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The mining industry as a net beneficiary of a global tax on carbon emissions

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The technology used in renewable energy production is resulting in a material increase in the demand for many minerals and metals. While the mining industry contributes to global carbon dioxide emissions, the industry is also critical to lowering global carbon emissions across the broader economy. Here we test the impact of a hypothetical international carbon taxation regime on a subsection of the mining industry compared to other sectors. A financial model was developed to calculate the cost of carbon taxes for 23 commodities across three industries. The findings show that, given any level of taxation tested, most mining industry commodities would not add more than 30% of their present product value. Comparatively, commodities such as coal could be taxed at more than 150% of their current product value under more intense carbon pricing initiatives, thereby accelerating the transition to renewable energy sources and the consequent demand benefits for mined metals.

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The 2015 Paris Climate Agreement resulted in 175 United Nations member states agreeing to pursue actions to limit global mean temperatures below 2 °C by 2100[1]. Even with all signing nations successfully implementing the promises made in the Paris agreement, global temperatures are predicted to rise by at least 2.6 °C by the end of the century[2]. To combat these destructive trends, the pricing of carbon pollution and investment in low-carbon technologies are critical to staying within the total carbon budget to limit global warming to 2 °C[3]. Specific industries, such as the metals and mining industry, will play a critical role in transitioning to a low-carbon future. While coal and gas extraction are expected to decline in a low-carbon future, the inverse is forecasted for mining with increasing demand for more than 20 energy transition metals such as iron, copper, aluminum, nickel, lithium, cobalt, platinum, silver, and rare earth metals[4,5]. What remains unexplored is the intersection of carbon pricing and the industry producing the materials necessary to transition to a low-carbon future.

In this article, we argue that the mining industry should be an international leader in the push to harmonize international carbon added tax (CAT). Furthermore, the mining industry has an economic incentive to support a CAT in addition to the moral and ethical arguments for supporting policy to prevent further climate change. While there are global oppositions to coordinated tax schemes, recent political movements have resulted in a proposed 15% global minimum corporate income tax, demonstrating consensus around tax levels on an international basis[6]. Historically, the mining industry's response to carbon taxation on a regional level has been general opposition. For example, when a price on carbon emissions was introduced in Australia in 2011, the Minerals Council of Australia was opposed to a public strategy in efforts to reduce the potential tax burden on the industry[7]. It should be noted that this position against carbon pricing has not been universal across the Australian mining industry, with BHP publicly declaring its support for carbon pricing in 2017 and distancing itself from the Minerals Council of Australia[8]. Rio Tinto has had a similar position on the need for carbon pricing to mitigate climate change[9]. This fractured industry standpoint on carbon pricing is also present in Canada, where some mining companies have made public commitments to carbon neutrality by 2050. Still, the Mining Association of Canada is silent on such targets and policy instruments that include a carbon price.

Carbon pricing instruments have been adopted in 40 countries, and an additional 24 instruments have been implemented at regional and local scales. In 2020, these initiatives generated USD 53 billion in revenue[10]. Two primary carbon pricing instruments are often proposed with regards to curbing global emissions: emissions trading schemes, commonly known as cap-and-trade, and carbon taxation. Trading schemes were embraced by the EU from the early 2000s with the goal of reducing emissions below 1990 levels[11]. While there were some successes in the pricing of greenhouse gas emissions, a reduction in emissions was not achieved[11]. Many studies on carbon taxation have focussed on the relative economic regressive impact of carbon pricing instruments[12,13]. However, most literature use macro-GDP models[12,14] and does not evaluate the micro-economic industrial level impact of macro-scale policy on products and commodities[15].

Intuitively, government policies that increase demand for renewable energy and electrification will lift industrial demand for metals. Recent consumption forecasts for metals such as copper and nickel show that in the coming decades, metal demands are multiples of what they are now[16–19] (Fig. 1). If action to prevent climate change becomes more ambitious, then this demand will increase even further. Metals used in the transition to the green economy are geologically constrained. More demand will result in some marginal supply increases and result in a higher price equilibrium due to a lack of ore body discoveries and new project pipelines.

This paper will show that carbon emission taxation economically benefits the mining sector. A financial model is developed to test the effect of a CAT of ten energy transition metals, given a hypothetical global carbon price of $30, $70, and $150 per tonne. The results are analyzed against the relative CAT taxation levels of other carbon-intensive primary industries such as power generation via coal, natural gas, and selected agricultural products. The global comparison shows that carbon taxes have a negligible effect on the cost of mining raw metals and minerals but will lift demand. We argue that most metals and mining industries should have an economically vested interest in supporting international carbon taxation agreements.

