The Economics of Mine Waste Reduction: The Case of Ore-sand

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Background

Amid rising mineral demand for **the renewable energy transition** and a long-term **decline in the average grade of metal ore**, the volumes of mine waste are expected to increase significantly.

Waste management, remediation, restoration, and mine rehabilitation can represent enormous costs for mining companies, especially if a major tailings storage facility failure occurs, during which mining operations often cease while damage is repaired (Armstrong et al., 2019). In some cases, **primary output may also be constrained by the capacity of tailings storage facilities**.

These costs may be further exacerbated by failure risks associated with **climate change effects**, such as heavy rainfall (Piciullo et al., 2022).

We present an economic model to assess the private economic benefits of extracting large-volume by-products to reduce mine waste.

Using the case of **ore-sand–a type of manufactured sand that can be produced as a by-product of metal ore mining**–this paper quantifies profitability across various adoption scenarios.

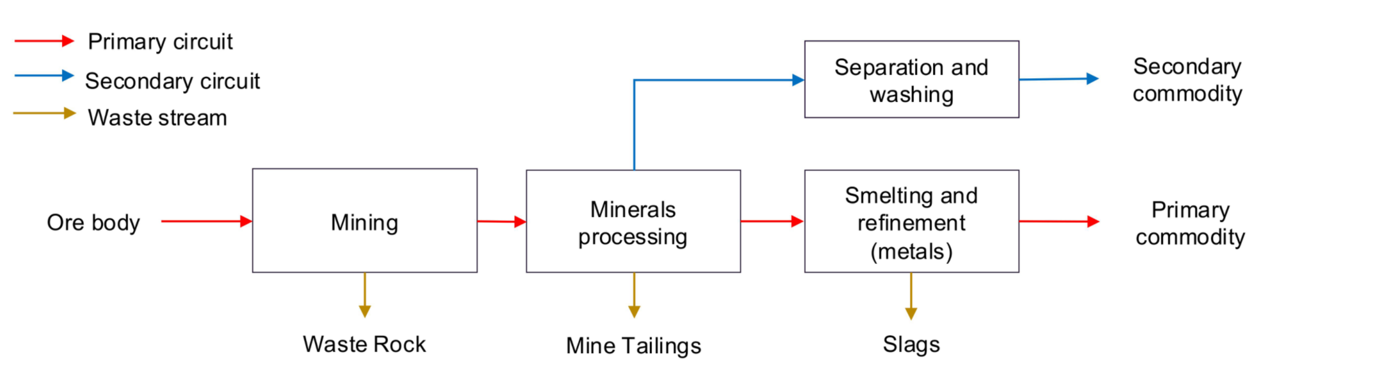

Figure 1. Production stages in a metal ore mine operation with secondary production.

Fig. 1 illustrates the stages of production in a representative metal ore mine operation with secondary production to reduce mine and metallurgical waste. Ore-deposits are mined, generating waste rock, and the extracted rock is processed. After mining, the mineral is processed, and the tailings waste from this process is placed in tailings storage facilities.

Secondary production of ore-sand reduces the waste material sent to tailings storage facilities, which translates into lower tailings risks, reducing failure likelihood, and lowering mine closure and rehabilitation costs.

Highlights

- We analyze the private economic incentives for mining companies to **reduce tailings through the adoption of large-volume sand by-products**
- We develop an economic model to quantify the effects of adoption using a representative medium- to large-scale iron-ore operation
- We use a parsimonious yet sufficiently detailed structure to capture the main elements of profitability of the operation and its response to various sources of uncertainty
- Our results demonstrate **substantial profitability in adopting ore-sand, though significant heterogeneity exists across the different scenarios**
- **Cost savings in tailings waste management and mine rehabilitation from the primary operation provide robust economic incentives for adoption**

Methods

To analyze the economic benefits of reducing waste material from mining operations, an **economic model was develop characterizing a representative medium- to large-scale iron-ore mining operation**.

The primary operation is calibrated with S&P data, while the secondary production is based on technical studies on ore-sand. The implications of various uncertainties related to adopting this secondary production technology were explored through simulation analysis.

