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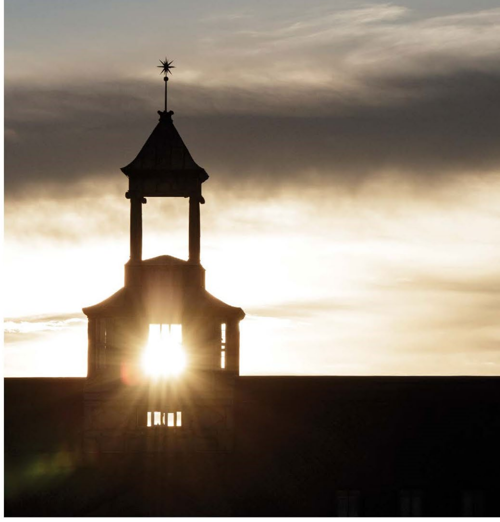

How effective are environmental taxes in the mining industry?

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Abstract

Environmental taxes allow mineral-producing countries to account for their mining footprint. However, several factors can limit their effectiveness. This article uses a cash flow model to critically examine the principles of tax regimes and the obstacles to design and apply environmental taxes in mineral-rich developing countries. Resistance is the first obstacle, mostly in economies with high dependency on mineral earnings. That is because environmental taxes are regressive as they aim to discourage harmful behavior rather than increase public revenues. This corrective tax purpose will affect the tax system's progressivity, simplicity, and neutrality. Consequently, implementing environmental taxes suggests that governments should redefine priorities with less emphasis on maximizing revenue. Nonetheless, measuring most tax bases and rates is difficult, and environmental taxes are no exception. Furthermore, flaws in environmental tax design can reduce their effectiveness. For example, only if the tax rate is set at an appropriate level, environmental taxes will give enough incentives to pursue mitigation strategies to minimize damage. On the other hand, when applied as an *ad valorem* charge on production, such as a royalty, Pigouvian taxes can be affected by transfer pricing manipulation. Therefore, the opacity of market prices can also compromise the effectiveness of environmental taxes. The results of this study confirm that authorities cannot design environmental taxes in the mining sector in isolation from other taxes. It must consider existing and new distortions of the tax system. Although this study focuses on the lithium mining sector in Chile, the findings may have implications for global coordination to implement environmental taxes in the mining industry.

Keywords: Environmental tax, global carbon tax, mining impact, ecosystem preservation, fiscal policy

1. Motivation

Low-carbon technologies are driving the current minerals super-cycle. As mineral prices rise, mineral-rich countries tend to accelerate resource depletion and implement fiscal measures to increase public revenue. The windfall is apparent, but some mining costs remain hidden. Mineral exhaustion comes at an ecological cost that business as usual has failed to account for. However, policymakers can ensure that environmental impacts are minimized and, if possible, avoided. One way to do this is by implementing environmental taxes to deter the industry from harmful behavior and compensate society for eventual damages. Tax regimes can therefore enable mineral-rich countries to capture windfalls, transform their economies, and influence how extractive companies treat the environment. The critical questions are, what factors can limit the effectiveness of Pigouvian taxes? Moreover, what fiscal policies for the mining sector are most likely to facilitate social and economic transformations in a fair and sustainable manner? This paper aims to answer these questions and use a financial approach to analyze the impact of environmental taxes on the Chilean lithium sector.

One of the main obstacles to implementing environmental taxes is that it can reduce mineral production (Roa et al., 2023), which can result in a significant drop in GDP and a deficit in the balance of payments (Mardones, 2022). At the country level, those effects are unfavorable in an economy with a high dependency on mineral export earnings like Chile.[1] Globally, lower mineral availability is undesirable if it implies slower energy and digital transitions (Roa & Rosendahl, 2022).

Rather than market-based tools, command-and-control policies and corporate citizenship (e.g., benefit-sharing agreements) have been the dominant methods for bringing sustainable development priorities to the private sector. However, industry initiatives are voluntary and can be abandoned in difficult economic times; depending on the community's bargaining power, they vary greatly between companies and projects, and compliance can be an issue (O'Faircheallaigh, 2015). Therefore, non-market-based policies have yet to prove to be the most effective way to protect the environment and regulate the mining sector.

The rush to meet energy transition mineral demand has resulted in projects being "fast-tracked" without adequate consultation and licensing procedures (Owen et al., 2022) and leading to more mining licenses in jurisdictions with weak governance (Carballo & Sahla, 2022). In Chile, the government has recently published a guideline (SEA, 2021) requesting companies to list and classify the effects of lithium mining on the environment without asking for any economic quantification of damages. A lack of quantifying damages increases the risk of overlooking the severity of mining's environmental impact (Gavin, 2004), which can result in economic benefits exclusive to mining companies at the expense of ecological losses, liabilities to human health, deepening inequality, and triggering long-term conflicts.

Environmental issues often trigger conflicts between mining companies and communities, and mining companies fail to adequately factor in the costs of conflict (Franks et al., 2014). For example, the Maricunga project, the second-largest lithium reserve in Chile, has escalated from demonstrations to tribunals. The project generates controversy due to blind spots in the environmental impact assessment, ignoring and bypassing communities' consent and underestimating the project's impacts on ecosystems and their cultural values.[2] Evidence has shown that the mining sector has long harmed the High-Andean wetlands on a social and environmental level (Blair et al., 2022).

Strategies to enhance the sustainable use of critical minerals such as lithium require a long-term and holistic perspective. Lithium mining is essentially groundwater mining from beneath arid basins. The process generates large volumes of salt mixture waste, which is reinjected back into the ground. As a critical refuge for native and migratory species, this dry landscape includes internationally recognized (Ramsar) wetlands

[1] Mining contributes 10% of the GDP and 52% of total exports. Critical materials such as copper and lithium are abundant in Chile, which makes it an important player in the global mineral market. According to the USGS (2022), Chile is the world leader in mine copper production (5.6 million tons in 2021) and the second-largest producer of lithium (26 thousand tons in 2021).

[2] More information about the Maricunga'a conflict can be consulted in Fundación Terra in this *link* (consulted in November 2022).

and protected areas. The vitality of ecosystems depends on water coverages and underground hydrological balances, and reservoirs may take decades to replenish (De la Fuente et al., 2021). Lithium mining expansion has already been correlated to environmental degradation during the last two decades in the Atacama salt flat in Chile (Liu et al., 2019). There is still uncertainty, however, on how brine extraction changes the underground hydrological balance and impacts sensitive ecosystems on the surface (Roa et al., 2023). The difficulty in accurately measuring the environmental impacts of mining operations can limit the effectiveness of any policy governing the mining sector.

The conflict in Maricunga is not an isolated case and may well represent common resistance to the extractivist aspects of the energy transition (Owen et al., 2022; Walter et al., 2021), and shows that traditional approaches to protect the environment and regulate the mining sector are insufficient to avoid conflict.[3] This issue also makes evident the need to translate social and environmental risks into business costs.[4] Indeed, when conflict costs are quantified, mining companies are more likely to reconsider corporate behavior and project design (Franks et al., 2014). It is, therefore, possible to investigate the opportunity costs of mining from a project and financial perspective, allowing us to explore the use of environmental taxes to strengthen mining regulations.

Tax reforms, however, may reduce mining profits, increasing the risk that companies will seek ways to minimize tax payments. Tax risks, like profit shifting along the extractives value chain, increase when foreign-owned companies have reserves, processing plants, and operations in different countries with substantial differences in tax regimes. In such conditions, mining companies have an easier time shifting profits to low-tax countries in order to minimize taxes (Beer & Devlin, 2021; Delis et al., 2022).

Discrepancies in regulations, like lack of transparency, exacerbate tax risks. In Chile, most major mining firms are multinational companies not obliged to disclose their financial accounts (Jorratt, 2022). At the same time, evidence that mining firms in Chile engage in profit-shifting has increased during the last decade (Solimano & Guajardo, 2018). While the debate continues about the effectiveness of government measures to deal with profit shifting (Bustos et al., 2022), researchers have yet to examine to what extent additional taxes, like environmental taxes, can aggravate this problem and create other distortions in the mining tax system.

To date, few studies have investigated how to account for the environmental impact of lithium mining (Roa et al., 2023). Other studies demonstrate that mining would be less financially affected by a global carbon tax than other industries because mineral extraction yields high economic rents (Cox et al., 2022). Although some research has been carried out on the economic rents and tax system of lithium mining in Latin America (Jorratt, 2022), the fiscal effects and challenges of enforcing environmental taxes on the lithium sector have yet to be discovered. It is still necessary to understand whether environmental taxes are effective in minimizing mining footprints and to what extent they encourage companies to do so.

This paper aims to critically examine the fiscal and financial aspects of taxing environmental damages. By employing a cashflow model, I analyze the Chilean lithium tax regime and look for generalizations that can be applied to the mining industry. I set an initial structure and level for carbon taxes and Pigouvian taxes for ecosystem damages (section 2). Then, (in section 3), I examine key features of tax systems such as progressivity as profits change, simplicity of tax bases, neutrality on new investments, and the reliability of the tax system at low-profit levels. In section 4, I discuss alternative scenarios for environmental tax reform in Chile, considering low and high tax levels and the possibility of reducing tax payments in legitimate and

[3] According to the Environmental Justice Atlas and Mining Watch Canada (2021), in the Americas are registered forty-nine (49) conflicts around environmental issues of critical minerals extraction. Lithium projects have raised eighteen (18) conflicts, five (5) in Chile. Socio-environmental conflicts are defined as mobilizations by local communities and social movements, which might also include support of national or international networks against mining activities, infrastructure construction, or waste disposal whereby environmental impacts are a key element of their grievances. See more in https://ejatlas.org/

[4] The Maricunga mining project is supposed to start in March 2022 with a capital expenditure of US$627 million. The company may suffer roughly US$2.75 million per week of delayed production.

non-legitimate ways (section 5). I finally discuss the implications of this study and suggestions for future work and conclusions (Section 6).

Based on the Maricunga lithium mining site in Chile, this study focuses on project-level analyses. It cannot cover the regional and national impacts of the project. Welfare and revenue distribution measures are beyond the scope of this analysis.

1.1. A review of the fundamentals of environmental taxes in the mining industry

Environmental taxes can be used to determine the "true price" of mineral exhaustion. Because mining damages impose costs on others, the social marginal costs (SMC) are higher than the private costs. Thus, environmental taxes are intended to equalize social and private marginal costs. The most common environmental damages of mining exhaustion are deforestation, soil erosion, air and water pollution, and natural habitat devastation. Taxes, however, might not be suitable to minimize all mining damages.

Sustainable mining suggests defining thresholds where damages can be avoided, minimized, restored, compensated, and offset (Figure 1). The estimation of optimal environmental taxes can depart from such thresholds and guide the decision path to advance mitigation strategies. It means that taxes should be used after reasonable actions have been taken to avoid and minimize damages. Such actions suggest denying mining licenses when mining is unsafe and poses risks to highly vulnerable and valuable ecosystems. It might also be necessary to reduce the project size before it starts and set quotas to limit water and brine depletion, as in the case of lithium mining in the High-Andean wetlands.

Figure 1. *Environmental and natural resource decision chain*

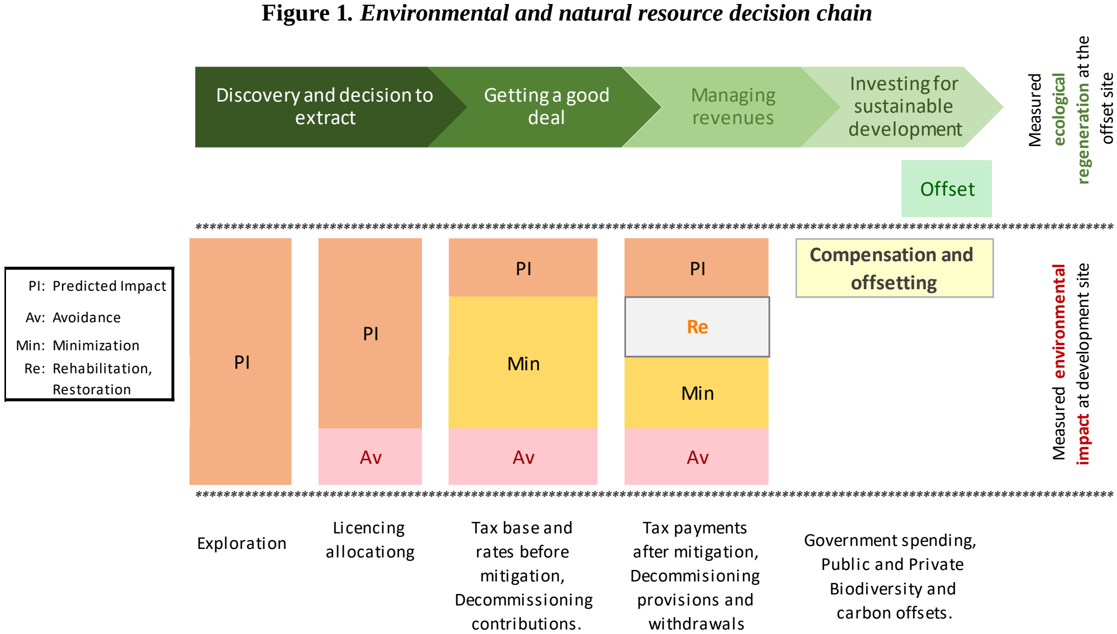

Fig. 1. Adapted from "The Natural Resource Charter" (NRGI, 2014); and "Biodiversity Offsets", Policy Highlights (OECD, 2016)

Environmental taxes must be justified primarily by the cost-effective achievement of environmental goals (Fullerton et al., 2008). If the tax rate is set at an appropriate level, environmental taxes will give enough incentives to pursue mitigation strategies to minimize damages. For example, brine lithium is processed using diesel-fueled thermal power plants. Suppose that alternative energy sources, like wind or solar power, are available and are cost-competitive. In that case, a certain part of the damage can be minimized, and in the end, it will reduce carbon tax payments. Other damages to habitat and ecosystem services might be irreversible, and the residual impact must be compensated with complementary instruments (e.g. carbon and biodiversity offsets).

