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Perspective

Addressing the social life cycle inventory analysis data gap: Insights from a case study of cobalt mining in the Democratic Republic of the Congo

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SUMMARY

Evaluating the human health and well-being effects of emerging technologies is essential. Yet, data to support rigorous evaluation of these effects through social life cycle assessment (S-LCA) are lacking, especially at local or regional rather than national scales. As a consequence, technologies and policies that use emerging technologies may drive inequality and detract from quality of life even if environmental life cycle assessments point to likely environmental benefits. Therefore, this Perspective describes our exploratory fieldwork in cobalt mining communities in Lualaba Province, the Democratic Republic of Congo (DRC), to identify barriers to and opportunities for collecting better data for conducting S-LCA. Our recommendations apply to the S-LCA of cobalt mining and other systems and, overall, enable more holistic evaluations of emerging technologies' effects on social well-being that are insufficiently robust for use in policy.

INTRODUCTION

Environmental life cycle analysis (ELCA) is a mature, widely used tool that has been formalized by the International Standards Organization (ISO)[1,2] to systematically evaluate the environmental effects of products, processes, and systems.[1] In an ELCA, material and energy flows for a product, process, or system are cataloged at each stage of a supply chain, including raw material extraction and processing, transportation and distribution to a consumer, use, and end-of-life. There are four phases of an ELCA (Figure 1): 1) definition of goal and scope, including, for example, specifying the system boundary; 2) life cycle inventory analysis, in which system inputs and outputs are identified and quantified using empirical data (e.g., electricity consumption) or engineering models; 3) life cycle impact assessment, in which system-level indicators are evaluated (e.g., global warming potential), using data collected from the prior phase; and 4) interpretation, in which analysts use Phase 3 results to identify the most significant life cycle impacts and communicate strategies for addressing them to relevant stakeholders.[1,3] This four-stage process permits a holistic assessment of a system's associated environmental impacts, including GHG emissions, water consumption, and air pollution.

Within the transportation sector, ELCA has been used to examine the environmental impacts of EVs[4,5] and the cobalt-containing lithium-ion batteries that power them,[6,7] as well as other potentially low-GHG-emitting transportation options including biofuels,[8] fuel cell vehicles,[9,10] and vehicles using natural gas.[11] The environmental effects of these options are then compared against those of a well-characterized baseline, such as conventional gasoline- or diesel-fueled transportation, to understand whether these systems offer advantages (e.g., lower GHG emissions per mile) or how they might be tailored to enhance environmental benefits.[12] As such, ELCA provides an evidence base for policymakers, corporations, and consumers to incentivize, develop, or purchase vehicle technologies that reduce GHG emissions and minimize broader environmental effects (e.g., on water and air quality). Accordingly, findings from ELCA have been used to develop policies and regulatory standards in the US[13] and Europe.[14] ELCA does not, however, consider how a technology impacts human health and well-being beyond environmental quality and resource use. For example, ELCA does not consider safe living conditions or fair wages.

Social LCA (S-LCA) has the potential to complement and expand upon the information generated by ELCA. Analogous to ELCA, S-LCA aims to assess the impacts of a product, process, or system on the health and well-being of humans and their surrounding communities (Figure 1).[3,15,16] S-LCA and ELCA differ, though, in their Phase 2 and 3 aims, methods, and indicators. For example, Phase 2 (inventory analysis) of ELCA involves characterization of material and energy flows through direct measurement or estimation with engineering models, whereas information about the health and well-being of stakeholders in a supply chain is collected for S-LCA. Data from the inventory analysis are then used to create aggregate indicators (Phase 3). Information

