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Review article

Mining and climate change: A review and framework for analysis

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ABSTRACT

In this paper, we demonstrate that climate change is critically important for the current and future status of mining activity and its impacts on surrounding communities and environments. We illustrate this through examples from Latin America, including a spatial analysis of the intersection between projected climate changes and existing mining operations. We then elaborate a framework to identify and investigate the relationships among mining, climate change, and public and private responses to them. The framework also notes the importance of political economy and learning processes to the forms taken by these relationships. Our paper then reports on a focused review of peer-reviewed publications that aims to identify the extent to which a core research literature on mining and climate change currently exists. We show that this literature is still very limited, but that the analysis that does exist can be encapsulated by the main elements of our framework. This enables us to describe the current structure of both peer-reviewed and policy research on mining and climate change, and identify areas for future research. In particular, we note the chronic absence of research on this relationship for the vast majority of developing countries, where some of the most serious vulnerabilities to climate change exist.

I. Climate change as an emerging driver of mining policy

On March 29, 2017, El Salvador's Legislative Assembly unanimously passed a law banning metal mining in the country. "El Salvador makes history as first nation to impose blanket ban on metal mining" The Guardian (2017) stated, while *The New York Times* (2017) reported that "El Salvador, Prizing Water over Gold, Bans All Metal Mining." Though passed by a left-of-center government of the Farabundo Martí National Liberation Front (FMLN), conservative, pro-market, anti-regulation lawmakers of El Salvador's Nationalist Republican Alliance (ARENA) also voted for the law. Reflecting on that vote, one of these ARENA legislators, Johnny Wright Sol, "who worked to persuade his business-friendly party to support the law, said that climate change was already having an impact on El Salvador. 'More than a theory or an uncertain science that it might have been 10 years ago, today for Salvadorans, it is a reality'"(*New York Times*, 2017).

El Salvador's law points directly to the increasing significance of climate change for strategic decisions on the regulation of mining. For several years prior to the law, critics of the mining sector in El Salvador had been drawing attention to the vulnerability of the country's water resources under conditions of climate change, and argued that to allow mining in the country would aggravate this vulnerability (Broad and Cavanagh, 2015; Spalding, 2013; Moran, 2005). A Strategic Environmental Assessment of the mining sector also noted that mining would use water resources that climate change would make scarcer, and that the increasing frequency of severe storms would threaten the failure of tailing dams and other mine infrastructure, with potentially serious consequences for water contamination (TAU, 2011; Bebbington et al., 2015).

Though perhaps an extreme example, the case of El Salvador demonstrates the significance of climate change for the future of the mining sector, particularly in water-constrained national environments. Indeed, even in a mining-country *par excellence* such as Chile, a senior executive of a leading global mining company insisted that climate change-related pressures on water and energy resources demand that the sector go through "a socio-technical regime change," not only as an adaptive response, but also because in a context of climate change, "the forms of gaining legitimacy have changed." A leader from Chile's national mining sector expressed a similar view, arguing that innovations related to water and energy had to be accelerated, not least because in the future, companies and metals are likely to be assessed in terms of their climate footprint.[1]

These emerging developments within at least some policy and industry communities draw attention to a relative lacuna in the academic

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[1] Interviews with second author on March 5 and 9, 2015, in Santiago, Chile.

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literature, where, we contend, the relationship between mining and climate change has received limited attention. This gap is borne out by a simple review of titles in this journal, one of the principal academic venues for debate on extractive industries. Since its founding, it has published no articles that have references to climate change in their title (though Holden's article on typhoon vulnerability deals with climate change risk: Holden, 2015). The scholarly literature on mining has been more concerned with themes such as: the relationships between extractive industry and development; extractive industry governance; community rights; consultation and resistance; the social and environmental impacts of extractives; corporate social responsibility; and, increasingly, artisanal and small-scale mining (ASM). This is not a criticism, but we do suggest that the literature is not yet equipped to speak to what seems likely to become a critical driving factor in extractive industry governance.

Given this lacuna, this paper does four things. First, in the following section, it develops the claim that climate change is a critical issue for the mining sector by presenting evidence on likely future relationships between mining and climate for the case of Chile. The data presented, in the form of maps, demonstrate clearly the potential for a spatial overlap between climate change impacts and mining operations, particularly in areas where water use by mines is of concern. This Chilean material is presented *not* as a fully developed case study that runs through the paper, but simply to make the point that climate change is an empirical problem for mining, not just a political problem. Second, the paper develops a simple framework for organizing thinking around the climate change-mining relationship. The framework is developed deductively, and describes a set of relationships that, we argue, structure how mining and climate change interact, and which require much deeper investigation by scholars. Third, the paper conducts a two-step review of existing literature in relation to this framework. The first step focuses on that smaller body of peer-reviewed publications that addresses the topic of climate change and mining as part of their main purpose. This initial review seeks overall patterns in this literature and shows that existing work falls within the relationships addressed in our framework, suggesting that the framework effectively captures the primary concerns of scholarly work to date. The second step of the review then offers a more in-depth discussion of both this literature and a broader set of existing research related to climate change and mining using the framework as an organizing structure. Finally, the paper uses this review and our framework to assess possible research agendas.[2]