Environmental taxes are regressive as they will likely deter low-grade, high-environmental-cost projects. When considering the whole tax system and profits on a lifetime basis, a regressive fiscal regime means an inverse relationship between profits changes and the government share of profits, i.e., the lower (higher) project's profits, the higher (lower) the government share. Lower profitability may come from lower prices or higher costs. And environmental damages are an additional and hidden cost of mining independent of the mineral market value.

In contrast to regressivity, a tax regime can be progressive if it considers that profit levels can change across the lifetime of a project and vary across different projects. Progressivity also implies a direct relationship between profits changes and the government share of profits, i.e., the higher (lower) are project's profits, the higher (lower) the government share or tax revenue. The literature (Daniel & Goldsworthy, 2010; IMF, 2022) suggests that progressive rate schedules may have appeal in terms of political economy, being more robust against political pressures in the event of high return outcomes than regressive schemes. Chilean big business, like mining, has had a long-standing and major influence on public policy and opposition to increasing tax burdens (Fisse & Thomas, 2014; Solimano & Guajardo, 2018). Thus, implementing regressive policies, such as environmental taxes, may meet with controversy and resistance from mining companies.

Government can still justify a less progressive system when pursuing further objectives (Wen, 2018). Despite profit distortions, an environmental tax can contribute to economic welfare if it provides environmental benefits, i.e., reduces pollution, and enhances ecological conservation. (Perman, 2003). Ultimately, environmental taxes have a regressive component by design because their goal is to discourage harmful behavior rather than increase public revenues. Therefore, tax regimes can be an instrument to enhance environmental preservation while seeking to maximize welfare rather than revenue.

Revenues from environmental taxes can be unpredictable and unstable. The tax base can be eroded due to mitigation actions by mining companies. Still, additional environmental tax revenues can possibly create distortions in the tax system. For example, Pigouvian tax revenues may exceed other public revenue sources (e.g., profit or income taxes) and crowd out other government sources of income. In Chile, there is evidence that mining tax windfalls have crowded out local revenue, promoting tax laziness among municipalities (Oyarzo & Paredes, 2019). One way to avoid distortions from environmental taxes is to put them back into the economy in a lump-sum way (Oates, 1995). For example, Pigouvian taxes can compensate victims for irreversible damages; and to finance all the supportive services related to it (e.g., capacity building in environmental agencies, R&D, infrastructure to monitor ecosystem changes, and data collection).

Environmental taxes not only induce mitigation damage and generate potential revenues but may also reduce the costs of the tax system. This is the so-called "double dividend" hypothesis. According to this hypothesis, revenue from environmental taxes can be earmarked or redirected to reduce other taxes. If those other taxes have distortionary effects, reducing their rate will create efficiency gains (Perman, 2003). Extensive theoretical studies support the double dividend hypothesis (Fullerton et al., 2008; Goulder, 1994; Oates, 1995; Perman, 2003). However, despite environmental benefits usually being achieved, the economic dividends of environmental taxes remain ambiguous and require further study (Freire-González, 2018; Patuelli et al., 2005).[5]

Although market instruments entail risks, tax policies are critical to environmental regulation since they allow governments to prioritize the most pressing issues (Taylor et al., 2012). A global concern on climate change has focused on greenhouse gases, particularly carbon emissions; therefore, carbon taxes have been a prominent research topic.

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[5] In praxis, it is hard to see the number of tax reforms that have implemented environmental taxes and in parallel, reduced other taxes. In Australia, discrete tax concessions related to environmental matters have been enacted, e.g. a concessional WHT rate of 10% can apply to distributions from a managed investment trust (MIT) that holds only 'clean buildings' (*see* here *for further details*).The reduction occurs despite the fact that Australia does not impose a tax on carbon emissions or have an emissions trading scheme either.

The mining sector globally contributes to an important share of carbon emissions. At the same time, many mining industry products have an exceptionally high value per ton of CO2 emissions compared to other sectors (e.g., agriculture and construction) (Cox et al., 2022). That high added value can be associated with high economic rents of mineral extraction, which implies that the mining industry would be less financially affected if a global carbon tax were introduced compared to other sectors (Cox et al., 2022).

In contrast to carbon taxes, up to now, far too little attention has been paid to taxes for ecosystems damages. To my knowledge, no mineral resource-rich country has implemented environmental taxes associated with ecosystem damage or water pollution. Although challenging, the potential ecological wealth losses from mining activities can be quantified, making it possible to calculate optimal tax rates that reflect the marginal environmental damage and subsequently calculate the mining profits forgone for ecosystem preservation.

Overall, environmental taxes can be an efficient solution to reduce the environmental impact of mining operations, but their effectiveness depends on several factors. There remain numerous aspects of the financial and fiscal implications of environmental taxes on which this research is focused.

2. Financial models and input data

Recent advances in financial cashflows models have assisted the analysis of fiscal reforms in extractive industries (Tarras-Wahlberg, 2022). The benefit of this approach is that it allows the design and evaluation of a fiscal regime by assessing a mining project's economic and financial characteristics. Another advantage is that it allows estimating the government and investor participation in a resource project, thus providing indicators and results in language understandable to business and financial analysts and government professionals. Currently, there are three well-known models publicly available. The first model is the "Fiscal Analysis Resource Industries" – FARI – by the International Monetary Fund.[6] The second model was developed by the Natural Resource Governance Institute (NRGI)[7]; the third one was developed by the ECLAC (United Nations)[8]. This study uses the FARI model to estimate the effects of environmental taxes, including sensitivity analysis, and I use the other two models to compare and verify preliminary estimations on project profitability and tax burden.

In this study, the input data comes from the Maricunga lithium project in Chile developed by the Company Minera Salar Blanco S.A.[9]. At full capacity, during 20 years of operation, Maricunga can provide roughly 4% of the global lithium supply.[10] The model inputs on fiscal regime parameters are presented in Appendices.[11]

The implications of changing fiscal regimes consider investors' and government's perspectives. From an investor's perspective, two key indicators are the project's post-tax net present value (NPV) and the post-tax internal rate of return (IRR). From a government perspective, two key indicators are the average effective tax rate (AETR) and government tax revenues. The AETR results from dividing the government tax revenues by the project cash flows. Table I displays a summary of the Maricunga project cashflows. The first column is the company estimations, and the following three columns are own estimations.

Table I. *Comparison of Maricunga's project financial indicators among sources and models' output*

	Company estimations	*Own estimations by model*

[6] The IMF model is available at: https://www.imf.org/en/Topics/fiscal-policies/fiscal-analysis-of-resource-industries
[7] The NRGI model is available at: https://resourcegovernance.org/economic-models
[8] The ECLAC – United Nations – model is available here: https://repositorio.cepal.org/handle/11362/47807
[9] Minera Salar Blanco S.A. (MSB) is a Chilean joint venture created in 2016 to explore and develop the Maricunga lithium project, in the Atacama Region, northern Chile. The company is owned by the Australian international firm Lithium Power International Limited (51%), the Chilean mining company Minera Salar Blanco S.p.A. (31%) and the Canadian Bearing Lithium Corp. (18%).
[10] According to USGS (2022), world lithium production was around 430 thousand tons of LCE in 2021. That year, Chile provided around 26% of that total production. The Maricunga project will produce 18 thousand tons, when at full capacity, increasing the Chilean global supply share by up to 30%.
[11] The data and excel model can be available under request.

Participants cashflows *(US$ Million NPV 8% real)*	Minera Salar Blanco S.A.	FARI (IMF)	NRGI	ECLAC (UN)[a]
Project pre-tax net cash flow	1 971	1 971	1 970	2 209
Government tax revenues	559	1 370	1 332	1 429
Government share (AETR discounted 8%)	28%	71.5%	67.6%	64.7%
Pre-tax IRR (Project's IRR)*	44.5%	35.1%	35.1%	30.9%
Post-tax IRR (Mining company's IRR)**	39.6%	18.6%	19.5%	19.1%

[a] *Nominal values without inflation effects*
**Project cashflow before taxes and decommissioning fund*
*** Net cashflow after fiscal regime: (Parent company returns excluding loan and related financial costs)*

The Company Minera Salar Blanco S.A. calculations come from their investor reports for 2022.[12] Following the Company's assumptions, all model estimations are based on an average lithium price[13] of US$ 24 000 per ton of LCE (constant 2022 USD) and assume no borrowing funds to leverage initial capital investments.

Table I illustrates the sensitivity of the project's financial results subject to methodological differences and data assumptions. The NRGI is derived from the FARI model, so both have a very similar structure, and the main differences lie in how the models treat the variable royalty rule, tax refunding (VAT), and depreciation schedules. The ECLAC model has a more robust assessment of the Chilean tax system and depreciation estimations. However, it only allows estimations for a 40-year period, does not assume equity and leverage shares, and all values are nominal without inflation effects. The FARI model considers carbon taxes and allows plugging other Pigouvian taxes into the analysis. Therefore, the rest of the estimates presented in sections 3 and 4 are based on the FARI model.

Decommissioning costs are another important source of difference in estimates. The Company does not present a plan to stabilize and rehabilitate the exploitation and production area after the mining closure. Therefore, it does not recognize the associated decommissioning costs. Financial management of closure costs and provisions affects capital, financial costs, and tax payments. For illustrative purposes, this study considers a decommissioning cost of US$33 million distributed over the last three years of operation.

Waste is a critical source of environmental damage since lithium extraction is chemical-intensive and generates large volumes of water and solid waste. However, the Company does not present information on recovery rates or a waste management plan. They only mention that solid waste will be sent by trucks to discard piles, and it will be handled following the current regulations of Chile. Such rules apply to copper waste and tailing management but not to lithium.

The lack of disclosed information and limited scientific knowledge makes it problematic to assess the entire lifecycle environmental impact of lithium mining. Due to practical limitations, this study focuses on environmental impacts related to ecosystem damage and direct carbon emissions from lithium production.

2.1. Pigouvian taxes for ecosystems damages

Without any conservation policy, lithium mining may destroy overlapping ecosystems. A way to minimize wetlands damage can be by imposing a tax that deaccelerate mineral extraction paths and reduces environmental damage (Roa et al., 2023). This section presents the tax base and rates of Pigouvian taxes for ecosystem damages.

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[12] The data used for this exercise comes from the investor's reports of the Lithium International available at their website https://lithiumpowerinternational.com/maricunga-chile/, consulted on January, 2023.
[13] According to the USGS Mineral commodity Survey (2023), the estimated lithium price per metric ton of LCE is US$ 37 000 during 2022. According to the Central Bank of Chile, the average lithium price received from lithium exports during the first semester of 2022 has been US$ 49 000 per ton and it is expected to observe an average of US$ 24 000 per ton by the end of 2022. (cf. Indicadores de Comercio Exterior segundo trimestre 2022, consulted on February, 2023.

Maricunga is one of the highest ore grades mining sites at current lithium prices, holding the second-largest lithium reserves after Atacama (Figure 2). Among seven salt flats in Chile where lithium has been discovered, Maricunga is the third largest wetland size. Economic rents, wetland size, ecosystem values, and damage levels are all important factors in determining the corresponding Pigouvian tax rate to compensate for ecological damages (Roa et al., 2023).[14]

Figure 2. ***Mineral revenues, ecosystem size and ecosystem values in seven salt flats in Chile***

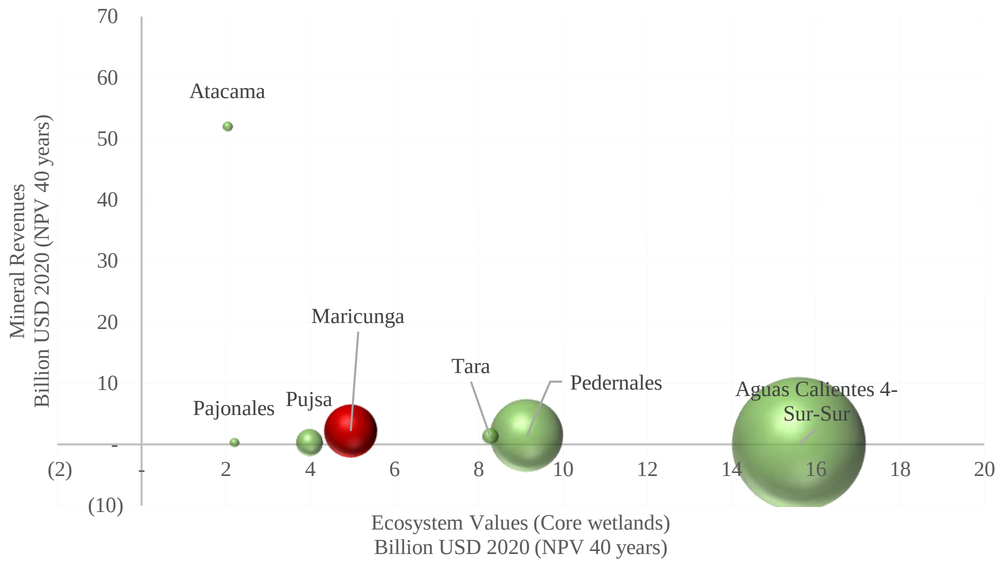

Table II shows how taxes for ecosystem damages in Maricunga vary with wetland size, ecosystem values, and damage level.[15] Estimations are based on Roa et al. (2023).