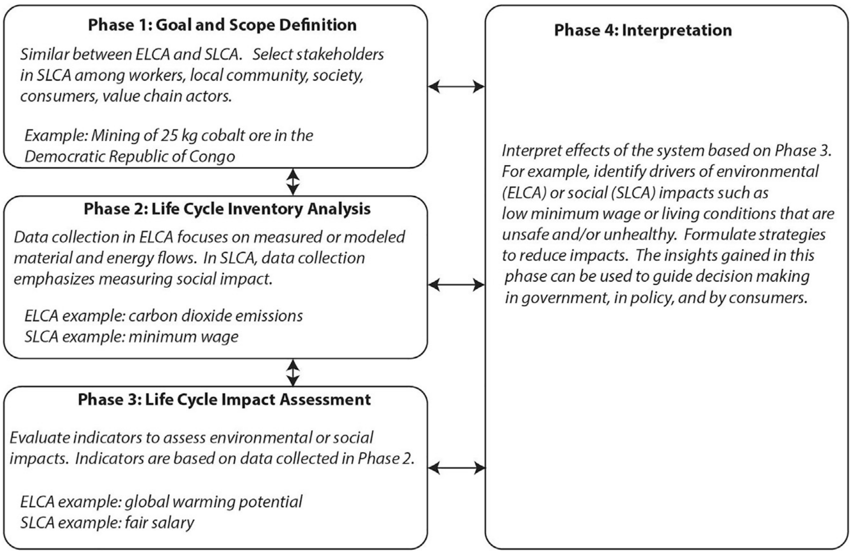

Figure 1. ELCA and S-LCA frameworks
The four phases of life cycle assessment with illustrative examples of how ELCA and S-LCA are similar and different. Both types of life cycle analyses are iterative processes and there are interactions between phases.

sources and data collection methods for Phases 2 and 3 of ELCA have been standardized by ISO,[1,2] allowing for comparison of results across studies and systems. In contrast, indicators for S-LCA have yet to be formalized,[17–19] making it difficult to determine the relative impacts of different processes and thereby limiting the tool's utility. Some groups, such as the Roundtable of Product Social Metrics, have developed standardized indicators, but methodological differences and data unavailability, particularly at high resolution, remain as challenges.[16]

There are multiple, and sometimes divergent, frameworks and methodologies applied to S-LCA.[16–20] These differ in terms of the overall goal (e.g., identifying hotspots in a supply chain versus comparing the social effects of multiple product options), social impacts measured, type of data included (e.g., qualitative or quantitative), method of data collection (e.g., from a database or interviews), and techniques to aggregate data into comparable indicators. Further, some frameworks guide the evaluation of social impacts for a single corporation, which has limited use for guiding policy development.[21,22] In contrast, frameworks that develop indicators using a "functional unit," such as impacts per mile traveled or per product produced,[23,24] are easier to compare across studies and often more actionable for governmental decision makers.

For S-LCA to reach its potential in the policy arena as a preferred decision-making tool as ELCA has done, the data that are the basis for S-LCA must be robust, efficient, transparent, and sufficiently specific to the regions that are relevant to the supply chain. The lack of guidance on best practices for conducting S-LCA, including a dearth of information about which data collection methods should be used, among which populations, and at which timepoints, has ultimately made it difficult to collect high-quality data that are comparable across settings, time, and studies. Furthermore, interviews and focus group discussions—which are often promoted in S-LCA guidelines—are resource intensive, yet there is little discussion of opportunities to use other data sources. Although it is well recognized that data for S-LCA are scarce,[15,17–19] most research to date has focused on the development of new frameworks for conceptualizing S-LCA, rather than identifying available data sources or methods for collecting data necessary for conducting S-LCA.[19] For example, Tokede and Traverso[16] review the different theories, methodologies, and indicators used in the recent S-LCA literature, but the scope of their review did not include a discussion of specific techniques to improve life cycle inventory analysis. Correspondingly, unlike ELCA, S-LCA remains mostly theoretical and has not yet become a widely accepted methodology or evaluation framework.[25]