Results and discussion

Economic value of commodities per tonne of CO2 emitted. Figure 2 shows the economic value per tonne of CO_2 for select energy transition metals (copper, nickel, lead, zinc, silver, gold, platinum, palladium, aluminum, and steel) compared to construction materials, energy industry, and agriculture commodities. All products' carbon footprint is in a final consumer state, meaning this includes the refining, smelting, growing, or power generation adjustment for each commodity. The industries and commodities were chosen for comparison to the mining industry within the carbon pricing model based on US Environmental Protection Agency data pertaining to the primary economic sectors contributing to global greenhouse gas emissions, which includes transportation, electricity generation, industry, and agriculture[20].

Electricity production, industry, and agriculture represent 58% of the total US CO2 emissions in 2019[21]. While transportation represents a further 29% of US CO_2 emissions[21], the model and analysis are constructed to apply the tax to the raw material instead of the end-user. Therefore, the transportation industry is excluded from the study. This assumption and the other model limitations are further discussed in the Methods section. The selected commodities within each industry represent a range of carbon footprints to test further and compare the CAT implications to the metals and mining industry. Economic modeling used for the generation of Figs. 2, 3 can be found in Supplementary Table 1 in Supplementary Data 1. Methods and Supplementary Table 1 in Supplementary Data 1 include a model and table that can be used to test carbon taxation at $30, $70, and $150 a tonne.

The global metals and mining industry contributes to approximately 8% of the global carbon footprint[22]. Mining is a material contributor to global carbon emissions, yet compared to the industry's economic contribution, the emissions footprint is small. All mining industry products have a uniquely high value per tonne of CO_2 emissions compared to the energy, construction, and agriculture products modeled (Fig. 2). The implication of this is that the mining industry, on the whole, would be less financially impacted if a global carbon tax is introduced compared to other industries. Conversely, commodities with a low economic value per tonne of CO_2 emissions—such as coal and natural gas—would be materially impacted by a global taxation scheme at any level. Base metals such as aluminum and steel generate relatively low economic value per tonne of CO_2 emitted compared to precious metals and copper. Further exploring the breakdown of the global CO_2 footprint contributions by the metals and mining sector, 90% of total emissions are from the manufacturing of iron and steel[22]. The primary CO_2

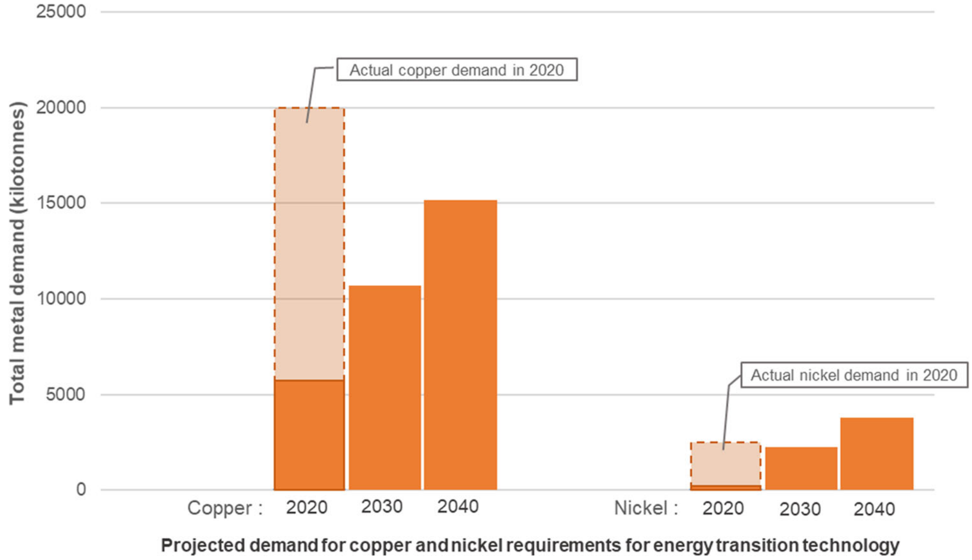

Fig. 1 Projected demand change for copper and nickel requirements for energy transition technology. Projected demand for copper and nickel required for low-carbon technology generation, electric vehicles, and battery storage (solid, orange bars) compared to the actual total metal demand (for all purposes) in 2020, using data from the International Energy Agency 2020 datasets on the metal demands requirements to achieve the Paris Accord global warming targets. This figure shows that in 2020 total global copper demand (dashed, transparent orange) was 20 million tonnes, of which 5.7 million tonnes, shown in the darker orange, solid bar was projected for use in energy transition technologies.