Table II. *Tax levels and rates by wetland size and ecosystems values and damages (USD per Ton and % of lithium price)**

Wetland coverage	*Average tax*	*Tax for high ecosystem damage*	*Tax for high ecosystems values*
Core (small)	197 (1.2%)	300 (1.8%)	430 (2.5%)
Semi-periphery (medium)	380 (2.2%)	570 (3.4%)	830 (4.9%)
Periphery (large)	650 (3.8%)	980 (5.8%)	1430 (8.4%)

** Estimations are presented by wetland coverage in USD per ton of lithium produced and as a lithium price percentage (current 2021 US 17 000 per ton). According to the USGS survey, during the last eight (8) years, around US$ 12 000 per ton, with a minimum of US$ 6000 per ton and a maximum of US$17 000.*

Table II shows that the tax range goes from 1.2% to 8.4% of the lithium price, depending on assumptions about the wetland coverage, ecosystem values, and damages. These rates are comparable to the estimations by Tost et al. (2020), who assume that the cost of ecosystem damage can be passed on to consumers through higher mineral prices. Such prices can increase between 0.8% and 7.9%. In the analysis in sections 3 and 4, I use only the minimum (1.2%) and maximum (8.4%) tax rates to show the fiscal implications of environmental taxes. The behavioral responses to low and high environmental taxes are presented in Section 4.2. and 4.3., and the effects on revenues in section 4.4.

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[14] In Chile, the largest reserves of lithium are placed in the Atacama salt flat where two companies have been producing lithium during the last decade. The second largest lithium reserves are in the Maricunga salt flat where other companies are preparing to starting lithium production in 2023.

[15] According to De la Fuente (2021), wetlands dynamics in the High Andean Chile depends on seasonal evaporation and precipitation rates and groundwater recharging. Wetlands' size can be distinguished between areas that are not covered less than 16%, 50%, and 84% of the time. The former category (16%) only includes areas covered with vegetation or water most of the time (84% or more) and can be thought of as the core of the wetland. The latter category (84%) includes a much larger *peripheric* wetland sporadically covered with vegetation or water (but at least 16% of the time).

2.2. Carbon taxes

In 2019, Chile's total CO2 emissions were the fourth largest in Latin America, after Mexico, Brazil, and Argentina. Considering the emissions per unit of GDP (kg per PPP of GDP), the Chilean economy is the most polluting in the Latin American region.[16] When counting direct and indirect emissions, mining is the third most pollutive sector in Chile, with 20% of the total CO2 emissions, after the transport sector (29%) and industry (37%) (Avilés-Lucero et al., 2021). These estimates reflect how important it is to decarbonize the mining sector and trace the path to decarbonizing one of the largest economies in Latin America.

In Chile, carbon taxes were implemented in 2017, with an average tax rate of US$ 5 per ton of CO2, much below the average social cost of carbon estimated by the Chilean government[17] (US$ 32.6 per ton of CO2) and recommended by consultancy companies (US$ 40 per ton of CO2).[18] By 2020, just two copper companies had paid carbon taxes, which suggests that the majority opted for tax deductions via carbon offsets (Mardones, 2022).

In this analysis, the carbon tax applies to direct emissions from lithium production. In a hypothetical low-tax scenario, the carbon tax is US$ 30 per ton of CO2, with an annual increase of 2% above inflation. In a high tax scenario, the carbon tax is US$ 180 per ton of CO2 and increases by 7% every year (Table III). In the financial model, carbon taxes are deductible for the tax base calculations of corporate income tax (CIT) and resource rent tax (RRT).

Table III *Carbon tax estimations in a low and high carbon tax scenario without any mitigation policy*

	Low Tax		High Tax	
	Yearly	Total during 20 years of operation	Yearly	Total during 20 years of operation
CO2 emissions for diesel combustion (Million Ton CO2 equivalent)	0.052	1.04	0.052	1.04
Carbon tax rate applicable (US $ per ton of CO2)	30	64 (last year)*	180	948 (last year)*
Annual increase above inflation (%)	2%		7%	
Carbon tax as a share of sales revenue (net)	0.69%		7.22%	
Carbon tax as a share of operating costs	3.05%		31.78%	

**Constant US$ 2021 after inflation adjustments*

According to the company investors' report, the project uses diesel to fuel light vehicles, trucks, machinery, and heavy equipment, corresponding to approximately 90 m^3/month of diesel consumption. The machinery includes salt harvest transport trucks, harvested salts handling trucks, and soda ash transport trucks, among others. In the production plant, diesel will be used mainly for steam boilers, and the diesel consumption is estimated at 1500 m^3/ month. Table III above presents the estimations of direct CO2 emissions (scope 1) after applying the corresponding energy combustion factors. The respective carbon tax during the total operational period (20 years) is assessed as a share of net sales and operational costs and deducted from the tax base to calculate income (profit) taxes.

The Company's diesel consumption in the production plant is the major component of operational expenses (about US$ 13 million per year), representing over 20% of the project's estimated cash operating costs. Table III shows that if a low carbon tax is implemented, the energy and emissions expenses will increase from 20% to 23.05%. With a high carbon tax, those expenses can go up from 20% to 52% during the entire operation period. These are a maximum estimate of the Company's expenses for the carbon tax, assuming

[16] Data source is the Climate Watch. 2020. GHG Emissions. Washington, DC: World Resources Institute. Website, consulted on February, 2023.
[17] The Chilean government carbon price estimates are published in the Ministry of Social Development website, consulted in January, 2023.
[18] Deloitte and the Santiago Climate Exchange has published a report called "Radiography 2022: Corporate Vulnerability to Climate Change of the 100 largest companies in Chile" published at the Santiago Climate Exchange, SCX Website, consulted on February, 2023.

that the Company does not take action to reduce its emissions. See section 4.3. for an alternative scenario when mitigation strategies take place.

3. Fiscal regimes among lithium-producing countries

The first part of this section briefly describes the evolution of the Chilean tax system in the lithium industry during the last two decades and compares their tax regime with other countries in the region. The rest of this section analyzes how environmental taxes affect the tax system in terms of progressivity, simplicity, neutrality, and reliability at low-profit levels.

3.1. Tax burden and mineral price gaps

Before discussing the fiscal implications of environmental taxes, it is essential to look at how the Chilean taxes on the mining industry have reached the current level. Since the 2000s, Chile has signed contracts with private companies to explore and exploit lithium resources. Therefore, the profits from mineral production have been absorbed mainly through taxes and not through ownership participation. As a rule, the Chilean mining fiscal regime's goal has been two-fold: (i) attracting foreign investments and (ii) maximizing government revenue over the project lifetime. The first goal reveals concerns about the country's sensitivity to international competition. The second goal explains why the Chilean government has taken advantage of the mineral prices' super cycles to increase the tax burden and secure an early and timely source of revenue.

In 2006, after a steady increase in copper prices, the Chilean government implemented tax reforms in the mining sector and applied a resource rent tax (RRT). Later, the government raised tax rates again in all sectors to cover the emergency of the 2010 earthquake. In 2018, the government negotiated new lithium contracts introducing variable royalties based on prices. More recently, the pandemic induced a temporary reduction in corporate tax -CIT- from 27% to 10% to encourage employment and new investments. This reduction was offset by a higher royalty rate that increased with higher mineral prices.

Figure 3 shows the average effective tax rate (AETR) evolution compared to lithium market prices. The AETR is the government's share of a project's pre-tax profits over its lifetime. The estimates consider observed mineral prices for each year and assume that all other cost variables do not change, i.e., *ceteris paribus*. Therefore, the increases in AETR reflect both an increase in the price and the changes to the actual tax terms. At current tax terms, and with an estimated lithium price of USD 37 000 per ton of lithium carbonate equivalent -LCE- for 2022, the undiscounted AETR in the Chilean lithium sector is 62.3%. At the time of this publication, the Chilean Parliament is discussing an additional 3% (flat) royalty in the mining sector, which could result in an even higher AETR.

Figure 3. Tax regime (AETR) changes due to changes in lithium price and tax terms

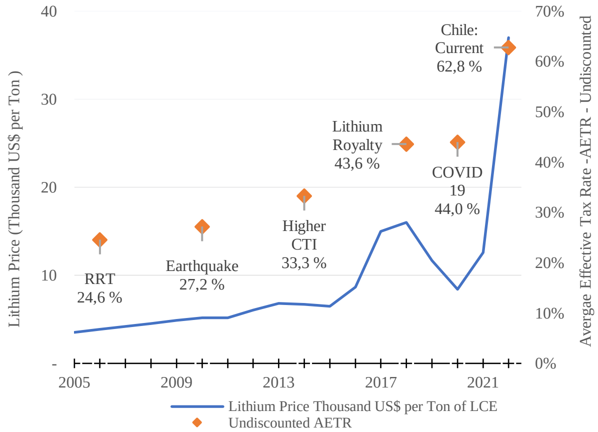

Figure 4. Chilean lithium exports and the difference in lithium market prices and export prices

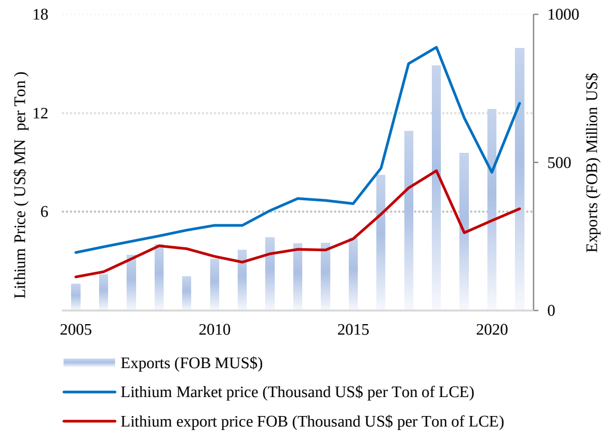

Figure 3. *Lithium prices are annual average-nominal, battery-grade lithium carbonate dollars per metric ton published by USGS (2023). See Appendix 1, Table 1 for more details of the current Chilean mining fiscal regime.* ***Figure 4.*** *For fiscal model evaluation, it may not be necessary to differentiate between production and actual sales or exports. Lithium export data are in LCE units from Cochilco (2022). Lithium export prices (FOB) come from dividing export values in FOB (MUS$) by total lithium production in metric tons of lithium carbonate.*

Figure 4 shows that the prices of Chilean exports are significantly lower than the market prices reported by the USGS each year.[19] Export prices are the companies' sales or book value reported in invoices or export declarations (FOB value). What is interesting about the data in Figure 4 is that the higher the lithium market price, the higher its difference with respect to export (FOB) prices. When comparing Figures 3 and 4, it is possible to notice that despite a sharp increase in lithium market prices and tax rates, the companies' sales (export) prices increase less.

Lithium is an example of a market with incomplete information. Market price opacity can be seen by the fact that lithium is not traded in major stock markets and, therefore, does not have spot prices or future contracts, which makes it difficult to predict and compare prices. The absence of lithium commodities in stock markets also reinforces market concentration in a few highly diversified multinationals.[20] Preliminary research by Jorrat (2022) suggests that the lithium price disparity is due to transfer pricing. Transfer pricing occurs when companies underreport the quantity, quality, or market value of the product or fail to declare valuable by-products. If mining companies intentionally understate market prices and project revenues that affect profit-based taxes, this practice is known as transfer mispricing. See a further discussion on this topic in section 5.

3.1.1. Tax effects on foreign investments and international coordination

On the question of tax burden and foreign investments, a high AETR in the Chilean lithium sector, too far above those available in other countries, create concerns about discouraging foreign investments. Figure 5 shows that the current tax burden in Chile is higher among the peer group and will be even higher if (low) environmental taxes are implemented (See section 4.2. for details on environmental tax levels). At first sight, it can make Chile less competitive in attracting exploration investments and more exposed to tax minimization, e.g., inflating costs and sending profits abroad to subsidiaries in low-tax jurisdictions.

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[19] The same trend has been observed in Argentina, where export prices are in average 58% lower than the market prices reported by the USGS (cf. Jorrat, 2021, page 40).

