[(X_{i,t}-X_{i,t-1})K_i]\right\} \le K$$

However, the constraints were considered, as illustrated the above, the whole equation could not cost more than the government's input money, K. Interestingly, the discount factor (δt )was also included in the constraint equation, which meant some mines were initially overfunded for rehabilitation to the extent it would not be rehabilitated in the first instance, the government maybe selected to rehabilitate the land after the cost of rehabilitation was made less affected by the discount rate."

## 3.2 Mine policy Model

The purpose of the government in remediating mines was to reduce the loss of social welfare. As mentioned earlier in the report, the pollution externalities from abandoned mines were factors that harmed social welfare. The Mine policy Model (MPM) could help the government determine what kind of policy would be more appropriate.

$$J = \sum_{t=0}^{T-1}\delta^t[\underbrace{p_tQ_t}_{\text{part 1}} - \underbrace{C(Q_t,X_t)}_{\text{part 2}} - \underbrace{w(E_t)}_{\text{part 3}} - \underbrace{d(Y_t)}_{\text{part 4}}] - \underbrace{\delta^T(S(Y_T))}_{\text{part 5}}$$

The entire equation was divided into five parts, as shown in the figure. At the head of the equation was the discount factor, which meant the whole equation was calculated by converting the future value to the present value. In part 1, ρ t was the discount rate, and Qt denoted the extraction rate during mining, and the two were multiplied to convert the value of minerals obtained in the future to the current value. The obtained value minus the damage caused during the acquisition process was the entire equation; except for part 1, the rest was the cost factor. Part 2 represented the mining process cost, which was the equation for the terrestrial mineral reserve (xt) and the mining rate (Qt). Part 3 was the spending on repairing damaged land that would not cause further damage after repair. In part 4, the damage caused per hectare of damaged land (d) multiplied by its hectare size (yt) was used to obtain the cost to the land. Notably, the cost of the same hectare of land used for different purposes would be different; therefore, d was only an estimate and not an exact figure. The last part, 5 in the whole equation, represented those social costs that were permanently damaged, which were irreversible, and this same part converted the future value of the damage to the present value. The function of maximizing social welfare was achieved by summing the values of the first four parts overtime and subtracting the permanently damaged costs. Similarly, constraints also existed in the MPM.

$$X_{t+1} = X_t - Q_t \quad \text{for } t = 0,1,\ldots T\text{-}1$$

$$Y_{t+1} = Y_t + hQ_t - E_t \quad \text{for } t = 0,1,\ldots T\text{-}1$$

From the figure, the ore reserve for the second year (xt+1) was equal to the previous year's reserve (xt) minus the current year's extraction rate (Qt). The area of damaged land hectares in the second year (yt+1) required the damaged area of the previous year (yt) plus the amount of extraction (hQ t) obtained after being affected by land degradation (h), then subtracted from the restored land (Et). Calculating the maximum social welfare value obtained under different policies could laterally contribute to the government's choice of an appropriate mining policy.

# 4 Data analysis

## 4.1 Analysis of Mine rehabilitation Model

The government decided to invest 450 to cleanup five mining sites and how to use these costs to achieve the most efficient disposal solution was the goal of this part.

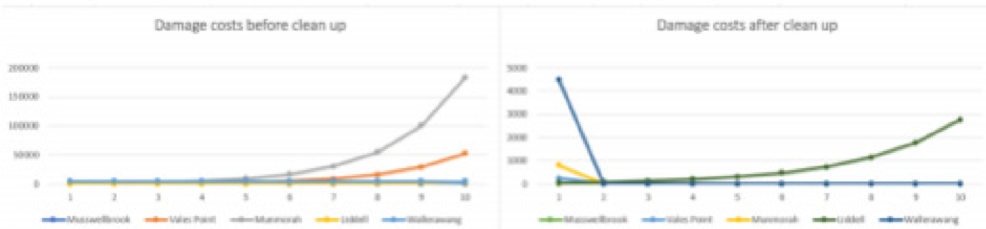



Table 1

| | | | | | | |
|---|---|---|---|---|---|---|
| Before analysis | | | | | | |
| k=450 | Rehablitation of mining area5 | Musswellbrook | Vales Point | Munmorah | Liddell | allerawang |
| p=0.05 | Pollution growth rate | 0.09 | 0.9 | 0.92 | 0.64 | 0.04 |
| PVD=569235.491 | Restoration Cost | 110 | 25 | 155 | 200 | 210 |
| PVsumKi=0 | Inital contamination | 1.5 | 250 | 800 | 50 | 4500 |
| PV(D+K)=569235.491 | Damage function coefficient | 0.03 | 0.01 | 0.4 | 0.5 | 5 |
| | Pollution after 10 years | 2.10003266 | 52001.8418 | 182851.0058 | 2766.0559 | 4128.657682 |
| After analysis | | | | | | |
| PVD=13167.565 | Whether to clean up | 0 | 1 | 1 | 0 | 1 |
| PVsumKi=390 | Pollution after 10 years | 2.10003266 | 0 | 0 | 2766.0559 | 0 |
| PV(D+K)=13557.565 | | | | | | |