To expand our understanding of the barriers and opportunities to improving data collection in S-LCA life cycle inventory analysis (Phase 2), we developed a social-natural science collaboration to identify generalizable methods, using cobalt mining in the Democratic Republic of the Congo (DRC) as a case study. The exploratory fieldwork for our brief case study, which afforded greater insights into our objectives than we could obtain from literature review alone, was carried out among cobalt mining communities in Lualaba Province, the DRC. We employed key informant interviews and focus group discussions in this work. Rather than producing a comprehensive dataset for S-LCA, we sought to identify the most salient human health and well-being effects of mining in the Province as well as existing and potential data sources for use in S-LCA among the two stakeholders groups most likely to be adversely affected by cobalt extraction: miners (classified as "workers" using terminology developed by the United Nations Environment Program) and local communities. Based on our findings, we suggest a number of quantitative and qualitative techniques that draw on social science methodologies, in addition to emerging data sources, including high-frequency, high-resolution satellite imagery, that have the potential for use in Phase 2 of S-LCA. Ultimately, the ability to incorporate efficient, low-cost methods that draw on interdisciplinary expertise and capture local-scale effects will expand the utility and comparability of S-LCA for policy.

CHALLENGE

The quality of information collected in Phase 2 of an S-LCA dictates the quality of the indicators generated in Phase 3, which in turn are the basis for the conclusions drawn and communicated to decision makers in Phase 4. Accordingly, the lack of regionally or locally specific data and guidance for collecting them are significant barriers to robust and effective S-LCA. To provide context, the S-LCA guidelines[3] developed by the United Nations Environment Program (UNEP) comprehensively describe S-LCA utility, methodology, and data sources. These guidelines include six distinct stakeholders: the local community, workers, society, consumers, value chain actors, and children. For each of these groups, "stakeholder subcategories" have been proposed for impact assessment (Phase 3).[26] For example, delocalization and migration are suggested subcategories for local community stakeholders compared to health and freedom of association for worker stakeholders. Within each stakeholder subcategory, generic and site-specific indicators are recommended for assessing impact.[26] Suggested data sources for generating such indicators include the Social Hotspot Database[27] and the Product Social Impact Life Cycle Assessment Database (PSILCA),[28] which mostly use information on employees' hours of work to infer broader social impacts,[29] and the UN's country-level International Migrant Stock data.[30] Importantly, many of these data sources[3] report information at the country or regional level, which masks heterogeneity within regions or subpopulations. As a result, there remains an urgent need to develop and incorporate additional indicators that reflect local perspectives.[17]

To generate critical site-specific information, the UNEP guidelines and methodological sheets most commonly recommend conducting stakeholder interviews. Yet, there is little guidance in the report or other S-LCA literature about how to conduct such interviews (Phase 2) or how to generate comparable indicators from these qualitative findings (Phase 3). There is also little guidance on how to use and analyze data from stakeholder surveys. This may be due, in part, to the fact that S-LCA has been conceptualized and formalized by natural scientists who often do receive training on procedures for accurately collecting and analyzing data related to human health and well-being.[17]

SOLUTION

We identified cobalt mining in Lualaba Province as an effective case study for motivating improvements in the Phase 2 of S-LCA given global promotion of electric vehicles (EVs), which rely on cobalt as a core ingredient in the batteries that power them. Many governments worldwide are considering or actively promoting electrification to mitigate greenhouse gas (GHG) emissions that contribute to climate change.[31–34] EVs have been promoted based, in part, on results from ELCAs that indicate that EVs emit fewer GHGs per mile than conventional cars.[7,8]

Previous ELCAs have found that EVs offer lower GHG emissions per mile than conventional, internal combustion engine vehicles, even when accounting for the environmental burdens (particularly GHG emissions) associated with lithium-ion battery production.[6,7,35] However, cobalt mining—a key part of the battery supply chain—is known to have adverse environmental impacts beyond GHG emissions at the mining site,[36–40] such as water pollution and soil degradation; such outcomes have only been quantified in detail in a handful of ELCAs.[41,42]

Over half of the world's cobalt comes from the Katanga region of the DRC, which comprises four smaller provinces including Lualaba Province, where we conducted fieldwork. Approximately 15–20% of cobalt mined here is extracted and processed by between 110,000 and 150,000[43] small-scale or independent miners (i.e., artisanal mining).[36] While cobalt mining can offer livelihood opportunities, it can also be deleterious to health and well-being,[44] such as elevated urinary and serum cobalt levels.[36] Cobalt mining can also undermine human rights and create conditions that increase violence.[43,45]