The optimization problem of the mine i, producing $j = \{primary, secondary\}$ outputs, in a year t, is defined by:

$$\mathcal{V}_{i,t}(K_{i,t}, O_{i,t}) = \max_{\mathbf{x}_{ij,t}} \left\{ \pi_{i,t} + \frac{1}{1+\vartheta_{t+1}} \mathbb{E}\left[\mathcal{V}_{i,t+1}(K_{i,t+1}, O_{i,t+1})\right] \right\}$$

where ϑ_{t+1} is the discount factor, $\mathbf{x}_{ij,t} = \{L_{ijt}, E_{ijt}, O_{ijt}\}$, representing inputs: labor, energy, and ore inputs, and $\mathbb{E}\left[\mathcal{V}_{i,t+1}(K_{i,t+1}, O_{i,t+1})\right]$ denote the expected value over future capital and ore reserves. With yearly profits given by

$$\pi_{it} = p_{it}\mu_i \left(\sum_j \delta j Q_{ijt}^{\rho} \right)^{1/\rho} - \sum_j c_{ijt} Q_{ijt} - \varphi_i$$

where φ_i capture fixed costs associated to waste. With output prices following a stochastic mean reverting process, and inputs represented with Cobb-Douglas technologies (see paper for more details).

The simulated cost structure and production over the **mine's life of 30 years** is shown in Fig. 2, in which the **business-as-usual scenario (without secondary production) is compared to the most conservative adoption scenario**.

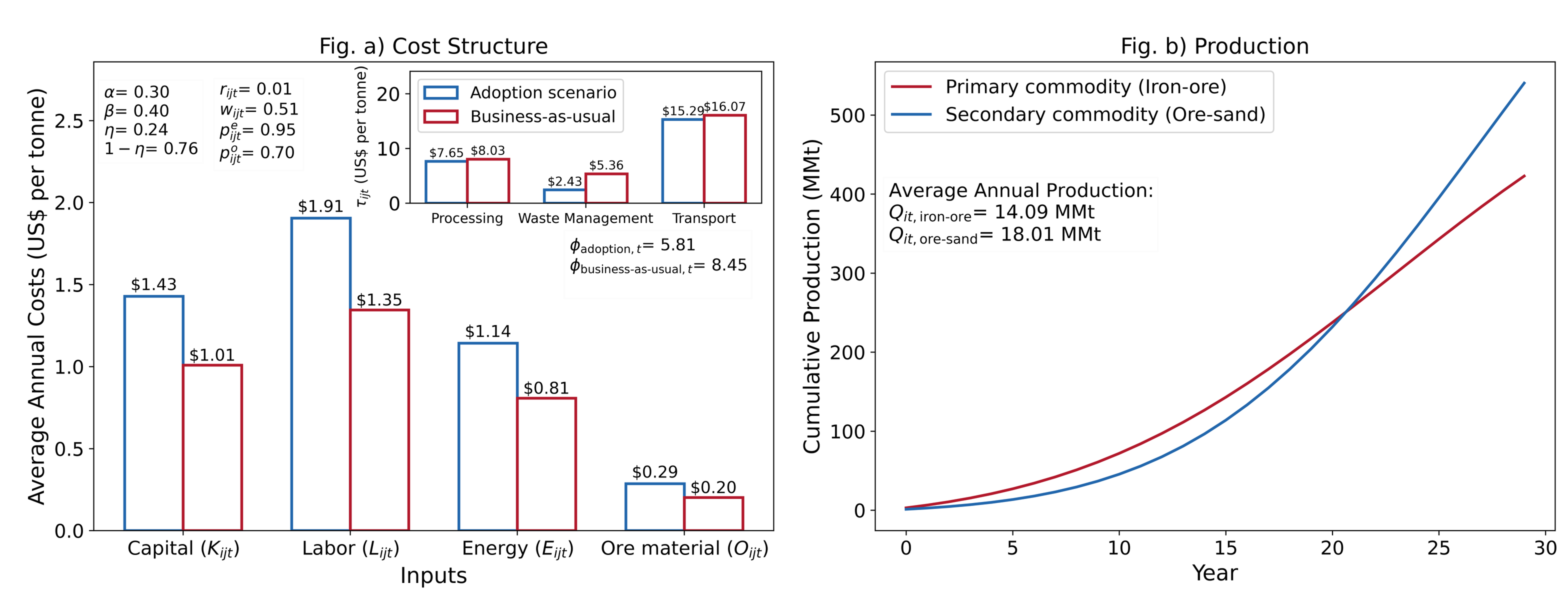

Figure 2. Cost structure and production over the mine's life.

The annual average total costs with adoption amounted to **36.06 US$ per tonne**, whereas for the business-as-usual scenario, costs were **41.28 US$ per tonne** (Fig. 2.a). These values represent approximately 28% of the mean output price in the adoption scenario (130 US$ per tonne, including both primary and secondary production) and 34% in the business-as-usual case (120 US$ per tonne of iron-ore).