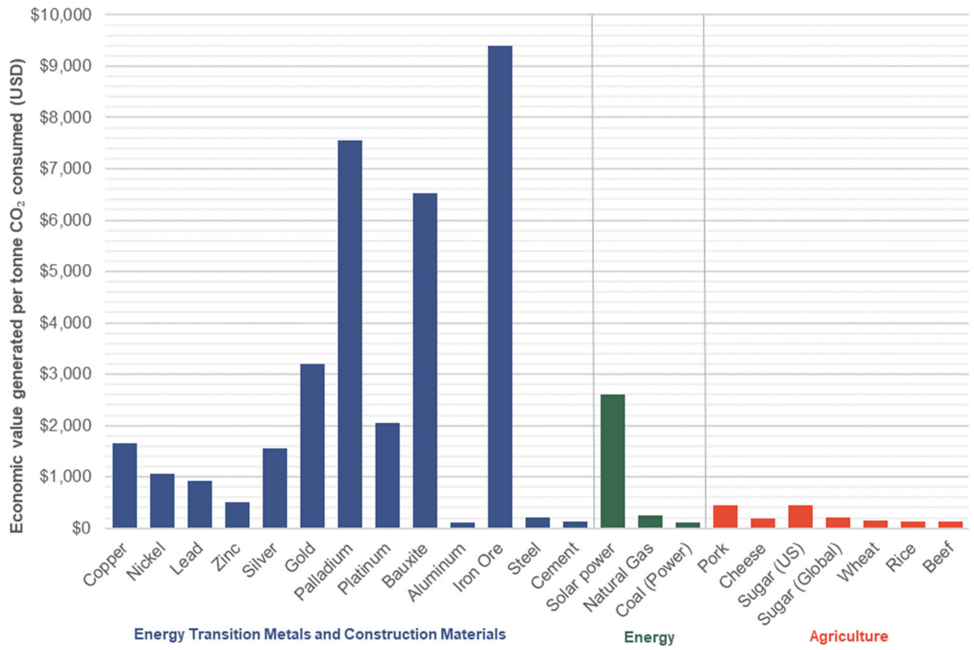

Fig. 2 Economic value of commodities per tonne of CO_2. Economic value per tonne of CO_2 emitted in USD for selected energy transition metals and construction materials (blue), energy industry commodities (green), and selected agriculture products (orange).

emissions derived throughout the lifecycle of iron ore and steel is through the refining and smelting processes which can be over 99% of the total emissions[23,24]; the actual process of mining the raw metal requires very limited CO_2 production[25]. This can be further shown through the disproportionate amount of CO_2 emitted between the mining process of raw metals such as bauxite and iron ore compared to emissions in the final product (Fig. 3).

Carbon taxation as a value-added tax and its impact on commodities. Carbon taxation can be viewed as an environmentally progressive value-added tax on products. Unlike standard value-added taxation schemes, the CAT will act as a progressive form of corporate taxation. The carbon tax will have more material financial implications for more carbon-intensive industries. Figure 4 provides the results of the CAT economic model developed for taxation at \$30, \$70, and \$150/t CO_2 emissions applied as a percent of the present product value. The impact of any pricing of carbon taxation is marginally higher taxes for most non-ferrous, non-energy metals and ores and resulted in materially higher taxes for all other industries tested. In the case of the mining industry, the most materially impacted non-ferrous, non-energy metals are lead and zinc, with the taxation making up at most 14% of their present product values under a \$70 taxation scenario. Compared to industries with adequate, low-carbon