[20] In Chile, the two leading lithium companies are Albemarle and SQM. The former owns lithium brine operations in Chile, USA and Australia. The later, SQM has primary business in Chile and has expanded operations to Australia and Argentina. Both companies have a long worldwide chain of corporate sales.

Figure 5. ***Average Effective Tax Rates – AETR- Country and lithium mining sector***

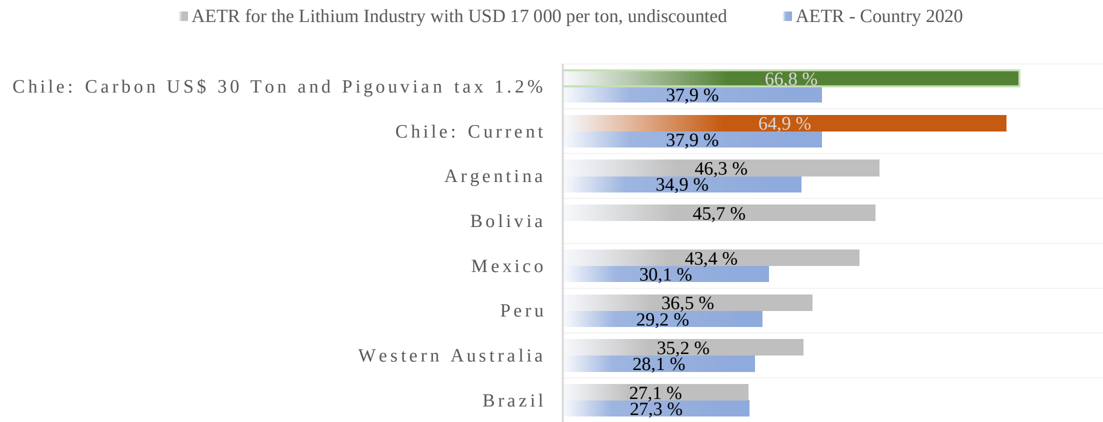


Figure 5. Fiscal regimes can be compared with international peers considering that investment projects (price, cost, production level) are the same as in the Maricunga project. Thus, the project's Pre-tax IRR and NPV will remain the same across countries and scenarios. However, the government share and AETR will change among countries and tax regimes. The lithium industry AETR 2022 was estimated with a nominal lithium price of US$ 17 000 per ton of LCE. The country AETR 2020 comes from the OECD Statistics database. There is no available information about the country AETR for Bolivia.

Using the AERT as a proxy of competitiveness should be viewed with caution because the choice of price and cost assumptions, including depreciation schedules, debt, and equity assumptions, heavily influences the AERT.[21] Thus, to analyze countries' competitiveness and attractiveness to investors, it is important to consider tax and non-tax factors along with other metrics. For example, Chile's lithium resources are highly profitable because of relatively high ore grades and low extraction costs.[22] Besides, Chile has been one of the most prosperous and stable economies in Latin America, which is also an essential factor for risk assessments. However, any additional tax, whether a new royalty or a relatively low environmental tax, will increase the mining sector tax burden and open the door to detrimental effects on investment decisions. Such trade-offs open two questions: (i) to what extent is it necessary for international coordination to tax the lithium sector? Moreover, (ii) how can governments tax the environmental impact of mining without exacerbating the possible disadvantages of their fiscal regimes?

Regarding international coordination to tax profits, persistent tax risks have justified the possibility of applying a global minimum corporate tax rate (of least 15%) (Delis et al., 2022; OECD, 2022). Research has shown that neither Chile nor neighboring countries need to engage in harmful tax competition because there is no evidence of geographical spillover effects after changing the Chilean mining tax system (Castillo, 2021). However, little is known about the additional implications of a global minimum corporate tax rate in the mining industry.

Regarding environmental policy coordination, it is common knowledge that carbon emissions are a global externality with widespread damage, and collective and harmonized action is urgent. Implementing a global carbon tax in the mining industry is, in theory, feasible as mining products have a high value per ton of CO^2 emissions and would be less financially impacted by additional carbon taxes than other industries (Cox et al., 2022). In contrast to carbon emissions, the ecological impact of mining is local and context-dependent, and Pigouvian taxes can slow down production and reduce profitability (Roa et al., 2022). However, lithium

[21] The estimations also vary by model type. For example, the FARI model allows us to consider whether the Value Added Tax applies from exploration or further production and the effects of refunding delays. When considering VAT refunding options and levies breaks, the AETR decreases considerably.

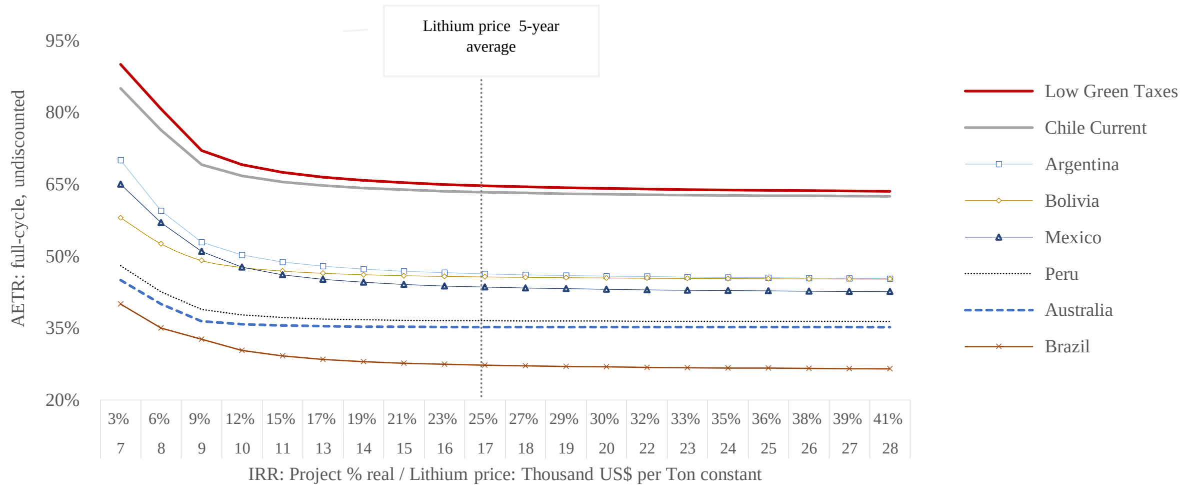
[22] According to the Frazer Institute (2021), many investment decisions are often based on the project's pure mineral potential. In line with that, Chile offers the greatest geological attractiveness among the Latin American lithium producers on top of its competitors Bolivia, Argentina, and Peru. (Junis, J., & Aliakbari, E. (2022). *Fraser Institute Annual Survey of Mining Companies 2021*. https://www.fraserinstitute.org/sites/default/files/annual-survey-of-mining-companies-2021.pdf).

reserves in Latin America comprise Argentina, Bolivia, and Chile, a region known as the Andean Altiplano Puna, which ecosystems are deeply connected by underground hydrological systems whose geographic boundaries do not correspond to the geopolitical ones (García-Sanz et al., 2021). Therefore, ecosystem taxes may have environmental benefits not only for Chile but for the Andean region as well.

3.2. Progressivity as profits change

This section discusses how environmental taxes affect the tax system's progressivity and how it compares with other countries' tax regimes. In a progressive tax regime, the government's share of revenue is smaller when profits are low and larger when profits are high. Figure 6 below shows how the AETR representing the government's share of revenue, varies with profitability in terms of the pre-tax internal rate of return (IRR) (which again varies with the lithium price levels). In this study, all countries provide similar conditions (extraction cost, production schedules) to develop a lithium project like Maricunga. Thus, the cash flows and pre-tax returns (IRR) of the projects are identical among countries, and the differences lie in their tax regimes.

Figure 6. ***Progressivity analysis across a range of lithium prices***



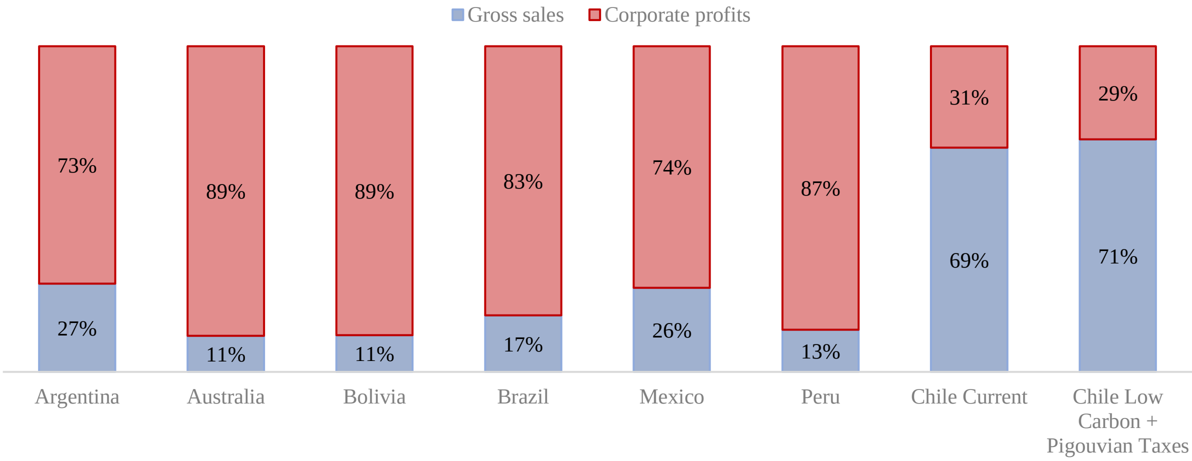
Lithium prices have skyrocketed recently, rising from US$ 6000 in 2012 to US$ 37000 in 2022. Increasing mineral demand can sustain high lithium prices. However, as discussed in section 3.1, the opacity of market prices adds uncertainty to profit levels, making it difficult to anticipate the tax system's progressivity.

In all cases, the progressivity or regressivity level can be defined by the sensitivity of the AETR with respect to changes in mineral prices. That sensitivity level will depend on the price threshold that we consider in the analysis. The average lithium price over the last five years is US$ 17000. Below that price, the Chilean AETR curve extends downward, suggesting that the tax system is more regressive to low mineral prices, especially after introducing environmental taxes. What is striking among the different tax systems is that the higher the AETR, the more sensitive to low mineral prices. These estimates consider that profit margins vary with changing prices and constant extraction costs. However, in practice, extraction costs can increase due to higher energy and operational costs or when the mine operations get deeper, and lithium becomes more difficult to extract.

3.2. Simplicity and tax bases

Increasing profit taxes (like withholding and corporate income taxes) increases the difficulty of measuring tax bases. In Chile, tax bases and rates for the mining industry have become more challenging to measure, and tax regulations have been circumvented by the companies' sophisticated tax planning practices (Bustos et al., 2022). However, despite the high tax levels and mounting tax planning, the Chilean lithium tax system is apparently simpler among its peer countries because it relies mainly on gross sales tax bases. Figure 7 below shows the proportion of taxes based on profitability (in red) and gross sales (in blue).

Figure 7. ***The proportion of government revenues by tax type and tax base simplicity across countries and fiscal regimes****



**The last scenario considers a Carbon tax of USD 30 per CO2 ton and a Pigouvian tax for ecosystem damages of 1.2%*

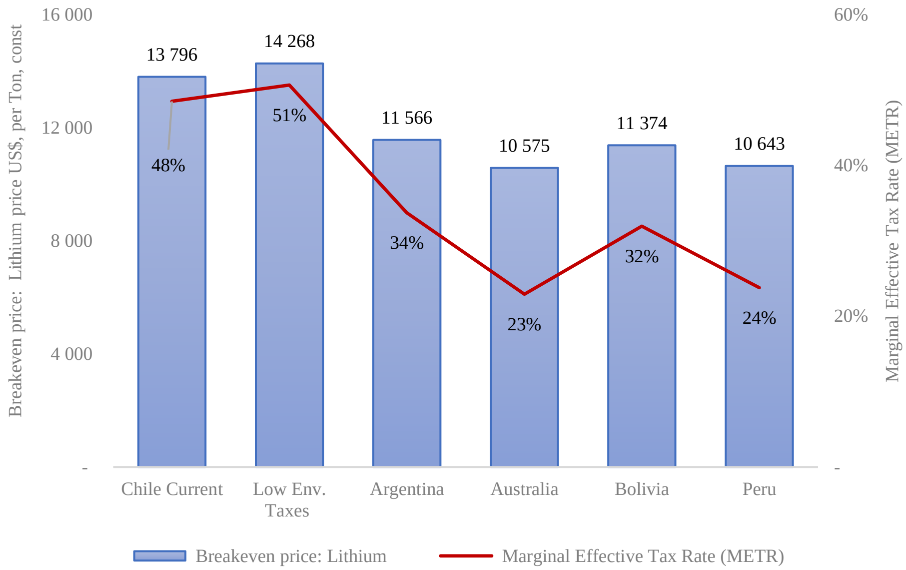
The simplicity of the tax bases is, therefore, essential when designing a new tax, like royalties or environmental taxes. Pigouvian and carbon taxes are not related to the project's profitability but to production and input intensity. As shown in Figure 7 above, environmental taxes would increase the proportion of revenues from a gross sales tax base, but this does not necessarily mean an increase in the tax system's simplicity.