After analyzing the five mines given by the government through MRM, the above and line chart were obtained. It was clear that if the government had left these abandoned mines untreated, the cost of the damage would reach 569,235 after ten years, and the trend would be increasing; notably, the growth rate of pollution in Munmorah (0.92) was substantial, although the initial amount of pollution (800) was not the highest among the five sites, however, the amount of pollution after ten years would be the highest among the five sites at 182,851. Moreover, the pollutants of the five mines were different. According to the data of the graph, all the mines except Wallerawang exhibited an increasing trend, which meant these mines were stock pollutants - not capable of being absorbed by the environment, while Wallerawang tended to decrease, which proved its type of pollutants should be fund pollutants - dilutable by the environment. Furthermore, only Wallerawang's pollution growth rate (0.04) was smaller than the discount rate (0.05). The next step was how to select the mine for rehabilitation, the initial contamination at Muswellbrook and Liddell and the post-decade contamination without treatment were less among the five sites (1.5 & 50; 2.1 & 2766.1), so it would be necessary to spend the cost on areas with high initial contamination and high growth rates. Since remediation costs were limited and not all areas could be remediated, after analyzing the data,rehabilitating Vales Point, Munmorah, and Wallerawang was the most efficient treatment option with an overall remediation cost (PVsumKi) of 390,which would reduce the overall pollution cost to 13,557. The selection above was based on a discount rate of 5%, and the Table 2 below illustrates the data at different discount rates.

Table 2

| Discount rate | p=0.02 | p−0.05 | p=0.1 |
|---|---|---|---|
| PVD | 14985.963 | 13167.565 | 10989.436 |
| PVsumKI | 390.000 | 390.000 | 390.000 |
| PV(D+K) | 15375.963 | 13557.565 | 11379.436 |
| 8 | 0.980 | 0.952 | 0.909 |

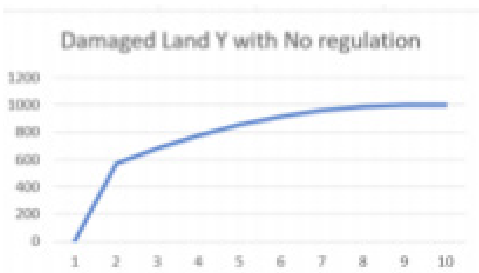
According to the graph, there were no changes in restoring the land at different discount rates; however, the final overall damage differed. The explanation for this result could be that when the discount rate was changed, the discount factor was also changed, and based on the formula $\delta$ = ,when the discount rate became higher, the discount factor became minor, which meant the future value was less valuable when converted to the present. Put into MRM could be interpreted as the greater the discount rate, the less the value of the future land converted to the present. Therefore, different discount rates would only change the present value of contamination spent rather than the choice of rehabilitating the mine.

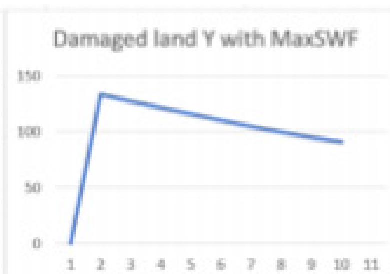
## 4.2 Analysis of Mine policy Model

Besides rehabilitating mines, how to ultimately reduce abandoned mines was the target of this part. Different policies would influence the choice of companies; thus, the selection of the suitable policy could help the government to aggravate the cost of abandoned mines for companies; once the cost increases, the digging firms would choose to rehabilitate or improve the efficiency of mining to reduce the damage to the land.