Research on cobalt extraction and processing, in particular artisanal mining, which has pronounced social impacts, is thus a high-priority area given the global push toward EV adoption and the limited knowledge about the social impacts of EV supply chains. While there is some precedent for S-LCA of conventional vehicles,[46] there has been no S-LCA of EVs. Accordingly, policies that promote EVs have a significant gap in addressing the social effects of the EV supply chain. This gap extends beyond accounting for cobalt mining's human health and well-being to other EV supply chain components including lithium, nickel, and copper. As such, we focus on cobalt in this perspective only as a starting point.

To carry out our field work, we assembled a research team that included an engineer, a human biologist, and two anthropologists. The team's expertise encompassed extensive experience with conducting ELCA and training in qualitative and quantitative social science and public health techniques. Further, one team member is a DRC national, which facilitated data collection and interpretation, including the elucidation of emic (cultural insider) and etic (cultural outsider) perspectives on the topic. Colleagues at the University of Lubumbashi and personal contacts also provided relevant contextual knowledge and assistance with identifying suitable individuals for interviews and focus group discussions. Local research assistants also assisted with recruiting such individuals and various aspects of data collection, including scheduling interviews, writing field observations, taking photographs, and verifying information about mining practices.

To identify prevailing data collection methodologies and data sources, we initially reviewed the literature on S-LCA methodologies[16,18,20–22,25,46] and studies of cobalt mining in the DRC.[36,39,41,47] This review guided our identification of relevant themes to focus on during fieldwork, including displacement, child labor, and occupational accidents. The literature review also revealed several shortcomings in S-LCA, principally the lack of identified site-specific data sources that can be used in S-LCA.[17–19,21] Most studies that did describe methods for collecting better data on S-LCA provided insufficient detail about their research methodologies to permit replication. For instance, one study described their study approach as "a literature review, telephone interviews and information derived or calculated from these data" but did not explain how interviews were conducted.[47] In contrast, Mancini et al.[39] provided detailed descriptions of the qualitative interview techniques they used to study the social effects of cobalt mining at two sites in the DRC. The data they generated could be used in the context of S-LCA or other responsible sourcing frameworks.

Given the lack of consensus about best data collection practices for S-LCA, we opted to use three well-established social science techniques that have proven useful for eliciting diverse perspectives and lived experiences in other contexts: key informant interviews (open-ended, one-on-one interviews with individuals knowledgeable about the topic),[48] focus group discussions (discussions with several individuals concurrently, organized around several prompts),[49] and participant observation (systematic observations during daily activities).[50] The use of multiple qualitative methods (see experimental procedures

Table 1. S-LCA stakeholder subcategories and generic indicators

Stakeholder subcategory	Generic indicators	Potential data sources
Stakeholder category: Local community		
Delocalization and migration	Forced evictions stemming from economic development	• Demographic data from local government offices • Land-related court claims • Community surveys of land ownership, population movement • Land office data on title transfers • SDG Indicator 1.4.2
Safe and healthy living conditions	Burden of disease	• Laboratory tests of water, air quality, and blood contamination • Provincial Division of Public Health epidemiological reports • Regional hospital and health center epidemiological reports • Reports of criminal activity • Surveys to characterize violence in communities • Remote-sensing-based analyses of changes in farmland near mining activity • All indicators for SDG 3 survey data from cross-culturally validated food (e.g., Household Food Insecurity Access Scale, Food Insecurity Experience Scale) and water insecurity scales (e.g., Household Water Insecurity Experiences Scale)
Access to material resources	Percent of population with access to improved sanitation facilities	• School and health center funding, performance metrics • SDG Indicators 1.4.1, 2.1.1, 6.1.1, 6.2.1, 7.1.1, 8.10.1, 8.10.2, 15.6.1
Stakeholder category: Workers		
Health and safety	Occupational accident rate by country	• Number of mining incidents in a month—site health center, community health center, and hospital incident reports • Survey data from validated scales, such as the Center for Epidemiologic Studies Depression Scale
Freedom of association and collective bargaining	Country-level restrictions on collective bargaining	• Number of workers associations/unions and respective membership • Sample worker's survey on association membership, perceived ability to bargain, and satisfaction with conditions
Child labor	Percentage of children working by country and by sector	• Workers ID and membership ID on sites (worksite survey) • School-age children involved in mining (school survey) • Number of children involved in mining (household survey) • SDG Indicator 8.7.1
Fair salary	Minimum wage by country	• Minimum and maximum monthly earnings (miner survey) and fee payments • Cost of living (government data) • Organization for Economic Co-operation and Development (OECD) employment database
Hours of work	Excessive hours of work	• Surveys used to determine minimum, maximum, and average time spent on site
Equal opportunities	Female labor force participation rate by country	• Inventory of cases of sexual harassment and gender-based violence (local police, civil society organizations data) • Women's empowerment scales