The totals of iron-ore and ore-sand produced during the mines' life amounted to more than 400 and 500 million dry metric tonnes, respectively (Fig. 2.b). With an average annual production of iron-ore of 14.09 MMt, and 18.01 MMt for ore-sand, representing **an average annual production ratio of approximately 1.3 tonnes of ore-sand per tonne of iron-ore.**

Results

Results of the annual and discounted profits from simulations under different adoption scenarios are reported in Fig. 3, considering a **3% annual growth rate** and a **5% discount rate**. The analysis includes two commercialization scenarios–one with low and another with high waste management and rehabilitation costs–, and two scenarios with and without ore-sand commercialization under identical conditions.

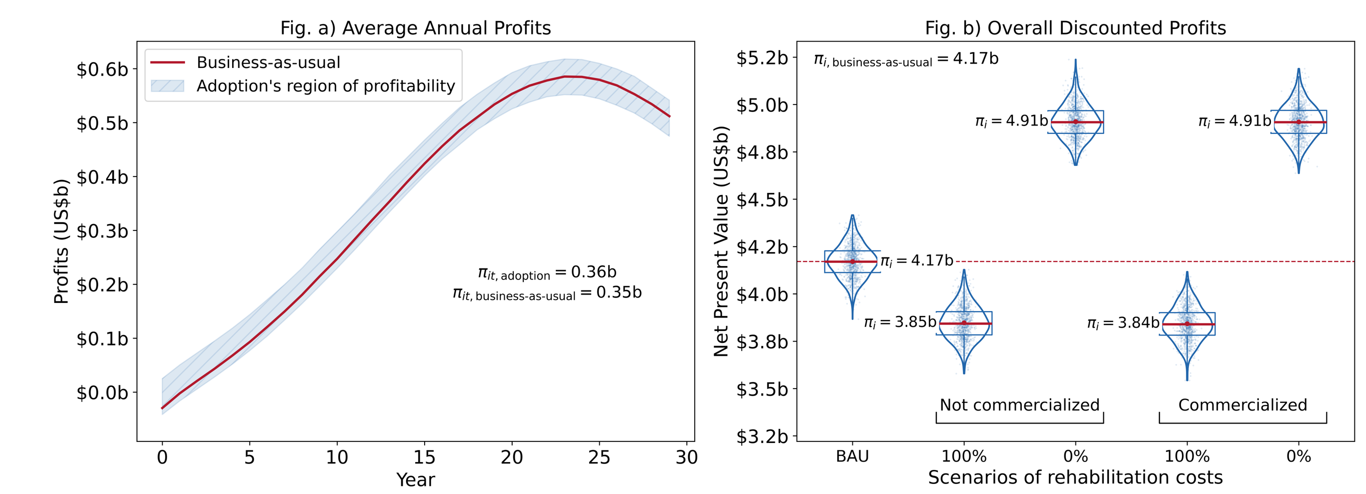

Figure 3. Economic benefits from the adoption of ore-sand.

Results suggest significant potential benefits from adopting ore-sand production. However, the magnitude of these gains depends on the extent to which ore-sand production reduces waste management and rehabilitation costs.

The **profitability of the adoption scenario has proven robust to revenue productivity shocks**, which include potential variability driven by deposit-specific or geological factors, such as ore grades and the concentration of silicate minerals in ore-sand. These factors can affect the cost efficiency of processing but are not enough to offset profitability.

	Discount Rate								
	4%			6%			8%		
	Waste Management and Rehabilitation Costs								
	20%	40%	60%	20%	40%	60%	20%	40%	60%
Growth Rate									
1%	1.33	1.08	0.93	0.98	0.83	0.67	0.79	0.62	0.46
2%	2.88	2.61	2.31	2.16	1.88	1.72	1.59	1.44	1.26
3%	5.3	5.31	4.84	3.87	3.63	3.61	2.91	2.78	2.48
4%	9.38	9.07	8.62	6.41	6.45	6.03	4.79	4.62	4.37
5%	15.53	14.62	15.03	10.36	10.72	10.2	7.67	7.46	7.5

Table 1. Profitability, growth and discount rates, and waste management and rehabilitation costs.

Table 1 presents the Net Preset Value (NPV) under different combinations of annual growth rates, discount rates, and waste management and rehabilitation costs.

The strong compounding effect of production growth translates into substantial profitability gains, especially at lower discount rates. This is a critical consideration for ore-sand adoption, particularly since primary production may be constrained by the volume of waste material generated. The significant variation in the NPV across different growth scenarios underscores the **potentially large gains that could result from expanding production capacity through waste reduction**.

The high heterogeneity of results highlight possible opportunities for policy intervention, particularly in **mitigating risks associated with the adoption decision, such as uncertainty from price volatility and ore grades**.

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