Table 3

| | DLT | Disc sWF/Sm | Disc NPV/Sm | Damage to the land in the ninth year | Soclal permanent land damage |
|---|---|---|---|---|---|
| No Regulation | 0 | −42.359 | 61.588 | 1.000 | −80,000.000 |
| MaxsWF | 200 | 51.143 | 51.143 | 90.69008584 | 0.0000001842 |
| DLT250 | 250 | −40.111 | 55.027 | 1.000 | −80,000.000 |
| DLT500 | 500 | 50.958 | 51.181 | 92.66872978 | 0.0000001819 |




The permanent damage to the land caused by the mining company reached 80 million when the government did not intervene in the abandoned mine, with the figure displayed. Therefore , the five million environmental bonds proposed by Wongalee Inc were inadequate. With no government restrictions, the company would have received the highest present value (61.588million) while also causing the highest social welfare impairment of 42.359 million. The government would not permit the situation to occur; when the damage land tax (DLT) was 200 at maximum social welfare, social welfare would be 51.143

million, although the present value of the firm would be about 10 million less than without the restriction, the damage to the land would be nearly 990 fewer in the ninth year, and there would be minimal permanent land damage. The trend in damage to land without restrictions and maximizing social welfare could be seen more visually in the line graph; because of the absence of restrictions, there was a clear surge between the first and second year, in the beginning, followed by a continuous increase at a slow rate. However, when maximizing social welfare, though there was also an increasing trend from the first to the second year, it started to decrease continuously after the beginning of the second year. The following section will compare the two different DLTs (250 & 500) given by the government. With DLT equal to 250, all values were close to unrestricted, implying that higher tax rates would not necessarily make firms choose to rehabilitate land; after all, DLT (200) when maximizing social welfare was smaller than 250. In contrast, with DLT equal to 500, all data were very close to the value of maximizing social welfare, and even permanent land damage was smaller than with MaxSWF. Therefore, 500 DLT should be used as the new policy. Meanwhile, DLT would be more suitable for use as a policy than environmental bonds. The value of land was difficult to estimate before use; in contrast, DLT could vary according to the value of land output, making the tax rate more realistic.

### 4.3 Model Limitations and Future Research Directions

The data analysis of the Mine Rehabilitation Model (MRM) and the Mine Policy Model (MPM) provides valuable insights into the cost-effectiveness of rehabilitation strategies and the optimization of policy mechanisms to maximize social welfare. However, several limitations inherent to these models must be acknowledged to understand their practical application and areas for improvement. Addressing these limitations through future research could substantially enhance the robustness and predictive accuracy of these models, enabling policymakers to make more informed decisions.

Firstly, the MRM assumes a fixed discount rate when calculating the present value of future rehabilitation costs. While this approach simplifies calculations, it fails to capture the fluctuating nature of discount rates, which can vary in response to economic conditions, inflation, and market risks. A static discount rate may thus misrepresent the true cost of rehabilitation over time, especially for long-term projects with substantial environmental impact. Future research could address this limitation by integrating dynamic discount rates that adjust in real-time according to economic indicators, providing a more accurate estimation of future costs. Such an approach would allow the MRM to respond flexibly to economic changes, yielding results that more accurately reflect current financial realities.

Another limitation lies in the MPM's focus on social welfare as a primary outcome metric without accounting for the full spectrum of environmental and social externalities. The model’s simplicity enables it to provide clear policy recommendations; however, it may overlook critical factors such as biodiversity loss, community health impacts, and long-term ecological degradation. Incorporating additional variables, such as biodiversity indices, public health costs, and soil regeneration rates, into the MPM could improve its comprehensiveness, allowing it to capture a wider array of environmental impacts associated with mining activities. This expansion would enhance the model’s utility in guiding policy decisions that prioritize not only economic welfare but also holistic environmental sustainability.

Furthermore, both the MRM and MPM are limited in their ability to handle real-time environmental data, which restricts their applicability in scenarios that require adaptive management. Mining sites often experience fluctuating levels of environmental degradation due to seasonal changes, weather patterns, and operational variations. Incorporating real-time environmental monitoring data, such as satellite imaging, air quality indices, and water contamination levels, into both models could allow for continuous updates and adjustments to rehabilitation and policy recommendations. This data integration would facilitate more accurate, location-specific predictions and support a proactive approach to environmental management, where policy adjustments can be made in response to emerging environmental risks.

Finally, future research could also explore the feasibility of incorporating machine learning algorithms into the MRM and MPM frameworks. Machine learning techniques could analyze large datasets on environmental impacts, rehabilitation outcomes, and policy effectiveness to identify patterns and optimize model parameters automatically. Such an approach could enable the models to “learn” from past data and improve their predictive accuracy over time, adapting to evolving environmental and economic conditions. Machine learning integration would also support the customization of policy recommendations for specific regions, industries, or types of mining activities, thereby enhancing the models’ precision andrelevance.