Measuring carbon taxes has become, to some extent, easier to calculate as more tools and calculation standards become available. In contrast, Pigouvian taxes for ecosystem damages depend on the context and require a comprehensive assessment of ecosystem dynamics. Moreover, implementing and enforcing environmental taxes require monitoring of mining activities on the ground and implies coordination with environmental institutions, which could add transaction costs and make the tax system less simple.

3.4. Neutrality on new investments

Neutrality refers to the tax cost of investing an additional dollar to increase mineral extraction. It is, therefore, an essential criterion for attracting new investments. One indicator of the tax system neutrality is the marginal effective tax rate (METR). The METR is the proportion of pre-tax profits on the marginal unit of production taxed. According to Figure 8 below, the Chilean fiscal regime has a higher METR than other lithium-producing countries, which can be seen as a disincentive for new investments to expand lithium production in Chile. The reason is the large proportion of taxes on gross sales that do not consider capital and financial costs. Therefore, the simplicity of the tax system opposes its neutrality.

Figure 8. ***Marginal effective tax rate (METR) and breakeven mineral price***

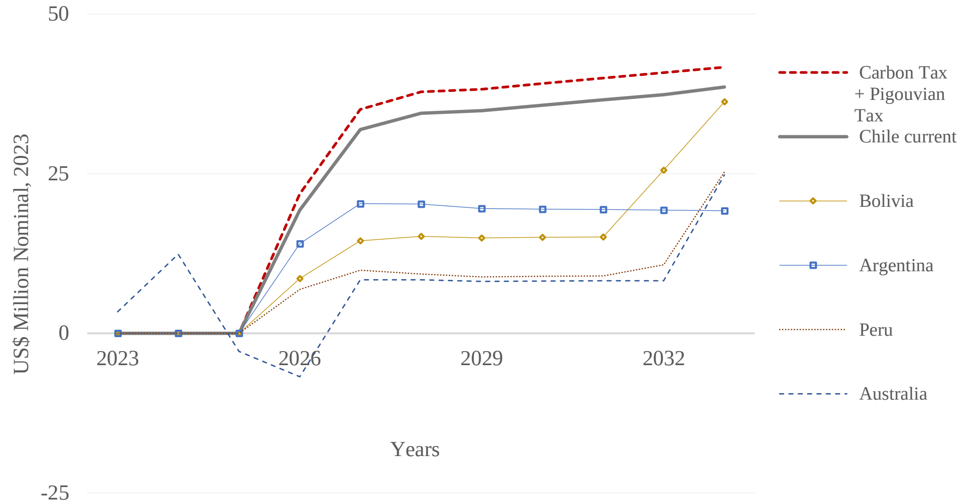


A complementary indicator to the METR is the breakeven price which represents the minimum price needed to yield a specific post-tax return on capital over the project's entire lifecycle. As shown in Figure 8 above, a new lithium project is viable in any of the lithium-producing countries because the breakeven price of all countries is below the reference price of US$ 17 000 per ton. Suppose Chile implements low environmental taxes, and new investments are needed to increase lithium production. In that case, the tax system will impose additional constraints (higher MERT and breakeven price) compared to its peer countries. Therefore, once environmental taxes are applied, the decision to invest and increase lithium production has additional (capital and tax) costs. Likewise, businesses with environmental tax costs are more susceptible to low lithium prices (below US$14 268 dollars) than their counterparts without such taxes.

3.5. Reliability at low-profit levels

Governments whose budgets are heavily dependent on the mining sector often favor regimes that generate at least a certain amount of government revenue each year, regardless of whether the mines generate profit. Like most mining projects, a new lithium project will generate limited or no profit in its first few years of development. In these years, the public revenue collected in the project's early years can give an idea of the regime's ability to generate revenue at a low or zero profit level. Figure 9 below shows how the government revenues profile follows the project cash flow and production schedule. According to the mining company Minera Salar Blanco (2022), lithium production in Maricunga will double in the second year of production and will gradually ramp up. See vary with hydrological conditions.

Figure 9. ***Government revenues profile during the first ten years of operations***



As mentioned in section 3.2., this study assumes that all countries have the same production schedules and cost conditions to develop a lithium project like Maricunga. For illustrative purposes, in all cases, taxes begin when production starts (in 2026) except for Australia. In this country, the government will secure early revenues, despite zero or no profits during the development phase. However, once production begins, and project earnings are positive, government revenues will be negative due to tax credits from past negative financial results. In Chile, a new royalty or a relatively low carbon or environmental tax does not prevent the mine from operating. Furthermore, suppose Pigouvian taxes do not provide sufficient incentives to mitigate damages. In that case, additional environmental taxes will increase overall government revenues, even at low-profit levels during the early years of production.

4. Alternative scenarios for Chile

This section describes the alternative scenarios for the Chilean tax regime, which include a new royalty of 3%; and the implementation of low and high environmental taxes, with and without mitigation policies. Table IV below summarizes the assumptions used to simulate these scenarios.

Table IV. *Alternative scenarios and main assumptions*

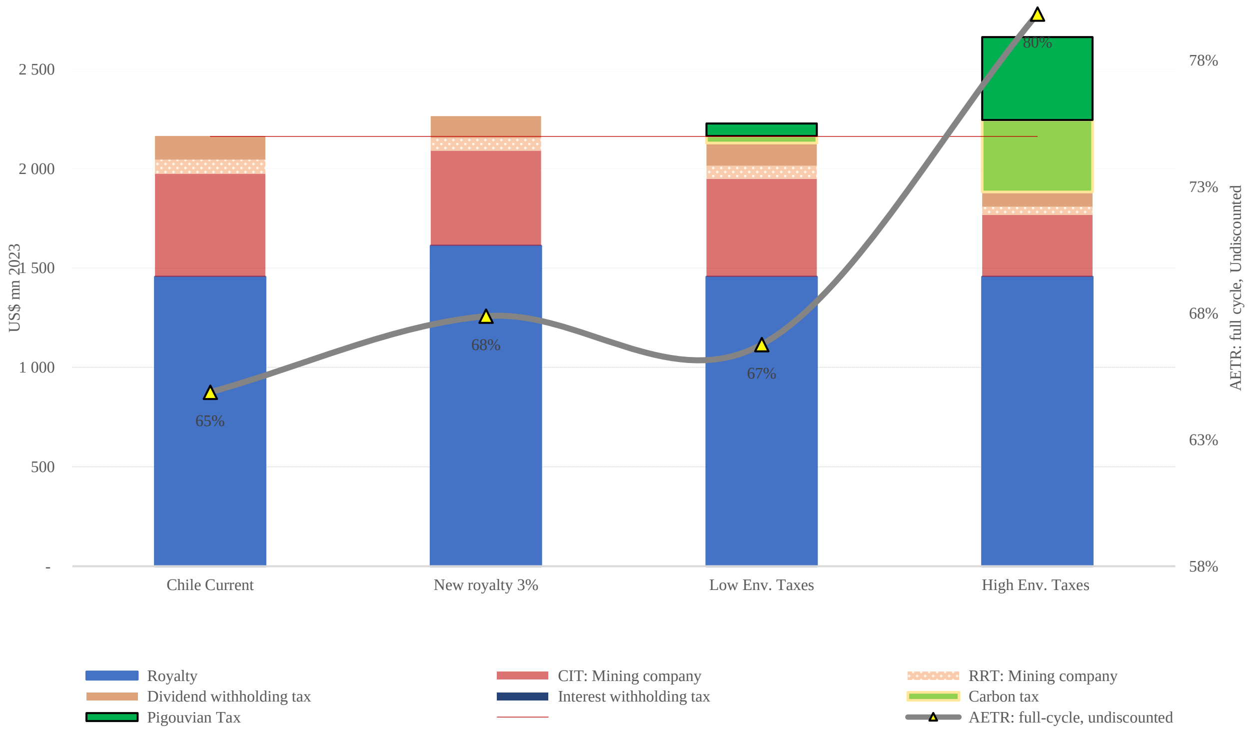
	Chile Current	*New Royalty 3%*	*Low Environmental Taxes*	*High Environmental Taxes*
Pigouvian (Ecosystem) tax rate	0%	0%	1.2%	8%
Carbon tax	0	0	US$ 30 ton of CO2	US$ 180 ton of CO2
*Royalty rate**	Variable	Variable plus a flat rate of 3%	Variable	Variable

** See Tables X and XI in the Appendix for more details about the price-variable royalty rate and profit taxes.*

4.1. New royalty

Amid the current mining boost and following the principle of revenue maximization, Chile aims to increase the public share of resources revenues by introducing an additional royalty tax of 3% on gross sales. The royalty will be new for the copper mining sector, which tax base has relied mostly on profits. Meanwhile, for the lithium sector, the royalty reform will add a flat rate to the current price-variable royalty. The proposal does not dismantle the previous special tax, resource rent tax, or variable royalty tax for the lithium sector. Thus, it is expected that the legislation might declare a hybrid tax model with both the new royalty and previous taxes. Still, many Chilean scholars consider that any additional taxes should be implemented only after the mining sector has improved its transparency. They also argue that a new tax system should encourage exporting more added-value materials, such as cathodes, instead of refined and unwrought minerals.[23]

Figure 10. ***Chilean government revenues under alternative regimes without environmental mitigation policies****



** In this financial analysis, royalties and Pigouvian taxes are deducted from the tax base to calculate corporate income tax (CIT) and resource rent taxes (RRT).*

From Figure 10 above, we can see that the new royalty elevates the tax burden (AETR increases from 63% to 66%). Since the project's overall profitability does not change, that additional government revenue will reduce private benefits (Figure 11). The new royalty scheme can potentially capture a greater proportion of the total value of Chilean resources, which is particularly beneficial during long-term high mineral prices. However, the royalty is regressive as it does not adequately address the costs of staying in business with depressed mineral prices.

4.2. Low environmental taxes

Carbon taxes are a form of Pigouvian tax. However, it is not the economic damages caused by emissions that determine the cost of carbon, but rather the cost of reaching a climate target. In a scenario where the government responds to environmental concerns with modest goals on emissions reduction, a starting point can be to incorporate a low carbon tax (US$ 30 per ton CO2). Notice that carbon taxes are applied to (fossil) energy inputs and are deducted from the tax base to calculate income (profit) taxes.

If carbon taxes exceed the marginal costs of reducing CO2 emissions, companies may reduce their direct emissions. Thus, it is important to know the relative costs of fossil energy compared to renewable energy. Table V below shows carbon emissions and carbon tax payments with low and high taxes. Such emissions will decrease if companies have incentives to invest in renewable energy, because of high carbon taxes or high diesel prices.

[23] cf. an analysis by Luis Felipe Orellana, ¿El royalty minero acabará con la inversión? published in this Website, on May, 2021.

In a low-tax scenario, companies will not have incentives to reduce emissions because replacing their energy source during the first year can exceed the corresponding (low) carbon tax expenses during twenty years of operation (Table V). In an alternative scenario with a higher carbon tax, companies may have better incentives to look for renewable energy, but that will greatly depend on diesel prices relative to renewable energy prices, including installation and maintenance costs of low-carbon technologies. Table V below shows the diesel and carbon tax expenses compared to the cost of using wind power in the production plan. It disregards the cost of electrifying the transport fleet. Only a small share of diesel (6%) is used from transportation – the very large share (94%) is used for electricity generation.