Overview of stakeholder subcategories and example generic indicators for "Local Community" and "Worker" UNEP stakeholder categories, with examples of locally relevant, spatially explicit data sources for measuring these indicators in Katanga, the DRC. SDG indicators and metrics are described in detail elsewhere and may be most useful for S-LCA when data disaggregated beyond the country level, preferably community level, can be used.

section for details and Figure S1 for a methodological flowchart) provided a more comprehensive understanding about the local impacts of cobalt mining and permitted the triangulation of findings.

OBSERVATIONS

We begin this section with a summary of mining in Lualaba and then describe our recommendations for improved data collection in S-LCA Phase 2 in the context of local community and worker subcategories (Table 1, with additional subcategories included in Table S1 of the supplemental information).

Artisanal mining in Lualaba, DRC

In Lualaba, mining occurs at artisanal and industrial scales. In accordance with the 2002 mining code, which was renewed in 2018, the central government has designated particular areas for mining based on provincial authorities' recommendations.[51,52] Individuals can then explore within these areas for mineral deposits. Many small-scale miners lack the resources necessary to independently assess an area for mineral deposits and therefore dig near or on the property of larger mining companies. Additionally, some residential communities (e.g., Kasulu) are located on mineral deposits, which artisanal miners may attempt to extract, although the process is not legal. The local government may therefore request that households with mineral deposits on their property relocate to allow for industrial operations, although demands to relocate can create conflict, as most homeowners do not have land titles and thus cannot claim land ownership to receive compensation. Alternatively, mining companies may attempt to directly buy-out miners through legal procedures. Many artisanal miners consider relocation and buy-outs to be acts of dispossession.

The majority of artisanal mining sites in Lualaba are controlled by cooperatives, which can be funded by local traders or foreign investors (e.g., elite Congolese or foreign individuals via a Congolese proxy). A cooperative is a group of artisanal miners who legally mine at a single site. Cooperatives develop exclusive contracts with local mining companies and agree to recruit sufficient labor to deliver a regular cobalt supply. Miners may work at these larger cooperative-controlled mining sites and sell their material to the cooperative, or they may work independently and sell their material at a cobalt marketplace. Miners who work at cooperatives must pay yearly membership fees (~USD$15). They must have an artisanal miner's identity card that is issued through the Provincial Ministry of Mining. Artisanal miners work at their cooperative-designated mining site. Membership in cooperatives is fluid, as miners often relocate in pursuit of more profitable sites.

Cooperatives are mandated to follow minimum safety standards set by the Provincial Ministry of Mining, such as wearing protective equipment. Miners are required to comply with site-specific environmental, health, and safety regulations for artisanal mining, although such codes of conduct are infrequently followed and penalties rarely enforced. Cooperatives are also meant to protect workers' rights, but most workers feel that cooperatives are exploitative, because they seldom advocate for better pay or working conditions. Some miners therefore form "associations" to protect their interests and hold cooperatives accountable to established working standards. These associations have limited authority because of the absence of formal labor contracts, but sometimes offer conflict mediation in instances such as violence between miners' groups or between miners and mining companies.

