Can the value chain of mining tires be circular? : The case of Chilean Mines

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The manufacturing of low-carbon technologies requires more metals and minerals than the manufacturing of conventional fossil fuel technologies (The World Bank, 2020). Therefore, the production of metals and minerals becomes crucial for the effective transition towards decarbonization, a key element for achieving sustainable development worldwide. However, increasing the demand for metals and minerals results in the generation of different and massive wastes such as mining scrap tires. In fact, today the mining industry is one of the world's leaders' generators of waste high tonnage tires (Oyola-Cervantes & Amaya-Mier, 2019). A typical mining truck tire has a height of around 4 meters, which exceeds 70 times the diameter of conventional passenger transport tires. Moreover, mining truck tires have a useful life of only seven months, and they are commonly discarded in stockyards after their use. In other words, due to non-stop production of metals and minerals and the short lifespans of mining truck tires, vast quantities of mining scrap tires have been accumulated in stockyards that can be seen even from the space (Australia's Mining Monthly, 2019).

Taking into consideration this problem, it is critical to assess how to transform from a linear value chain of mining truck tires to a circular value chain (Reike et al., 2018). In the scientific literature, several investigations have been focused on evaluating technologies that can extend the useful life of tires or recycle them. For instance, some researchers have proposed that tires can be retreaded for extending their use (Leung & Wang, 2003a), incinerated for producing energy (Machin et al., 2017a), or recycled for recovering materials through pyrolysis (Alam & Qiao, 2020; Machin et al., 2017b), gasification (Kaur et al., 2021; Leung & Wang, 2003b; Machin et al., 2017c) or liquefaction processes (R. Chen et al., 2022; Nkosi et al., 2021). Other investigations have evaluated the environmental, economic, and social impacts related to the use of these technologies (Bowles & Fowler, 2022; Chen et al., 2022; Goksal, 2022; Valenzuela-Levi, 2021). However, all these investigations have focused on assessing the transformation of conventional scrap tires. To the best of our knowledge, there are scarce or even inexistent investigations focused on assessing the transformation of mining scrap tires.

Conventional and mining tires differ in composition, materiality, and size. In the case of mining tires, the exact material composition of the tires is managed confidentially

by the manufacturing companies (Essadiqi, 2005). Regarding materiality, a mining tire mostly has natural rubber to support the tons of ore transported by long distances. On the other hand, a conventional tire prioritizes the use of synthetic rubber to improve grip on asphalt at high speeds. Finally, depending on the size, mining tires have a size above 57 inches, while conventional tires have a size below 57 inches. These differences mean that the results of investigations focused on conventional tires cannot be directly applied to mining tires.

To shed light on this gap, this research aims to assess the opportunities, challenges, and impacts of the transition from a linear to a circular value chain of mining scrap tires. To achieve this aim, we have considered a case study of mining companies operating in Chile since it is one of the main mining countries in the world. In fact, Chile is the leading copper producer in the world as it supplies a third of the global copper output (USGS, 2021). The copper mining industry has historically been a fundamental pillar of the Chilean economy. For instance, in 2021, copper mining accounted for approximately 13% of the GDP, with copper exports contributing 48% of total exports, and 3,18% of employment at the national level (Cochilco, 2021). In this context, the case study of Chile allows us to understand the phenomenon of mining scrap tires. In turn, leading mining multinationals (e.g., Xstrata, BHP, among others) operate in Chile, which are committed to operating more circularly since failures to meet expectations or legislated standards lead to the destruction of company value, whether these failures are environmental or safety-related. Moreover, since 2016, the extended producer responsibility (EPR) law has forced producers to take charge of the waste. Finally, in Chile, there are companies and researchers who have started to design and implement pioneering recycling and reusing processes for mining tire scrap.

We have selected a case study because this method is defined as an in-depth description of a bounded system, which will facilitate obtaining a comprehensive appreciation and insights into contemporary aspects of the unique and singular technical and social factors that affect the mining companies on the path toward circular economy. The case of study involved two main stages. First, we have reviewed the literature and companies' archival data to evaluate the technologies and the environmental (e.g., CO2 emissions) and productive (cost and percentage of valuation) impact of these technologies. Second, we have interviewed 6 experts of mining and recycling companies, and then by inductive and recursive analysis, we have identified opportunities and challenges for the transit of the mining tires toward a circular path.

Theoretically, this research demonstrates that pyrolysis and retreading reduce CO2 equivalent emissions by 90% and 70%, respectively, compared to tire disposal. From an economic standpoint, retreading can yield seven times more benefit than the sale of pyrolysis byproducts (carbon black, pyrolytic oil, and steel). Therefore, implementing some of these technologies to attain a circular economy is technically feasible.

However, mining companies have a high risk of accidents that can be catastrophic for employees or the environment, which motivates them to prioritize short-term efficiency and operational continuity. These characteristics make experimenting with new technologies more difficult and even hazardous, impeding the implementation of new circular technologies such as refurbishment, which are inherently uncertain and

expensive. Similarly, the absence of a manufacturing industry that incorporates the reuse of pyrolysis products, a problem shared by the region. The findings of this study indicate that the implementation of a circular economy is not only a technical challenge, but also a sociotechnical issue that must be addressed comprehensively.

Lastly, empirical studies on the transition to a circular economy have often left out developing contexts. This has skewed the growing body of evidence and policy discussions toward advanced economies, which have different resources, capabilities, and needs than developing countries. Therefore, the results of this study contribute to identifying the specific barriers and enablers facilitating the development of ad-hoc public policies that foster circular economy in these particular contexts.

Keywords: Circular Economy, mining scrap tires, supply chain, socio-technical analysis, pyrolysis, retreading.

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