Table V. *Carbon tax estimations in low and high carbon tax expenses compared to renewable energy costs.*

	Low Tax		**High tax no renewable energy investments**		**High tax WITH renewable energy investments**	
	First year of operation	Total during 20 years of operation	First year of operation	Total during 20 years of operation	First year of operation	Total during 20 years of operation
CO_2 Emissions for diesel combustion (Tons)						
Transport	2 949	58 980	2 949	58 980	2 949	58 980
Production Plant	49 148	**982 960**	49 148	**982 960**	49 148	**217696**
Carbon Tax Payments (US$ Million Nominal 2023)	$1,6	$36	$9,4	$362	$9,4	$76
Carbon tax as a share of sales revenue (net)	0.69%		7.22%		1.1%	
Carbon tax as a share of operating costs	3.05%		31.78%		5.2%	

Emissions avoided by ONE wind turbine (metric tons CO2/year/wind turbine installed)	**3 679*** (7% of total annual emissions)	
Cost of Wind turbines installation, operation, and maintenance	$5 Million per wind turbine**	$70 Million for 14 wind turbines to operate the production plant
Costs of diesel (US$ Million) †	$ 12.5 Million per year	$ 250 Million during 20 years of operation

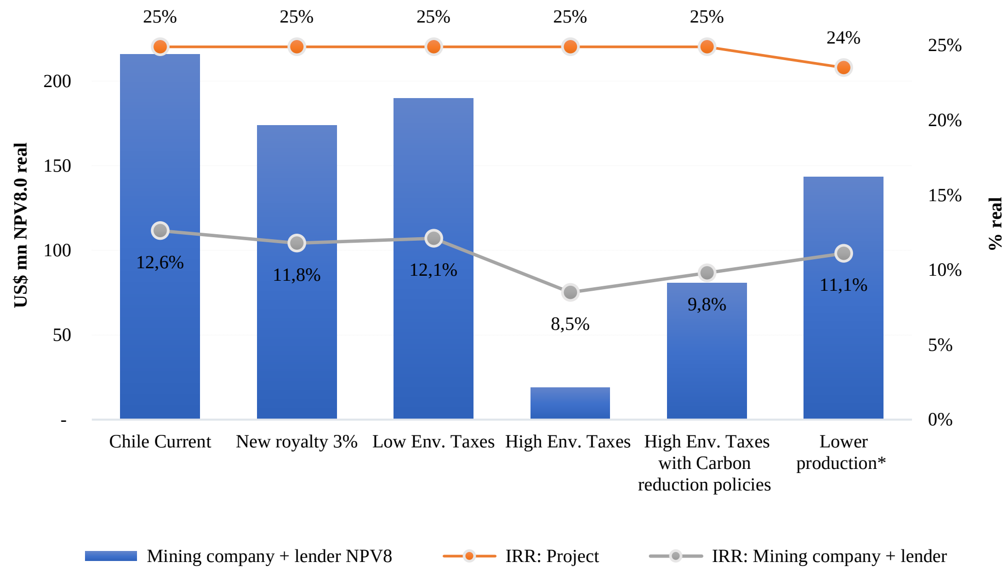
* Estimations based on the conversion factors used in the GHG emissions calculator by the United States Environmental Protection Agency https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results
** Source: Weather Guard Wind, costs in 2021. Including maintenance costs.
† Estimations based on the Company's investors report (January 2022) data with diesel price was $ 2.5. By March 2023, that price has doubled.

Regarding Pigouvian taxes for ecosystem damages, if these taxes were designed based on competing uses of landscapes for lithium mining versus ecosystem values per area, the first way to reduce ecological damage would be to reduce the amount of land extracted, thereby reducing production. According to Roa et al. (2023), without any intervention, between 5 and 35 hectares of Maricunga's wetland landscape can disappear during 20 years of the mining operation. Their study also suggests that in case the government enforces a low Pigouvian tax (1.2%), that additional cost will constrain the Company to cut five thousand tons (1.43%) of the total accumulated lithium production in 20 years of mining operations. The measure will likely result in the protection of 0.07 hectares of the core wetland during the entire period of mining operations.

In principle, the additional Pigouvian tax cost will discourage the project from getting too large. Although low environmental taxes will increase the tax burden (AETR increases from 63% to 65%), it does not affect private benefits to a significant degree, not as much as a royalty could do it. Figure 11 below shows how investors' NPV and post-tax IRR will change under alternative tax regimes.

Usually, any IRR above the discount rate will make the project feasible. In this study, both government and investors assume a discount rate of 8%. However, it is generally accepted that social discount rates are lower than private return rates. According to Lopez (2008), the social discount rate for the Chilean economy would be in the range of 3% and 5%, considering past economic performance and an investment horizon between 10 to 25 years. On the other hand, investors may have a different (higher) rate of return from investments, i.e., the hurdle rate. This rate considers capital costs, the country risk involved, the returns of business expansion, and the opportunity cost of similar investments elsewhere. A proxy to the hurdle rate is the weighted average cost of capital (WACC). According to Jorrat (2022), the average WACC for the lithium mining companies operating in Chile between 2000 and 2019 was 6.6%. The importance of knowing these return rate levels is that if the private (hurdle) discount rate is set too high, this is likely to lead to the false rejection of projects that will aid in social development (Møller-Sneum et al., 2022). In our case study, the project's real post-tax IRR is higher than our hypothetical real discount rate of 8% and even higher than the proxy hurdle rate (6.6%). Therefore, the project is cost-effective in all alternative scenarios (Figure 11).

Figure 11. ***Investors' NPV and IRR under alternative regimes (real discount rate 8%)***



** In this scenario, instead of the Pigouvian tax, the government reduces the project size. A high carbon tax with its subsequent carbon reduction is still applied.*

Thus far, mining companies may have less resistance to low environmental taxes because it does not prevent a lithium mine like Maricunga from operating. However, low environmental taxes do not seem to provide sufficient incentives for companies to reduce damages, nor are they a guarantee that ecological benefits will be realized. So, a remaining question to explore is how high these taxes should be to influence the mining companies' polluting behavior.

4.3. High environmental taxes

This section assesses the tax level necessary to persuade mining companies' behavior to mitigate damages. If decarbonization is a matter of human survival, then the level and path price of carbon prices should be consistent with limiting global average temperatures to 1.5°C. Many international mining companies, including the Chilean lithium company SQM, have made public commitments to carbon neutrality by 2050. However, local authorities remain silent on such targets and on the corresponding mitigation measures.

A discussion about the implications of carbon taxation in the mining industry was presented by Cox et al. (2022), showing that the mining industry would be less affected financially if a global carbon tax were introduced compared to other industries, even if tax level were USD 150 per ton of CO2. Other researchers have concluded that the recommended cost of carbon is USD 180 per ton of CO2 equivalent in 2025, with annual growth of 7.2% (Wangsness & Rosendahl, 2022). This cost of carbon can be applied in a cost-benefit analysis throughout the economy independent of trading system regulations (i.e., European ETS). They also point out that, *a priori*, it seems reasonable for developing countries to have lower CO2 prices than industrialized countries. This may, however, encourage excessive investment in high-emitting projects in developing countries (Íbid, 2022, p. 7). A side note is that the lithium industry is not a local business but an international industry where few multinationals trade commodities at international market prices.

Figure 12 below provides the results of implementing a high carbon tax of USD 180 per CO2 ton, growing 7.2% annually. Without surprise, a high carbon tax will lead to an even higher AETR. If companies do not undertake mitigation policies, high environmental taxes will generate some additional government revenues. Despite meager benefits to investors (Figure 11), a high carbon tax does not prevent the mine from operating. And the mine could emit approximately one million tons of CO2 during twenty years of operation by running their business as usual. If environmental taxes do not deter the industry from harmful behavior, the proposed tax payments are to compensate for damages, not prevent them. Companies may still avoid such payments through tax minimization practices such as transfer mispricing. (See discussion in section 5 below).

Nevertheless, a high carbon tax can greatly exceed the investment cost of renewable energy (Table V above), which provides good reasons to switch to renewable energy sources and reduce emissions. In that case, government revenues from carbon taxes will gradually vanish while the mining site becomes carbon neutral, which can happen before 2050.

Figure 12. ***Chilean government revenues under alternative regimes with and without environmental mitigation policies***

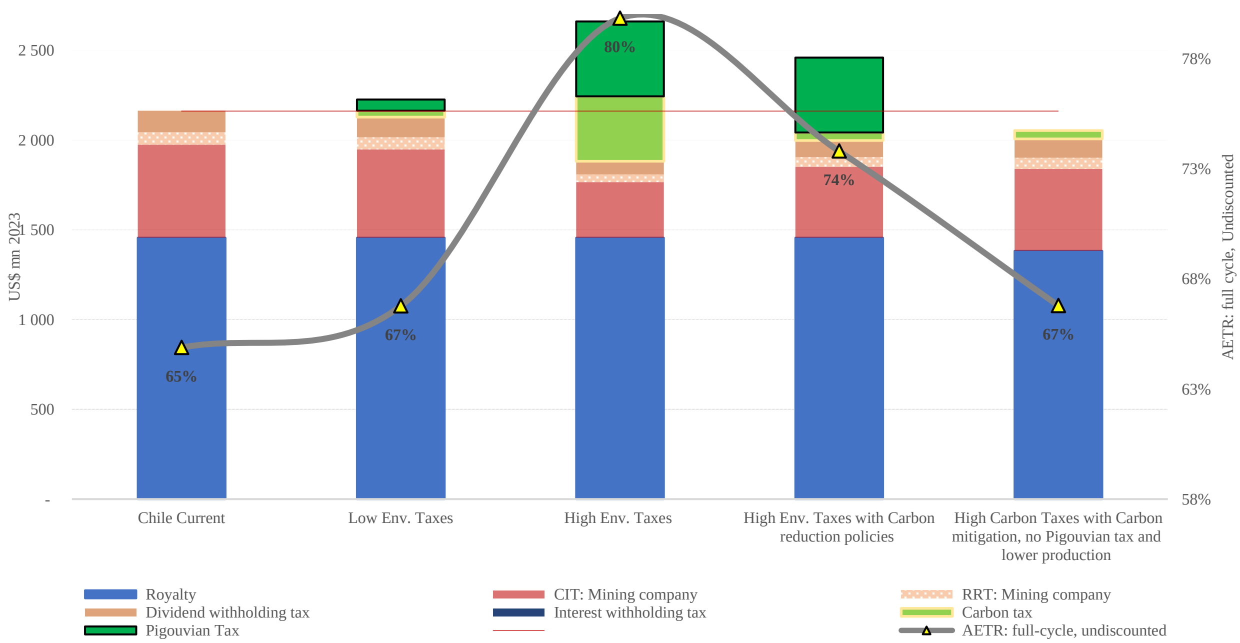


Table VI. *Environmental damage reduction from policy intervention*

Environmental Benefits	Low Env. Taxes – *No mitigation strategies*	High Env. Taxes – *No mitigation strategies*	High Env. Taxes With Carbon Reduction Measures	High Carbon Taxes With Carbon Reduction Measures, No Pigouvian Taxes, And Lower Production (5% less than business as usual)
CO2 Emissions Reduction	0	0	73 %	73 % †
Wetlands Damaged (Hectares-Ha-)	5-35 Ha	5-35 Ha	5-35 Ha	4-30 Ha

† It may vary with production levels, but we assume emissions are related to production plant operations independent of production level.

Regarding ecosystem damage, the ad valorem Pigouvian tax is intended to constrain the project size with additional costs and prevent too much damage to ecosystems. A high Pigouvian tax (8%) will reduce investors' benefits but do not prevent the mine from operating (Figure 11). Therefore, the tax payments will serve to compensate for damages to ecosystems. If the Pigouvian tax could more directly target input levels (i.e., brine extraction), firms might have incentives to reduce damage while maintaining production levels.

If Pigouvian taxes are difficult to implement or are suspected to be ineffective, the only way to prevent ecological damages is to reduce mining projects and leave mineral resources in the ground at the expense of less public and private revenue. Thus, instead of a high Pigouvian tax, the government can reduce the project size from the beginning by, for example, 5% of the total accumulated production. Following Roa et al. (2023), a reduced accumulated production will protect a small wetland area (between 0.1 and 5 Hectares), reducing at the same time project cash flows, mining project profitability, and government revenues (Figure 12). At this point, policymakers are facing a trade-off: hopefully, less environmental damage but less mining revenues.

Figure 12 shows the results of constraining production by 5%. In that case, both public and private benefits from mineral extraction will decrease. Still, according to Roa et al. (2023), within 20 years of operation, with and without taxes, mining will inevitably create some damage to the ecosystem. Table VI presents the damage reduction from each intervention.

Overall, the extent of carbon emissions reduction will depend on tax levels. Low carbon taxes do not necessarily give incentives to undertake mitigation policies. Moreover, carbon taxes have a low financial impact on project profitability. Therefore, it is possible to set a high carbon tax, making investments in renewable energy more attractive. The main implication of high carbon taxes is that they will allow the mining industry to shift to responsible energy substitutes and drive innovation to decarbonize mining operations.

On the other hand, high Pigouvian taxes for ecosystem damage will not necessarily prevent those damage from happening. Still, it will prevent the project from getting too large and guarantee fair compensation for potential damages. Instead of Pigouvian taxes, an alternative will be to reduce the project size. Then, the opportunity cost of preserving ecosystems will be less private and public revenues.

4.4. Revenue management

Concerning revenue management, in the case of Chile, there is little denying that mining has brought considerable economic gains reflected in their macroeconomic indicators and central government budget management (Solimano & Guajardo, 2018).[24] However, the literature suggests that fiscal policy has failed to incorporate local government (Oyarzo & Paredes, 2019). Chile is a highly centralized country, implying that revenues are distributed from the capital city of Santiago de Chile. Decentralization suggests non-uniform provisions that better match the needs and preferences of citizens (Breton, 2002). Nevertheless, a failure of decentralization in tax revenue management may neglect to compensate those directly affected by mining. Most mining damage to water, land use, and ecosystems is localized and unevenly distributed. There is a question, however, as to whether environmental taxes can be effective in strengthening natural resource governance beyond ensuring fair and direct damage compensation.

Environmental taxes provide additional public revenue, but they will vary when mitigation policies are implemented. Table VII. below displays the differences in project returns (Post-tax IRR) and cash flows (Million US$, NPV 8%) and the changes in public revenues under alternative tax reforms. Notice that all alternatives, except at lower environmental taxes, will provide lower Post tax IRRs than the one under the current tax regime (13.8%). Figure 13 shows that in most cases, the additional revenue from environmental taxes is significantly higher than the reduction in project profits. However, the government's additional *net* tax revenue will be proportional to the reduction in profits, i.e., excess tax burden. An exceptional case is the last scenario when companies are forced to reduce production.