II. Climate change and mining in Chile: visualizing the challenge

In this section, we examine the potential spatial relationship between climate change and mining, using the case of Chile as an illustration.[3] The purpose of the analysis is to give empirical support to the claim that climate change already is, and will continue to be, a critical issue confronting mining. Chile has employed mining to drive its economic development, and is the world's largest producer of copper. Its mining sector accounted for 54% of national exports and 12% of GDP in 2015, and an average of nearly 20% of annual government revenue between 2004 and 2015 (COCHILCO, 2010, 2015). Since the country's return to democracy in 1990, this development model has helped Chile to maintain one of the highest average GDP growth rates in Latin America and a decrease in both poverty and inequality (World Bank, 2016). The mining operations driving this growth are concentrated in the country's arid northern regions—some of the driest areas on Earth—leading to water scarcity and conflicts with local communities over access to water, water contamination, and community rights to livelihood (Babidge, 2016; Budds, 2010; Prieto, 2015, 2017; Urkidi, 2010). Small climatic changes in these mining regions could therefore have severe consequences for mining operations, local communities and environments, and the country as a whole.

Fig. 1[4] shows projected changes in mean annual temperature in Chile from current (1970–2000) levels to 2050, and where they overlap with mines (including small, medium, and large-scale operations) presently operating in the country (as of 2011 and 2012). Fig. 2 does the same for total annual precipitation in the country. Fig. 3 offers a frequency histogram of the number of mines shown in Figs. 1 and 2 that are projected to experience a given change in mean annual temperature (a) and total annual precipitation (b) by 2050. The climate projections are based on two different Representative Concentration Pathways (RCP) employed by the Intergovernmental Panel on Climate Change (IPCC) in its most recent Assessment Report (AR5). RCP 4.5 represents an optimistic scenario in which the amount of energy added to the earth's atmosphere increases by 4.5 W/m^2 over pre-industrial levels by 2100. In contrast, RCP 8.5 assumes a pessimistic trajectory for current anthropogenic greenhouse gas (GHG) emissions, in which energy in the atmosphere increases by 8.5 W/m^2. Conclusions from these figures should be drawn with caution, as they represent a basic exercise in examining the potential relationship between climate change and mining in only one country, using only one Global Concentration Model (GCM). Moreover, precipitation levels are known to be particularly difficult to predict, lending more confidence to Fig. 1 than Fig. 2 (Hegerl et al., 2015; IPCC, 2014a: 42).

Despite these caveats, the figures present information that can be useful in examining the potential spatial relationships that may emerge between climate change and mining, particularly in water-scarce regions. Figs. 1 and 3a indicate that most of Chile's mines will experience an increase in average annual temperature of between 1 and 3 °C by 2050 under RCP 4.5, and between 1 and 4 °C under RCP 8.5. Interestingly, Figs. 2 and 3b predict a slight increase in precipitation in most mines under both RCP 4.5 and RCP 8.5. These absolute measurements of precipitation change, however, mask differences in relative impact between regions that receive divergent amounts of rain in the same period. That is, the Atacama Desert in the northern region—the site of many mining operations—is considered one of the driest areas on Earth, and thus, even miniscule changes in precipitation (positive or negative) could have far-reaching ecological and social consequences (see, for example, Bozkurt et al., 2016).

Moreover, higher temperatures could increase the rate of glacial melt along Chile's Andean chain, which could have substantial impacts on water availability given the country's dependence upon runoff (Bellisario et al., 2013; Fiebig-Wittmaack et al., 2012). Glacial melt leads initially to an increase in run-off and associated water availability, followed by a long-term decline (Bury et al., 2013; Magrin et al., 2014).

[2] In doing so, we build off of and expand upon Phillips' (2016) recent literature review. While he reviews existing research with an eye to the potential physical implications of climate change in terms of biophysical, chemical, ecological, and hydrological processes, we seek to elucidate both the physical and social interactions between climate change and mining, as they play out in socio-economic processes, industry practice, public policy, public perceptions, and actual physical outcomes.

[3] We could have chosen a number of countries or regions with similar dynamics to demonstrate the spatial relationship between climate change and mining, but selected Chile due to the authors' familiarity with the case, and the availability of necessary data.

[4] Data sources for Figs. 1 and 2: **Basemaps**: (**1**) Chile administrative boundaries: "DIVA-GIS, " n.d. (**2**) Global boundaries: "DIVA-GIS," 2011. **Mine sites**: (**1**) Data from SERNAGEOMIN, 2011a, 2011b, 2011c, 2012a, 2012b. (**1.1**) These "atlases" offer mining data for Chile by region and commune. We identified mine sites by isolating all operations listed in these documents as having an "Installation Type" (*Tipo Instalación*) of either "Open Pit" (*Mina Rajo Abierto*) *or* "Subterranean" (*Mina Subterránea*), and a status (*Situación*) of "Active" (*Activa*), regardless of operation size or material mined. The total number of mines identified was 1027. (**1.2**) Special thanks to Christoph Albers of *Cartografía Rulamahue* for identifying these documents, which he used for his map, "Mines," under the section "Economy," at this citation: Albers, 2016. **Current Temperature and Precipitation**: (**1**) Fick and Hijmans, 2017 (via worldclim.org). (**2**) All data were downloaded with a spatial resolution of 10 min. **Future Temperature and Precipitation**: (**1**) Hijmans et al., 2005 (via worldclim.org). (**2**) All data were downloaded with a spatial resolution of 10 min. (**3**) The HadGEM2-ES GCM was selected following Chou et al.'s (2011) use of it for climate change analysis in South America.