In summary, while the MRM and MPM provide a foundational framework for assessing mining rehabilitation and policy effectiveness, future research could enhance these models by incorporating dynamic discount rates, additional environmental variables, real-time data, and machine learning capabilities. These improvements would enable a more nuanced, responsive, and accurate approach to managing the complex environmental impacts of mining, ultimately supporting the development of more effective and sustainable policies.

## 5 Policy Recommendations

To address the complex challenges posed by the mining industry in Australia, a multi-faceted policy approach is essential. Current policies, such as environmental bonds and land damage taxes, have laid the groundwork for holding mining companies accountable. However, these measures have proven inadequate due to regulatory loopholes and insufficient enforcement, allowing some companies to evade their rehabilitation responsibilities. This section proposes a series of policy recommendations aimed at enhancing environmental accountability, strengthening regulatory oversight, and promoting sustainable practices within the mining sector.

### 5.1 Strengthening Environmental Bonds and Land Damage Taxes

One of the primary issues with existing environmental bonds is their relatively low cost compared to the substantial profits generated by mining companies. As a result, many companies find it more financially advantageous to abandon sites rather than rehabilitate them, knowing that the bond amounts are insufficient to cover the actual restoration costs (Ngugi & Kusy, 2015). To counter this, the government should consider revising the bond system to make it more reflective of the true costs of rehabilitation. A tiered structure based on the scale of potential environmental damage and the specific characteristics of each mining project could ensure that bonds are appropriately tailored and sufficient to cover full rehabilitation expenses.

Additionally, increasing the land damage tax could incentivize companies to minimize environmental harm from the outset. A higher land damage tax would make it costlier for companies to engage in environmentally damaging practices, thus encouraging them to adopt more sustainable methods. Research indicates that a combined approach—using both strengthened bonds and elevated land damage taxes—can be more effective than either policy in isolation, as it both secures funds for future rehabilitation and discourages environmentally harmful behavior (Campbell, Lindqvist, Browne, Swann, & Grudnoff, 2017).

### 5.2 Implementing Rigorous Eligibility and Compliance Audits

To enhance compliance, the government should implement stricter eligibility requirements and regular audits for companies seeking mining permits. Companies with a history of abandoned sites or insufficient rehabilitation efforts should face higher barriers to entry or be required to provide additional financial assurances. By imposing stringent vetting processes and more rigorous ongoing compliance audits, regulators can reduce the likelihood of irresponsible environmental practices and ensure that only companies with a track record of environmental stewardship are granted mining rights (Ngugi & Kusy, 2015).

Moreover, audits should be conducted regularly throughout the lifecycle of mining projects, rather than solely at the project's conclusion. Continuous oversight would allow regulators to identify potential environmental breaches early and hold companies accountable before irreversible damage occurs. This proactive approach would not only mitigate environmental impacts but also enhance the credibility and enforcement of mining regulations.

### 5.3 Reducing Economic Dependence on Mining and Supporting Diversified Industries

Australia's heavy reliance on the mining sector creates economic and environmental vulnerabilities. To reduce the pressure on natural resources and mitigate the influence of the mining industry on policymaking, the government should support the growth of other economic sectors, such as renewable energy, technology, and tourism. This diversification would decrease the country's economic dependency on mining, making it easier for the government to implement stringent environmental regulations without facing resistance from powerful mining interests (Bell & Hindmoor, 2014).

Encouraging investments in industries with lower environmental footprints could also create alternative employment opportunities, especially in regions currently dominated by mining. Over time, this transition could lead to a more balanced and resilient economy, where sustainable practices are prioritized, and environmental considerations are integral to economic planning.

### 5.4 Promoting Environmental Awareness Among Stakeholders

In addition to regulatory measures, fostering environmental awareness among mining stakeholders, including companies, employees, and local communities, is crucial. By promoting an understanding of the long-term consequences of environmental degradation, the government can encourage stakeholders to take a more active role in advocating for sustainable practices. Environmental education initiatives could be integrated into the corporate social responsibility programs of mining companies, promoting a culture of ecological responsibility within the industry.

Furthermore, communities affected by mining activities should be empowered to hold companies accountable. Local stakeholders who are informed about environmental issues are more likely to support and participate in sustainable practices, creating a grassroots movement for ecological stewardship. By raising environmental awareness, the government can foster a collaborative approach to environmental protection that involves both regulators and local communities.

### 5.5 Integrating Technological Solutions for Monitoring and Rehabilitation

Advances in technology offer promising solutions for monitoring environmental impacts and improving rehabilitation efforts. The government could support research and development in environmental monitoring tools, such as satellite imaging, remote sensing, and data analytics, to enhance oversight of mining activities. These technologies would enable more accurate and timely detection of environmental breaches, facilitating immediate intervention when issues arise.