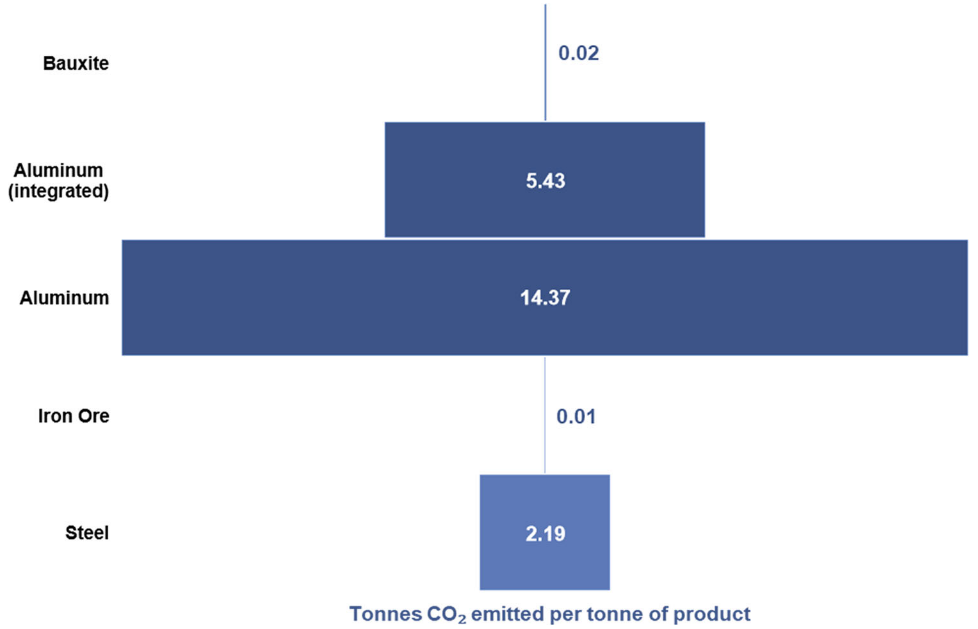

Fig. 3 Comparison of tonnes of CO_2 emitted per tonne of raw mineral and final metal production. Tonnes of CO_2 emitted per tonne of raw minerals (bauxite and iron ore) and finished metal produced (aluminum and steel). Integrated aluminum refers to companies that vertically integrate processes from raw metal mining to finished metals production.

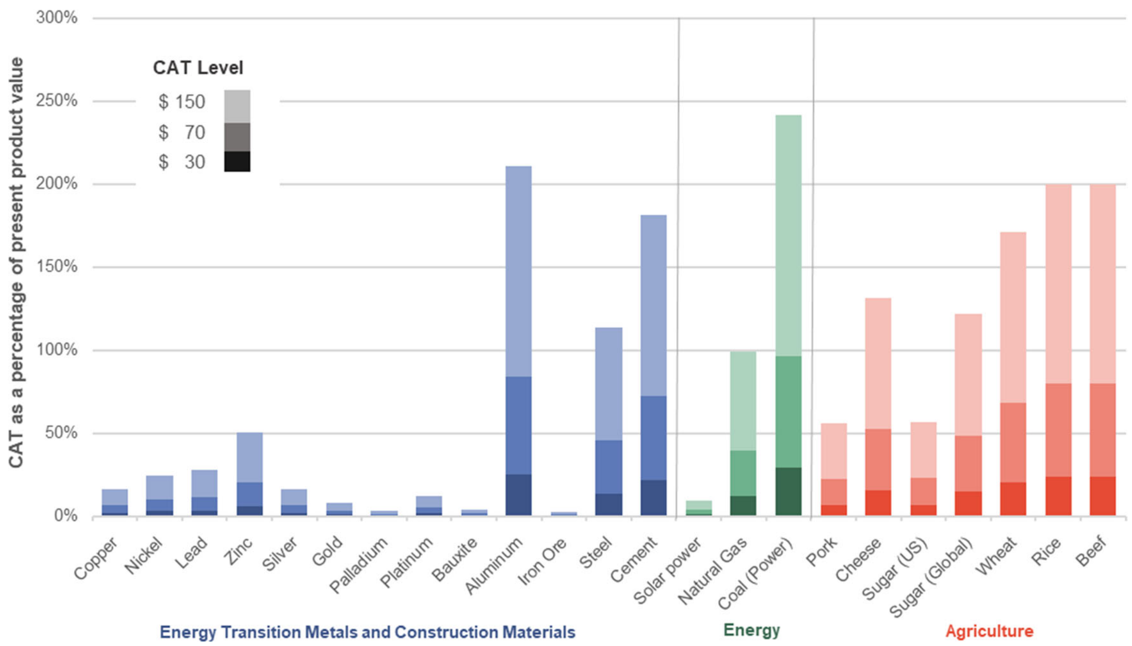

Fig. 4 Three levels of carbon taxation modeled as a percentage of present product value for selected commodities. The impact of a 30, 70, and 150 USD CAT modeled as a percentage of the present product value for selected energy transition metals and construction and smelting products (blue), energy industry commodities (green), and selected agriculture products (orange). The increasing level of carbon added taxes are shown by increasingly lighter shades, 30 USD per tonne of carbon emitted is shown in the darkest color shade, whereas 150 USD per tonne of carbon emitted is shown in the lightest color shade.

substitutions such as construction and food production, the highest level of carbon taxation results in tax added increase in prices of upwards of 55% of the present product value at $70/t CAT.