Table VII. *Profit losses and additional tax revenues (US$ Million Nominal, NPV 8%, real) compared to the current tax regime*

	Low Env. Taxes	High Env. Taxes	High Env. Taxes with Carbon	High Carbon Tax, mitigation, and lower production

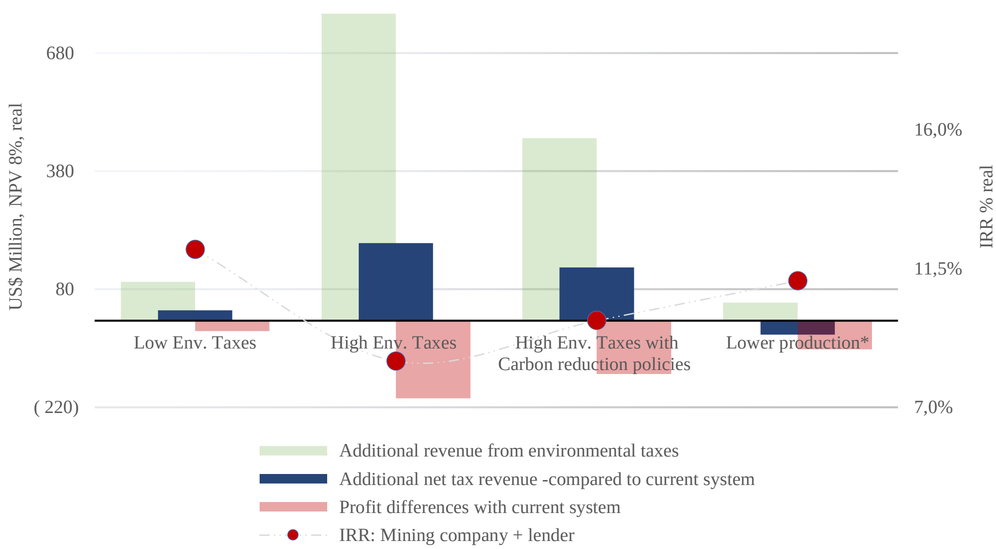
[24] For decades, Chile has shown exceptional mining revenue management. Their strategy includes a fiscal rule, a stabilization fund under a flexible exchange rate, and an inflation-targeting regime (Solimano and Guajardo, 2018).

			reduction policies	
Post-tax IRR (%) *	12.1%	8.5%	9.8%	11.1%
Profit differences with the current system**	(26)	(197)	(135)	(73)
Additional revenue from environmental taxes	98	780	463	46
Additional net tax revenue -compared to the current system	26	197	135	(36)

* *The Post tax IRR* is for the Mining company and lender considering capital costs.***Numbers in brackets mean negative values.*

From Figure 13 below, we can see that the subsequent profit reduction (red bar) is equivalent to the increased net government revenues (blue bar), but these net changes are lower than the environmental tax (green bar). In most cases, the excess burden, or the additional net tax revenue, will equal the profit reduction. Again, the lower production scenario is an exception because the profit loss will double the additional government revenue, and the additional environmental revenue will be marginal.

Figure 13. ***Excess bu***



Regarding the entire mine lifecycle, environmental management can influence decommissioning costs, including closure and remediation expenses at the final stage of mining operations. In the case of the Maricunga project, the financial and technical planning for decommissioning and remediation have yet to be adequately considered. In Chile, a legacy of closed and decommissioned copper mines has secured an environmental debt. To my knowledge, no clear responsible parties or funds are designated for addressing decommissioning issues.[25] Since decommissioning funds management affects the project's net cash flows and related tax provisions, it is therefore important to investigate to what extent how decommissioning funds and environmental taxes payments may interact and determine the best mechanism to administer them.

5. Transfer mispricing

Companies can reduce their environmental tax payments by adopting mitigation strategies to minimize environmental impacts. However, there is always a possibility of reducing tax payments in non-legitimate ways. As explained in section 3.1., although production and export levels grow following a sharp increase

[25] Today, there mapped 740 mining tailings, from which 170 are abandoned, 101 are active, and 469 are inactive. Researchers have shown that living near tailings vicinities can result in severe health and environmental problems (F. Campos Medina et al., 2022). The location maps of tailing are publicly available on the Sernageomin website, consulted in January 2023.

in lithium market prices, a gap exists between lithium market prices and export (sale) prices, suggesting the possibility of transfer pricing. This section extends the analysis of how the effectiveness of environmental taxes can be affected by tax planning practices like transfer pricing.

Multinational enterprises use transfer pricing to determine the prices for the goods, services, and intangibles that are transferred among their subsidiaries. For example, in the mining industry, companies frequently sell minerals in the form of concentrate or mineral compounds to related parties abroad for further processing.[26] To ensure that transfer pricing is fair and reasonable, and that profits are allocated appropriately, the multinational should apply the "arm's length" principle. According to this principle, in a transaction between two related parties, the agreed price must be the same as the market price in a comparable transaction between two unrelated parties (Readhead, 2016). However, if the parties negotiate that transaction at an artificially lower price with the intention of minimizing their taxes, this fraudulent behavior is considered transfer mispricing.

Transfer mispricing will erode tax bases and reduce government revenues. Production and sale prices can be under-reported by, for example, non-reporting of by-products or by selling minerals to related marketing hubs at a discount.[27] Tax base erosion can also occur when companies over-report project costs by setting illegible costs,[28] inflating goods and services, and debt terms.

During the last decade, the Chilean lithium export sale prices have been on average 40% lower than the market prices (See Figure 4 above).[29] For illustrative purposes, and in line with Jorrat (2022), it is possible to assume that despite all government measures to deal with transfer mispricing, mining companies can still report a sale price 20% lower than the market price.

Table VIII. *Differences in taxes, projects, and government share metrics with a 20% transfer mispricing*

Fiscal regime	Chile current system	Low environmental taxes	High environmental taxes	High env. Taxes and Carbon mitigation	Lower production
Royalty	-29 %	-29 %	-29 %	-29 %	-34%
Carbon tax (input)	0	0	0	0	0
Pigouvian Tax (*ad-valorem*)	0	-20%	-20 %	-20 %	0
CIT: Mining company	-32 %	-33 %	-46 %	-36 %	-35%
RRT: Mining company	-32 %	-33 %	-46 %	-36 %	-35 %
Dividend withholding tax	-30 %	-31 %	-44 %	-34 %	-32 %
Total Revenue Loss	**-29.7%**	**-29.3%**	**-26.2%**	**-28.3%**	**-29.8%**

Table VIII above shows the government revenues implications under transfer mispricing. In the presence of transfer mispricing, royalties will change more than proportionally, given the price-variable royalty rule. What is striking from the results is the large reduction of profit tax payments (e.g., CIT, RRT, and Dividend withholding taxes). The reason is that in the current system case, companies will perform a transfer mispricing twice, first in the royalty tax base, then by deducting mispriced royalties from a lower profit tax

[26] Albemarle is the second largest lithium mining firms with mineral resources and conversions plants in Atacama, Chile. The company has also a lithium production plant in Langelsheim, Germany, and laboratories in USA and India. The company itself describes its Chinese headquarters as cost-effective flexible platforms. See albermarle.com/locations. Consulted in January 2023.

[27] Fair taxation requires not only monitoring production, but also applying it to each relevant tax instrument. In Chile, an investigation in 2012 discovered that some companies were paying resource rent tax -RRT- only on minerals extracted from new mines but not on minerals produced from old tailings (cf. Hubert, D., 2017)

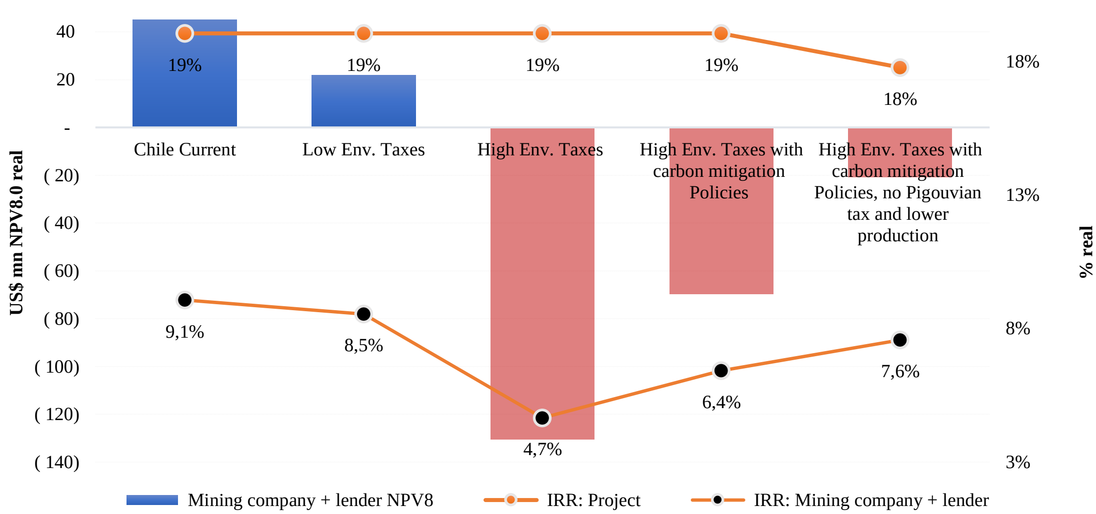
[28] In 2017, the Chilean lithium company SQM paid more than $15 million in criminal penalties for committing tax fraud by claiming non-existent costs and false invoices for transfers to Chilean politicians. (cf. The United States Department of Justice, Office of Public Affairs, Criminal Fraud Section in this link, consulted in January 2023.)

[29] An special parliamentarian commission has raised questions about distrustful transactions between SQM Chile and its affiliates in Europe with sales prices below market prices, both for lithium and its by-products such as potassium, which could result in underreporting tax payments to Chilean government agencies (CORFO), (cf. Comision Investigadora de Litio, Camara de Diputados, Congreso de Chile, Junio 2016)

base. Notice that carbon tax payments are the only charge not affected by transfer mispricing as it is independent of lithium prices. The carbon tax base depends directly on fossil energy use. Thus, the revenues from carbon taxes are not sensitive to the volatility and transparency of mineral market prices.

In contrast, a Pigouvian tax base similar to an *ad valorem* royalty will vary with mineral market values and be susceptible to transfer mispricing. Therefore, flaws in environmental tax design can also reduce their effectiveness. Moreover, in the presence of transfer mispricing, implementing high environmental taxes would make this mining project unfeasible (Figure 14).[30] Once again, it is important to know more precisely the private hurdle and discount rates because if set too high, they will likely lead to false rejection of projects that will help social development. See Appendix II for additional results with lower discount rates.

Figure 14. ***Changes in Investors' benefits in the presence of transfer mispricing (20%)***



As a standard regulatory measure, it has been suggested that establishing a reference price to calculate royalty and tax payments may be more effective than attempting to ensure actual sales reflect fair market value.[31] Still, for environmental tax purpose, a first-best Pigouvian tax should instead consider the non-market resource values and a tax base that reflect the direct input and damages of resource extraction. A compromise between market value and environmental damage would be to use tons of production as the tax base. So, the tax is more targeted than the market value, and one also avoids the transfer pricing problem. Furthermore, companies can also be incentive to reduce production (brine) inputs without necessarily reducing production output. Future research should assess brine and freshwater's market and non-market value and how underground resource depletion adversely impacts the ecosystem's integrity. With that information available, we can calculate a Pigouvian tax based on the stocks and intrinsic values of brine and freshwater, being less sensitive to lithium market price volatility and transparency.

6. Conclusions

The present study was designed to reveal the obstacles to designing and enforcing environmental taxes in the mining industry. The contribution of this study was to confirm that an environmental tax reform must consider existing and new distortions of the tax system. This research has raised relevant questions about

[30] For 24 years, a Chilean copper mine operated at a loss, accumulating USD $ 575 million in tax credits. The funds that could have been declared as profits were paid to affiliated companies in terms of interest payments to headquarters based in Bermuda (cf. https://www.engineeringnews.co.za/article/chilean-lawmaker-sues-over-coppermine-tax-evasion-2002-09-02/rep_id:4136, consulted in January 2023.)

[31] References prices have been established in the Chilean copper sector. A metric ton of refined copper in Chile is valued by the Chilean Copper Regulator (Cochilco) based on the average value and copper qualities.

how governments in mineral-rich developing countries can introduce environmental taxes without exacerbating the possible disadvantages of their fiscal regimes.

The industry typically resists the imposition of additional taxes, especially regressive ones. Mineral-dependent governments may also be wary of regressive taxes. Environmental taxes have a regressive component by design because it aims to discourage harmful behavior rather than increasing public revenues. Thereby, it goes against the well-grounded progressivity approach based on revenue maximization. However, a lack of public intervention means the mining industry will continue destroying overlapping ecosystems and contributing to global carbon emissions. Therefore, implementing environmental taxes implies a redefinition of priorities and raises a much-debated question about whether governments should prioritize welfare, in terms of environmental protection, over revenue maximization. Further research must explore how environmental taxes can be an instrument to enhance a more decentralized natural resource governance that better apprehends the needs and citizens' preferences for their natural resource wealth.