Additionally, promoting technological innovations in mine rehabilitation can make the restoration process more effective and cost-efficient. For instance, bioengineering and ecological restoration techniques can accelerate the recovery of mined land, reducing long-term environmental damage. By investing in technology, the government can modernize environmental management in the mining sector, improving both regulatory enforcement and the quality of rehabilitation efforts.

## 6 Conclusion

Australia's mining industry has undeniably been a cornerstone of its economic prosperity, contributing significantly to GDP, employment, and infrastructure development. The sector’s growth has raised national income levels, attracted foreign investment, and elevated Australians' standard of living. However, these economic gains come at a substantial environmental cost, manifesting in soil degradation, air and water pollution, and lasting ecological harm from abandoned mine sites. As the country faces the cumulative impacts of these environmental challenges, there is an increasing need to address the trade-offs between short-term economic benefits and long-term ecological sustainability.

In Canada, the mining sector has similarly been integral to the nation’s economic success, particularly in resource-rich provinces like Ontario, Quebec, and British Columbia. The sector contributes significantly to Canada’s GDP and employment, generating billions in revenue and creating hundreds of thousands of jobs. However, much like Australia, Canada faces substantial environmental risks from mining operations, including habitat destruction, water contamination, and the abandonment of legacy mine sites. For example, the Alberta oil sands and mining projects in northern Canada have raised concerns about pollution, particularly regarding water bodies and surrounding ecosystems. These issues, while contributing to economic growth, pose challenges for both ecological and social sustainability (Natural Resources Canada, 2023).

The analysis presented in this study highlights the limitations of current policies in both Australia and Canada, such as environmental bonds and land damage taxes, in adequately addressing the environmental impacts of mining. In Australia, environmental bonds are designed to ensure that companies set aside funds for site rehabilitation before mining begins. However, these measures often fall short due to inadequate financial requirements and regulatory loopholes that allow companies to avoid fulfilling their rehabilitation obligations. Similarly, in Canada, while financial guarantees are required for mine reclamation, there are concerns over the effectiveness of enforcement, particularly in remote mining regions where monitoring is limited. These gaps result in significant costs being shifted to the government and taxpayers, illustrating a classic market failure where private profits are prioritized over public environmental well-being (Martin, 2022).

The proposed policy recommendations—strengthening environmental bonds, revising land damage taxes, implementing stricter audits, promoting economic diversification, fostering environmental awareness, and utilizing advanced technologies—offer a more comprehensive framework for managing the environmental challenges posed by the mining sector in both countries. Strengthening financial penalties and increasing regulatory oversight would incentivize companies to adopt more responsible practices. Investments in technology could improve monitoring and rehabilitation effectiveness, enabling more efficient and transparent tracking of mining operations and their environmental impact. In Canada, advanced technologies, such as remote sensing and real-time environmental monitoring, have been tested to enhance regulatory compliance in remote areas, providing valuable lessons for Australia (Martin, 2022).

Diversifying the economy away from overreliance on mining would reduce both Australia’s and Canada’s dependency on resource extraction, fostering a more resilient and balanced approach to resource management. Economic diversification could involve investing in renewable energy, technology, and sustainable industries that do not pose the same environmental risks. In both countries, encouraging the transition to green technologies and sectors would enable long-term economic sustainability while reducing ecological footprints.

Implementing these policy recommendations requires a concerted effort among regulatory bodies, industry stakeholders, and local communities in both Australia and Canada. Potential obstacles include political resistance from powerful industry groups and financial constraints, which may be addressed through phased policy rollout and inclusive stakeholder engagement initiatives. For instance, in Canada, several provinces have started integrating Indigenous communities into decision-making processes regarding mining projects, creating more equitable and sustainable development models (Canadian Mining Association, 2021). This approach could serve as a model for Australia, where collaboration with Indigenous communities on land use and environmental restoration is increasingly viewed as essential.

In conclusion, ensuring a sustainable future for both Australia and Canada requires a balanced approach that integrates economic growth with environmental stewardship. While mining remains a critical component of the economy in both nations, long-term national interests demand that environmental impacts are addressed rigorously. The adoption of a holistic policy framework, as outlined in this paper, would allow both countries to continue benefiting economically from their mineral resources while preserving their natural environments for future generations. This dual commitment to economic prosperity and ecological responsibility is essential for achieving sustainable development in the 21st century.

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