Aluminum and steel are outliers for the mining industry. As previously discussed, the majority of the carbon footprint from aluminum production is generated through electricity consumed in aluminum production. The high carbon footprint of aluminum is driven by the embodied energy of 211 GJ per tonne for aluminum coupled with a lower metal value[26]. This is over three times greater than the average of all base metals at 63.26 GJ per tonne of metal refined (See Supplementary Table 1 in Supplementary Data 1). Therefore, the CAT would have a higher impact on miners with aluminum and alumina production in their portfolios. However, two major western miners of aluminum, Rio Tinto and Alcoa, have vertically integrated aluminum productions, meaning the operation encompasses the entire lifecycle of aluminum from the mining of bauxite to the production of the finished aluminum (vertical integration)[27,28]. The processes at these integrated operations use hydroelectricity and other renewable energy for the majority of electricity consumption. Both operations are shown to have a net 8.9 tonne of CO_2 emissions advantage per tonne of aluminum produced compared to the average non-vertically integrated global aluminum producer (Fig. 3). The implications of the electricity-powered carbon-intensive smelting process for aluminum make it an excellent case study for how carbon taxes can shift the mining industry, promote innovation and drive responsible energy substitutions[29].

The steel industry may also not be a prime supporter of the CAT; the reasons for such are more nuanced than that of the aluminum industry. Like bauxite miners and aluminum producers, there is a major CO_2 emissions difference between the raw mining of coking coal and iron ore and the smelting of finished metal production. This conflict is due to the bulk of the emissions from steel manufacturing being generated by coking coal and other energy sources in the coke-fire blast furnaces. A difference between aluminum producers and steel production is that the major mining companies which mine iron ore are not vertically integrated. While the mining of iron ore would not be impacted by a global CAT, the downstream producers and consumers of steel would likely face the burden of the tax. Therefore, under this model, a global CAT would hypothetically increase the price of steel but not the price of iron ore. Decarbonization in the steel industry is a current area of research. Energy and emissions reduction technologies such as blast furnace optimization and smelting reduction are gaining traction in the green industry[30–32]. However, the CO_2 emissions from the need for coking coal in the process of steel manufacturing will be considerably harder to remove. Currently, there is no substitution for the use of coking coal in steel manufacturing at scale. The authors therefore argue that mining companies with portfolios that include coking coal might have conflicted support for a global CAT; however, the elasticity in demand for coking coal due to the lack of direct substitution will result in higher steel prices. Research on the correlation between consumption of steel and steel pricing from 1960–2015 has shown that consumption is far more sensitive to per capita income than price[33]. Metal demand has minimal elasticity of demand to changes in metal prices. Additionally, the minimal impact from a CAT will likely be offset as the aluminum and steel demand intensity increases due to the requirements for the low-carbon economy.

The impact of a CAT on material flows and recycling. Concerns around resource constraints have shifted and focussed more discussions on supplementary supply of energy transition metals from recycling[34]. The use of environmental taxation with the intent to increase recycling rates is currently a part of United Kingdom policy, specifically directed at the aggregate industry. The Aggregates Levy was created to tax the mining of new sand, gravel, or rock and promote the recycling of aggregate material and, in turn, may shift the total waste rock deposition[35]. Extractive industries that have faced higher relative taxes on waste disposal, such as in the Aggregate Levy case, have had substitution from recycled materials[35]. However, we argue that the CAT tax will not have the same economic or recycling impact on mining and metals required for low-carbon technologies.

The mining of raw metals, production of finished metals and recycling will need to work in conjunction to address the increasing metal demands[36,37]. Figure 5 shows the impact of the CAT on selected metals and their recycled counterparts. The copper and steel recycling industries are the focus of much research around material flows analysis[36,38,39]. A CAT economically impacts raw metals mining and production more than twice as much as recycled metal. A fundamental challenge with recycled metals is due to low-grade scrap metal losses. Addressing this challenge would require an overall to the municipal waste management system globally, and a CAT tax will not necessarily generate enough revenue to justify that change. However, even given a theoretical 100% recycling rate, the current metal and mineral supply would not meet the current or future demand. Using copper as an example, required above-ground stocks per capita will increase by an estimated 2–3.5 times by 2050; material flows analyses demonstrate that current recycling rates can only account for very limited amounts of this demand due to the fundamental lack of existing above-ground stocks[40].