Flaws in environmental tax design can reduce its effectiveness. In this study, the Pigouvian tax is similar to an *ad valorem* royalty because it uses revenue from mined ore at market value as the tax base. One problem arising from this assumption is that the Pigouvian tax will vary with the mineral market value, making it sensitive to transfer mispricing and compromising the environmental benefits of the tax. Instead of taxing the mining output, the Pigouvian tax could target the production input directly. For example, taxing the depleted brine input in lithium production can incentivize companies to reduce groundwater extraction without necessarily reducing mineral production. Therefore, a tax more targeted to production inputs than production value will avoid the transfer mispricing problem. Future research should investigate the optimal groundwater brine and mineral recovery rates to produce lithium. These estimations will allow setting control parameters to regulate the impacts of groundwater exploitation. Altogether, measures considering the production methods and inputs of mining operations can increase Pigouvian tax effectiveness.

The choice of tax bases is crucial to determine the simplicity of the tax system and enforcement level. In this study, environmental taxes would increase the portion of revenue calculated from the gross sales tax base. A priori, taxes calculated from gross sales are simpler than taxes on profits, which can slow down the race between government auditing and corporate tax planning. However, assessing the optimal environmental tax rate requires detailed information and a comprehensive record of ecosystem values and estimated damage costs. In addition, environmental taxes require constant monitoring of production and ecological balances, including coordination with environmental institutions. Consequently, environmental taxes add transaction costs and require strengthening enforcement systems.

Environmental tax rates should be high enough to make mitigation measures attractive. In this study, low environmental taxes do not significantly affect profits and do not give companies enough incentives to mitigate damages. In that case, the environmental tax will only guarantee partial compensation for predicted damages. Suppose taxes are difficult to implement or are suspected to be ineffective. In that case, the only way to prevent environmental damage is to reduce mining projects and leave mineral resources in the ground at the expense of less public and private revenue. Nevertheless, suppose governments allow mineral extraction and tax the related environmental impact. In that case, investing and increasing mineral production has additional tax costs, increasing investors' exposure to lower mineral prices.

In this case study, relatively high carbon and Pigouvian taxes do not prevent a lithium mine like Maricunga from operating. With a hypothetical discount rate of 8% and without transfer mispricing, a project like Maricunga will provide reliable public revenues. However, if the private (hurdle) discount rate is set too high, this will likely lead to the false rejection of projects that will aid social development. Moreover, environmental tax payments will increase government revenues without any environmental mitigation policy. Then, the government's additional *net* tax revenue will be proportional to the reduction in private profits. A further study could assess the best mechanism to administer environmental tax revenues alongside decommissioning funds.

One area to improve in this study is the assumptions on alternative energy sources and mitigation policy costs. The decision to invest in renewable energy is susceptible to those assumptions, including variations in diesel prices, affecting our estimates of project profitability and public revenues. In addition, a financial cash flow analysis does not allow us to infer whether environmental taxes bring second dividends to the economy. Further research must consider the welfare and distribution effects of environmental tax reforms in the mining sector. Despite its exploratory nature, this study offers insight into essential control parameters to account for the environmental damage mining and the fiscal effects of environmental taxes at the project level. The study certainly adds to our understanding of why tax systems can be a tool to account for the hidden costs of resource extraction and reinforce environmental regulation.

Although this research focuses on the lithium mining sector in Chile, the findings may well be related to the importance of global coordination to implement environmental taxes. Two main reasons support this argument. First, if a country enforces environmental taxes, that will increase its tax burden. A high tax burden, well above those applied elsewhere, may encourage profit shifting because mining companies can send profits to low-tax countries. Second, the physical boundaries of the High Andean ecosystems do not correspond to the geopolitical ones. Aboveground ecological landscapes are influenced by underground water systems expanding to neighboring countries. So, what happens to the water balance of a salt pant may affect others in one way or another. Thus, ecosystem taxes can bring benefits not only for Chile but for the High Andean region as well.

Mining is portrayed as an environmentally and socially destructive industry, yet it is the primary source of income in many resource-rich developing countries. The mineral boom fueled by low-carbon technologies offers an opportunity to modernize resource-rich nations, but it must be done with proper accountability of mining footprints. A critical political priority should be planning mineral use with a holistic and long-term perspective and undertaking environmental tax reforms to facilitate social and economic transformations fairly and sustainably.

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Appendix A. Fiscal model assumptions

Table IX. *Current Chilean Mining Fiscal regime*

Fiscal instrument	Tax rate	Tax base	Other details	Legal source
Royalty	A uniform tax of 3% on the market value of copper, lithium, and any concessible substance.	Gross sales	This measure was approved (May 2022) in the first instance by the Parliament.	Parliamentary bill to be legally enforced.
Resource Rent Tax - RRT-		Taxable income after deducting capital costs (except interest). CIT is deductible	Since 2006, a specific mining tax has been in force in Chile. This tax is applied to profits obtained by a mining firm based on its annual sales level. The tax rate varied between 0.5% to 1,93% for small mining firms whose annual sales were between 12 000 and 50 000 tons of mineral. For bigger companies whose annual sales exceed the value equivalent to 50,000 metric tons of mineral, the tax rate varies between 5% and 14%, depending on the profit margin. The tax rates and bases apply to all concessional metals and minerals produced in Chile.	Tax code
Corporate Income Tax – CIT-	National rate 10-27%	Taxable profits	27% under the general regime and 10% under regime applicable to small and medium-sized companies until 2022, and 25% for 2023 and following.	Tax Code
Withholding tax	35% 4%-35% 0%/ 15%/ 30%	Dividends Interests Royalties	35% of additional withholding income tax applies to branch profits remitted to the head office, with full or partial credit granted for CIT paid, depending on whether the tax head office is in the tax treaty country.	Tax Code

Data source: https://taxsummaries.pwc.com/chile/corporate/withholding-taxes

Table X. *Price-Variable royalty thresholds and marginal rates*

Lithium threshold price		Marginal rate
0	4 000	6.8%
4 000	5 000	8.0%
5 000	6 000	10.0%
6 000	7 000	17.0%
7 000	10 000	25.0%
10 000		40.0%

Source: Jorrat (2022).

Table XI *Fiscal regime assumptions to calculate the Chilean AERT evolution*

	Tax reform - RRT	Earthquake	Tax reform Higher CTI	Royalty CORFO	COVID-19	**Current (2023)**
Royalty rate: (nominal) price-variable				10.00%*	20.00%**	24.5%***
CIT	17%	20%	27%	27%	10%	27%

* The price-variable royalty was calculated with an estimated nominal lithium price in 2006 (US 6 000 per ton of LCE)
** Calculated with an estimated nominal lithium price in 2018 (US 12 000 per ton of LCE)
*** Calculated with the estimated lithium price for 2021 (US 17 000 per ton of LCE), according to the USGS (2022)

Table XII *Fiscal regime assumptions for peer group*

Regime name	Argentina	Australia	Bolivia	Brazil	Mexico	Peru
Royalty rate (Flat) Tax base: gross revenues Royalty is CIT and RRT deductible	8%	2.5%	3.4%	3%	7.5%	3%
CIT rate	35%	30%	25%	15%	30%	30%
RRT tax rate			13%			1.93%
Dividend withholding tax	7%	5%	13%	10%	10%	5%
Interest withholding tax	12%	5%	13%	15%	1%	4%
VAT	21.00%	10.00%	13.00%	12.00%	16.00%	18.00%

Source: https://taxsummaries.pwc.com/

Table XIII *Fiscal regime assumptions for alternative scenarios*

Regime name	Chile Current	New Royalty 3%	Low Env. Taxes	High Env. Taxes
CIT rate	27%	27%	27%	27%
RRT rate	5%	5%	5%	5%
Dividend withholding tax	8%	8%	8%	8%
Interest withholding tax	4%	4%	4%	4%

* The price-variable royalty was calculated with an estimated nominal lithium price in 2021 (US 17 000 per ton of LCE)

Table XIV *Mine profile*

Summary assumptions	units	
Total production (20 years of operation)	Tons	307 000
Average annual production	Tons	13 348
Production starts	year	4
Production life	year	20
Development costs	$m	627
Replacement capital costs (depreciable)	$m	43
Production to DEV CAPEX	units/$m	490
Mineral Price	$/units	24 000
Operating cost per unit	$/units	3 864
Transport and TC/RC	$/units	-
C1 cash cost minus royalties	$/units	3 864
Total C1 cash costs	$/units	8 589
Discount rate (government)	%	8%
Discount rate (investors)	%	8%
Inflation	%	2 %
Real interest rate	%	5%
Leverage (equity/total assets)	%	50 %

Table V below shows the production ramp-up by type of lithium quality, showing that at full capacity, 90% of the production will be battery-grade lithium carbonate and 10% technical-grade lithium carbonate.

Table XV. *Li2CO3 Production ramp-up*

	2026	*2027*	*2028*	*2036*	*2042*	*2045*
Li2CO3 Battery Grade	4200	12000	14850	13050	14400	14940
Li2CO3 Technical grade	4200	3000	1650	1450	1600	1660
Total production per year	8400	15000	16500	14500	16000	16600

Data source: Minera Salar Blanco S.A., Maricunga Project investors' report, January 2022.

Appendix B. Additional results

Figure 15. *Changes in government revenues in the presence of transfer mispricing (20%) and lower discount rates (6% real)*

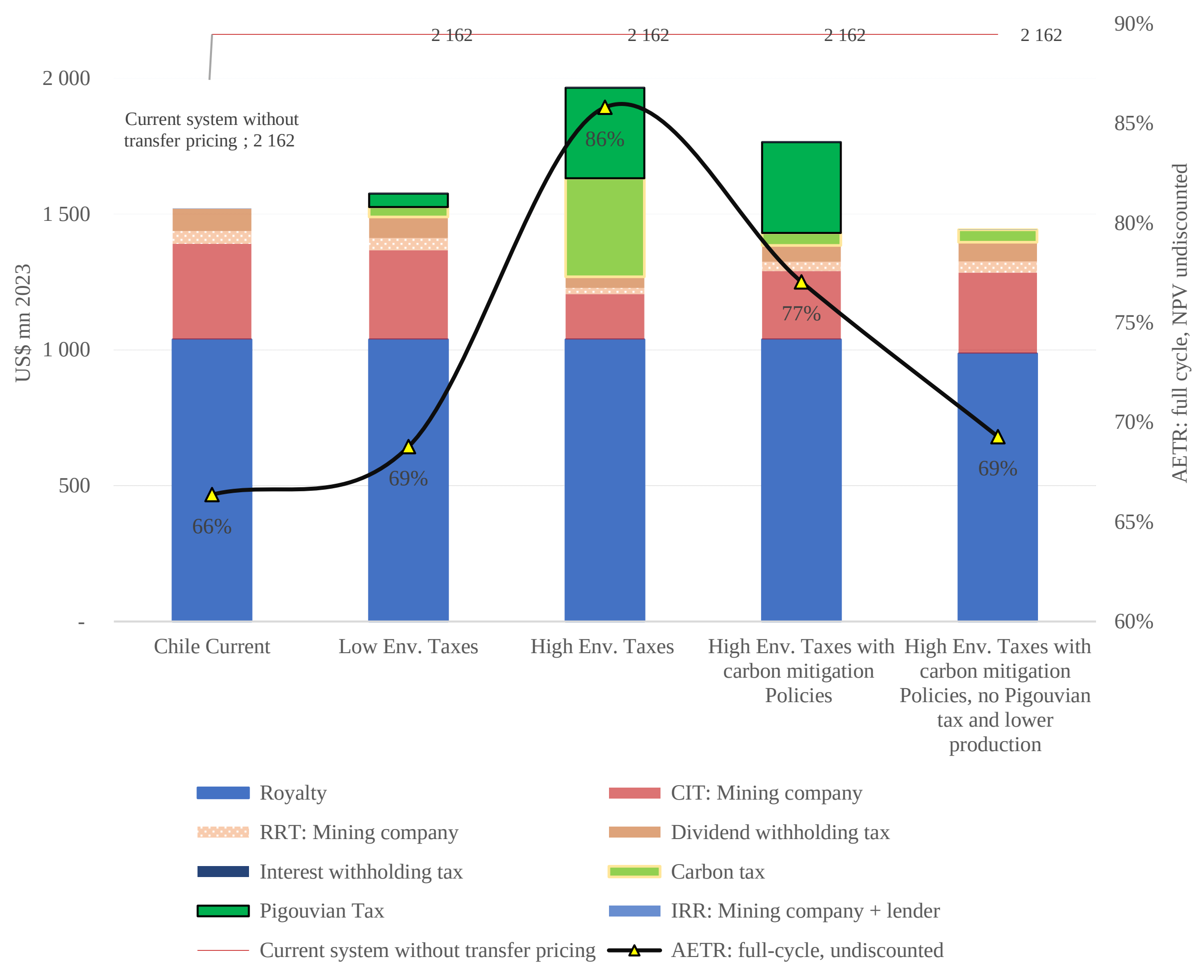

Figure 16. *Changes in Investors' benefits in the presence of 20% transfer mispricing and 6% real discount rate*