Ore is extracted with hand tools. Companies that partner with cooperatives may own equipment to help excavate an open pit for the miners to dig the ore. Pieces of greenish cobalt ore are removed, along with earth and other materials, from mining galleries and shafts. Only men are permitted to climb down in the shafts, which can exceed 30 m in depth.[43] Women may work to collect cobalt ore from an open-pit surface. After the ore-containing earth reaches the surface, it is often transported to an off-site body of water to be washed. Cleaned ore is then placed into 25 kg bags for sale.

Miners in a cooperative must sell directly to the company with which they are affiliated. Typically, a cooperative purchases bags of minerals from miners at a fixed price (at the time of our field interviews, an average 25 kg bag with approximately 1.5% cobalt ore was sold at USD$25). The cooperative then sells these bags to trading companies at an undisclosed price. In contrast, independent miners have greater bargaining power because they can (illegally) sell their products at the marketplace.

Local community inventory subcategories

Delocalization and migration

One major impact identified across interviews was loss of communal land and subsequent relocation in the case of both artisanal and industrial mining. According to the DRC's 1982 Land Law, the land and its resources belong to the state. Mining companies must therefore obtain permission from the central government to establish a mining site. However, in the DRC, tradition and customary law dictate that land belongs primarily to local communities and that traditional leaders are responsible for ensuring its protection and allocation.[53] Mining companies seeking to establish industrial sites must therefore request permission to use land from traditional leaders. In exchange for permission, companies provide leaders with gifts (e.g., direct cash payments) or build schools and health centers for the community. Such contradictions between local and customary law often lead to disputes over the legal status of land holdings as well as mining rights, including for cobalt.

Several community members reported that traditional leaders often ignore their responsibility to protect the communal land and give preferential access to mining companies in return for resources or the prestige of being connected to a major mining company, the benefits of which are not always shared with the community. Indeed, the mining companies' land use often alters the primary purpose of the community land (Figures 2A and 2B), and subsequent environmental and social impacts, such as soil contamination and relocation, which compromise local homesteads and small-scale farming. One interviewed activist noted, "Traditional leaders, like politicians, are corrupted by the mining companies and do not work for the interests of the people anymore."

Conflict over land and mining rights, as we learned during field interviews, can occur at the artisanal level as well. When mineral deposits are discovered in a neighborhood, mining companies may try to acquire residential land and relocate residents, either

Figure 2. Images collected during fieldwork
Images related to cobalt mining practices and their impacts from fieldwork conducted in Lualaba Province, the DRC.
(A) A street in the residential community of Kasulu, which is economically dependent on mining. On the far right, adjoining the orange tarp, is a street shop that retails artisanal mining tools.
(B) Mining in the residential community at Kasulu, near Kolwezi.
(C) A recently dug artisanal mining hole in Musonoyi.
(D) Miners at a cobalt cleaning site.
(E) Cobalt market in Kawama. A child near the gate carries a bag of cobalt to the market.

by paying residents or bribing their local leaders. In some cases (e.g., the Kasulo neighborhood), the government has relocated and compensated residents who can prove land ownership. Most residents, however, do not possess land titles and cannot obtain them, as they have relied on customary law. Some residents described how land bureau officers produced fake land titles to usurp their land and benefit from relocation compensation, which was set at approximately USD$10,000 per household. One resident of Kasulo reported, "This is our land and we have always lived here. There are people who produce fake land titles, not only to take the compensation money, but also to grab our land. That is why we do not want to move. We do not want to lose." Residents who did have land titles criticized the government for relocating them to less desirable locations with poor physical infrastructure or far away from family and other social networks. As such, most residents refused to relocate.

The opportunities of artisanal mining attract individuals from different provinces (e.g., from Kasai province, where diamond mining is common). Respondents complained about groups of migrant miners setting up separate temporary villages with power structures and social institutions that differ from those of the local community. This was perceived as an attempt to take over community land and resources. A focus group discussion member commented, "Soon, in the temporary villages they set up, they will appoint a traditional leader from their group and this person will oversee the community land of the village." This is significant because, as previously noted, a major function of a traditional leader is to protect and redistribute community land as a livelihood asset.