Implications of carbon taxation on the mining industry. The role of the mining industry in climate change mitigation is contentious. In many instances, the mining industry is portrayed as environmentally and socially destructive yet is the primary supplier of the infrastructure needed to mitigate climate change-induced destruction[4,18,19]. To the best of our knowledge, this research has introduced a new perspective on the role of the mining industry and climate change mitigation. While the mining industry is an intensive energy user and greenhouse gas emitter, for primary energy transition metals, the processing of ore into metals has low energy intensity for the amount of economic value created (with the notable exception of aluminum and steel). A primary reason for the low energy intensity of metal mining is the result of market dynamics. The mining industry is an inherently supply-constrained industry due to the lack of and depleting number of economically viable ore bodies. This supply constraint results in an economic rent that mining companies capture, resulting in a higher revenue compared to the CO_2 emitted. Additionally, the mining industry is unique because metals are not easily substituted in end products. However, compared to the other industries and commodities considered in this paper, modeled substitutions are available. For example, in the case of agricultural commodities, the progressive CAT would result in interesting externalities where beef consumption may shift to less carbon-heavy protein sources, further driving the value difference between the protein sources.

Based on the financial modeling results, the implications of a global CAT on the mining industry are two-fold. First, we argue that the mining industry has a more substantial relative economic base in a carbon-tax-based economy on a comparative taxation basis. If implemented on a global scale, the CAT would not materially impact or change the underlying cost or processes of the base metal business. At the same time, the carbon-intensive, substitution available industries would be forced to reduce CO_2 emissions or face an economic substitution threat. Second, by supporting carbon taxation, the mining industry can publicly support the 2050 zero-emission goals while paying relatively minor taxes relative to all other sectors and focusing on easy carbon reduction strategies. The combination of relatively low costs of mining carbon taxation, increased demand for metals as others work to reduce their tax footprint by not emitting carbon creates an opportune environment for global mining to be a prime promoter of carbon taxation.

This paper also has implications for policy makers. In our analyses we have assumed the scenario of an internationally harmonized CAT regime. Future papers could examine the effects of a situation where some regions have low CAT rates and others have high CAT. Given the small impact of a CAT on mining, we think it is unlikely that we would see a race to the bottom as mining operations are moved to low-taxing jurisdictions. Nonetheless, policy makers should enroll the mining industry to advocate for similar CAT rates between nations. The other insight

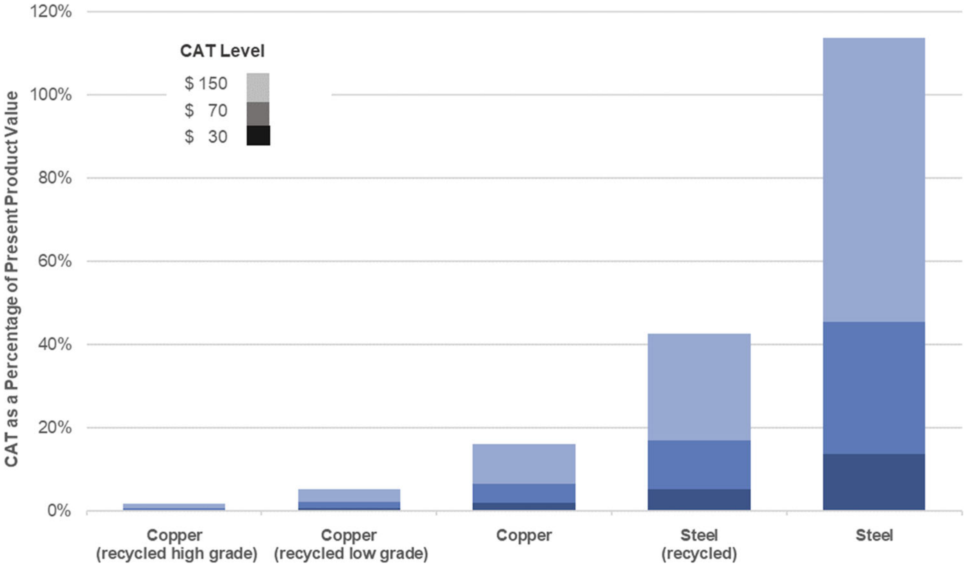

Fig. 5 Three levels of carbon taxation modeled as a percentage of present product value for selected primary and recycled copper and steel. The relative impact of a 30, 70, and 150 USD CAT on recycled and primary metal production on copper and steel. The increasing level of carbon added taxes are shown by increasingly lighter shades, 30 USD per tonne of carbon emitted is shown in the darkest color shade, whereas 150 USD per tonne of carbon emitted is shown in the lightest color shade.

that this paper has for policy makers is that the loss of jobs in the mining sector due to carbon taxes, that is often claimed by industry, is unlikely to occur. Indeed, governments endowed with mineral resources are likely to see growth in employment with the harmonized introduction of CATs.

Implications of CAT on the energy transition. The use of carbon taxation schemes paired with low-carbon technology investment and implementation is critical in keeping to climate goals[41]. The implication of a CAT on the production of energy transition metals and the non-ferrous mining industry has resulted in a positive feedback loop scenario whereby introducing a global CAT continually and progressively reinforces the movement towards low-carbon technology. Mining has a very high economic value per tonne of CO_2 emitted compared to the other industries modeled, resulting in the CAT tax benefitting the mining business. The modeled CAT delivers an economic boost of low relative taxation and a push for the energy sector to transition to low-carbon yielding yet high metal consumptive solutions, such as transitioning from coal to natural gas to solar. Furthermore, the lack of available substitutions for the mining industry, especially core energy transition metals like copper and nickel, has implications for rising commodity demand and market prices. While it is widely acknowledged that the transition to low-carbon energy sources will drive a material shift in the need for energy transition metals. It is not widely recognized that the cost of solar, a primary end product of many energy transition metals, has exponentially decreased relative to conventional carbon-intensive energy sources (Fig. 6), to the point where it is already economically competitive without subsidy. A CAT tax would further shift the demand for solar that is already occurring.

Fair carbon taxation on a regional or global level should be enthusiastically supported by the base and precious metal mining industry. Rarely does an industry benefit from increased taxation. Furthermore, the reputational value of publicly supporting a global green initiative is a substantial added benefit. Several top-tier mining companies have begun to divest from their steaming coal assets, further strengthening the business case of the support of a CAT[42–44]. The only way to zero emissions in 2050 is to reduce fossil fuels, and the CAT tax on any scale will further reinforce that shift. Between the relatively low level of taxation and the projected increase in demand, mining has a compounded incentive to support taxation. While the mining industry and its support for a global CAT presents a pathway to mitigate further global warming, it cannot come at the destruction of other environmental commons; mining must pursue holistic approaches to mining necessary energy transition metals.

Methods

CAT model. Supplementary Data 1 includes Supplementary Table 1 and Supplementary References 1 which contain the detailed model used for the development of the CAT analysis and sourcing for all model inputs. The model uses a commodities price and carbon footprint to calculate a commodity-specific CAT for a given carbon pricing scheme. An extensive review of commodity pricing, carbon footprint, and global production was completed to create the inputs to the CAT model. The goal of the model was to document how much applying different levels of a CAT would act as a relative economic brake or incentive for various industries. Different economic pricing levels: 30 USD/tonne, 70 USD/tonne, and 150 USD/tonne were used as tax regimes; however, the attached model can be adjusted for any tax rate. The CAT pricing levels were selected based on a review of the current carbon taxation schemes and literature on the impact of carbon pricing on industries of interest[45–47]. The CAT model developed was then applied across commodities and energy sources.

The presentation of the tax was output through two outcomes: 1. revenue or product value per tonne of CO_2; and 2. CAT as a percentage of the product value. These outputs demonstrate the industries and commodities that are susceptible to the tested CAT levels. The total carbon tax by commodity was taken on a global basis by considering the average carbon footprint of the industry as a whole and multiplying it by the carbon taxation levels. A central underlying assumption within the model is the adoption of an equal and fair level of CAT globally.

This analysis has included the refining to finished metal, including blast furnaces and smelting of metals in the CO_2 emissions. For copper, nickel, lead, and zinc, differing extraction methods required a weighted average for the carbon footprint based on the global distribution of extraction usage. The CAT was developed as a hypothetical policy tool that would be collected at the point of carbon generation instead of electricity consumption. Therefore, the downstream carbon consumption used in post-smelting manufacturing processes[48] was excluded. The calculations used in this analysis are simple ratios and neither complex nor optimized. The ratios may be further refined through future research; however, we argue that the model does not require fine optimization given the macro-scale of the analysis.

The core calculations for the CAT model are as follows:

$$\text{Economic Value per tonne of } CO_2 = \frac{\text{Market price per mWh or tonne of product*}}{CO_2 \text{ emitted per mWh or tonne*}} \tag{1}$$