Safe and healthy living conditions

Violence is common and adversely impacts the living conditions in Lualaba. During our fieldwork, participants reported conflicts between different ethnic groups, especially between migrant miners and local village residents. Verbal and physical conflicts between local miners and migrant groups seeking to establish their own cobalt operations were also reported. Low mining yields or changes in market conditions can also precipitate theft or violence, as miners struggle to support themselves and their families. Criminal reports and repeated surveying about violence could therefore serve as a potential way to track changes in violent activity over time.

In Lualaba, there was general agreement that cobalt mining negatively impacted soil, air, and water quality. For instance, participants noted that the water at a local cobalt cleaning site was polluted with mining waste and thus unfit for human consumption or other productive uses (Figure 2D). Farmland may also be rendered infertile due to the toxins and pollutants released from cobalt mining. In fact, some participants noted that the proliferation of cobalt mining has decreased crop yields and availability at local markets; some residents reportedly sourced most of their food from neighboring Zambia as a result. Furthermore, individuals near at-home or industrial mining operations are at increased risk of falling into mine shafts and exposed to greater air pollution that can affect respiratory health. UNEP's methodological sheets note that pollution from activities pertaining to a supply chain can negatively affect human health through multiple pathways.[26] Yet, there is no specific indicator in the methodological sheets for measuring this relationship aside from "pollution levels by country," which does not capture the heterogeneity of effects in local communities.

Access to material resources

Participants provided divergent narratives about the impacts of mining on local infrastructure. Some interviewees perceived mines as indirectly financially contributing to the establishment of new schools and health centers, while others believed that mines detract from the overall quality of these institutions. Participants reported that some students leave school for mining sites. Similarly, teachers supplement their salaries by working part-time at mines during the school year or full-time during the summer.

Worker inventory subcategories

Health and safety

In the DRC, mining safety standards are set by the Service d'Assistance et d'Encadrement du Small-Scale Mining ou Production Minière à Petite Echelle.[54] Miners reported that these standards are generally not enforced and therefore frequently worry about on-the-job injuries. During visits to artisanal mines, no safety measures to reduce the risks associated with mining shafts (representative shaft opening in Figure 2C) were immediately obvious (e.g., guard rails, signage). Artisanal miners also reported digging cobalt ore with their bare hands (which can increase the risk of cobalt toxicity[55]), often in unsafe mineshafts that are prone to collapse. Several miners reported using locally produced cannabis, alcohol, and tobacco to cope with the stress associated with working in these dangerous conditions. Taken together, these reports suggest that cobalt mining can be harmful to both physical and mental health through numerous pathways.

Freedom of association and collective bargaining

Collective bargaining and freedom of assembly are core workplace values promoted by the UN and the International Labor Organization.[56] As previously described, many miners join cooperatives and associations but report that they do not have the freedom to associate or exchange information about working conditions. Miners also reported that they do not have access to collective bargaining as a tool to advance dialogue for better working conditions. Rather, miners perceive cooperatives as profit-driven institutions that recruit cheap labor for the benefit of mining companies. Independent miners may fare better and are free to negotiate the price of their products, but must prospect for mineral deposits on their own, which can be dangerous or unfruitful. As such, the proportion of miners who are members of cooperatives and associations may not be an appropriate indicator of miners' freedom of association.

Child labor

Child labor is common in mining communities (Figure 2E). Individuals and cooperatives alike may falsify ages to secure employment.

Fair salary

The DRC's labor laws require companies to regularly report the size of their workforce, working conditions, and benefits offered to employees, although these may not be made publicly accessible. In the case of cobalt mining in the DRC, and artisanal mining in particular, these metrics could be particularly difficult to reliably access or track over time. For instance, while artisanal miners earn their incomes based on the value of the cobalt they mine, trading companies control measurement equipment and trading processes—unfair practices such as rigging scales used to weigh ore were noted in focus group discussions. This arrangement raises issues of reliability and transparency in the supply chain.