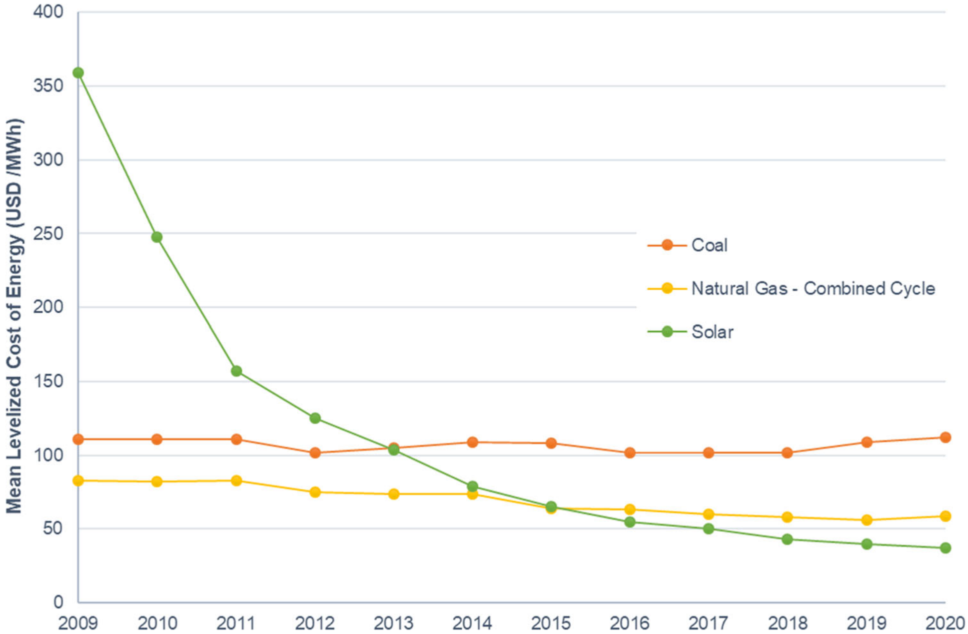

Fig. 6 Mean trends in levelized cost of coal, natural gas, and solar power. Modified graph from Lazard showing the historic mean levelized energy costs of coal, natural gas, and solar power since 2009[53]. In 2020, the mean levelized cost for energy sources in USD per MWh of solar (green) is shown to be lower that both natural gas (yellow) and coal (orange).

$$\text{Carbon Added Tax (CAT) per unit of product} = CO_2 \text{ emitted per mWh or tonne}^* \times \text{price of } CO_2 \text{ per tonne}^{**} \tag{2}$$

* Externally sourced inputs
** CO_2 price at USD 30, USD 70 or USD 150/tonne

Data sourcing. All data sourcing can be found in Supplementary References 1 in Supplementary Data 1. To build the CAT model and its application to the selected industries, data were sourced from research reports[18,26] and the market and consumer statistics database, Statista[49]. Further refinement for data on selected metals, as discussed above, was undertaken. The 2020 average market price of commodities was used. 2021 spot pricing was not used due to current market conditions and lack of market stability. Sourcing comparable carbon footprint data proved a challenging task. However, the 2012 CSIRO report[26] allowed for the analysis of common energy transition metals and the breakdown of carbon footprinting based on the smelting processes used. We argue that despite the ten-year-old data used in the development of the CAT, the mining and chemical transformation processes of the metals modeled have improved to the point where the findings would not be influenced materially. There are limitations associated with using a singular number of CO_2 emissions per tonne or MWh for commodities as opposed to a range of emissions. Weighted averages were calculated where available, such as copper, nickel, lead, and zinc.

The selection of industries (energy, construction, and agriculture) is based on global carbon footprint levels, as the selected industries compose the majority of the global carbon consumption within the U.S[22]. The minerals and metals selected for the analysis of the mining industry include the top five highest produced base metals and top four highest produced precious metals[50]. All minerals and metals selected, apart from gold, are critical energy transition metals[51,52]. For all other energy transition metals and industries tested, the data on the carbon consumption to produce these commodities is underreported. Therefore, data availability on commodity carbon footprint impacted the selection of commodities tests within the CAT model. For the energy industry, only variable forms of energy were selected for modeling, meaning forms of energy derived from infrastructures easily integrated into current grids. The infrastructure materials and agriculture system commodities are used as comparators, therefore only a limited suite of commodities from the sector were selected. As research and disclosure on carbon footprints improve within industries and commodities, the CAT model can be updated.

Data availability

The authors declare that the dataset generated during the study are available in the Scholars Portal Dataverse repository [See, https://doi.org/10.5683/SP3/K9JXTK]. The dataset is also available in the supplementary data file.

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Author contributions
The initial design and methodological development of the research project originates from B.C.; data collection, analysis and writing were jointly conducted by B.C. and S.I.; S.I. prepared the figures and tables with input and modifications from B.C., N.C.K., and J.S.; J.S. made contributions to the introduction based on their area of expertise; N.C.K. and J.S. made contributions and revisions throughout the writing process. All authors reviewed the manuscript.

Competing interests
The authors declare no competing interests.

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