Hours of work

Just as there is no set salary, there is no set work schedule for miners. Compensation is based solely on the amount of cobalt ore mined and the market rate for a 25 kg bag. Miners often work as long as they can (sometimes all day and night) to increase their income.

Equal opportunities

In the UNEP methodological sheets,[26] "equal opportunity" refers to fair hiring practices, working conditions, and financial compensation regardless of race, ethnicity, sex, age, or other differentiator. Although mining activities remain highly gendered, participation of women in artisanal mining activities has increased women's wage-earning possibilities. Fieldwork suggests that while expanded economic power has the potential to increase women's empowerment, it also exposes many individuals to greater risk of harm; gender-based violence and sexual harassment are prevalent at mining sites. We are unaware of any active efforts to promote equal opportunity in mining cooperatives.

RECOMMENDATIONS FOR IMPROVED S-LCA DATA COLLECTION

Based on the observed human health and well-being effects of cobalt mining, we identified five categories of data sources that can be leveraged or created to capture the localized effects of this mining in S-LCA. In this section, we describe these five categories as they relate to our case study. The next section contextualizes these recommendations beyond our case study for improvement of S-LCA in general.

Local data collection: Interviews and focus groups

Interviews and focus groups are well-established research techniques in the realm of social science. For each study that uses these tools, it is important that the implemented strategy is documented so that results can be evaluated within the context of the applied methodology and so that others can repeat the study. We identified many instances in which these methods would yield more robust data in S-LCA than national-level statistics, particularly those pertaining to the experiences of miners in this region. For example, open-ended interview and survey-based methods may best quantify miners' working experiences and the effectiveness of shared action to improve conditions for the freedom of association indicator. Likert-type scales could also be developed to measure miners' perceived ability to collectively bargain and satisfaction with the benefits offered by mining companies or cooperatives. Precise information on the payments miners receive for their labor and cobalt extracted, as well as any fees they are required to pay (e.g., to be a member in a cooperative), could be used to assess whether individuals are earning an equitable and fair salary. A formula to calculate a fair price for cobalt—the basis of a fair salary—would consider the hours worked to obtain a 25 kg bag of ore and the fraction of that ore that is cobalt and other valuable metals (e.g., copper). This information would be best collected through interactions with individuals or groups. It should be noted that interviews and focus group discussions are time intensive and expensive. Their utility, therefore, may be limited, especially on the accelerated timescales necessary to produce data needed for S-LCAs that might guide decision making related to addressing climate change.

Surveys, which are less resource intensive than focus groups and interviews, could also be used. For example, to characterize migration, both the sending and host communities could be surveyed for information on population movement. They could provide insight into hours of work in the artisanal mining sector. Company records, if released, would also provide these data. To note, hours of work are the most widely available type of S-LCA data.[28,29,57] S-LCAs relying exclusively on hours of work data do not, however, capture other aspects of cobalt mining conditions that are critical to understanding its social effects in the DRC (e.g., impacts on healthy living conditions, delocalization, and migration).

Local public records

Collecting data from local public records can support evaluation of S-LCA indicators with greater rigor than national-level statistics, but at less financial and time expense than interviews or surveys. For example, there are several possible approaches to quantifying the social consequences of migration, including reviewing the number of land-related court claims and documentation of forced migrations in mining areas over a discrete period of time. Similarly, data on schools' and health centers' funding, as well as performance indicators from each, could be used to empirically test the impact of cobalt mining on institutions that positively contribute to better living conditions. Publicly available health records (e.g., from community health centers), which may be more accessible than on-site workplace accident reports, can be used to evaluate injuries and psychosocial distress caused by mining. Regarding the child labor indicator, human resource records are unlikely to be reliable indicators because individuals may not provide their true age. Instead, miner identification cards may be a useful way to measure a miner's age until such cards are issued by the state.

Cross-culturally validated scales

Within social science disciplines, cross-culturally validated scales are used and applied to understand many different aspects of human health and well-being. For example, cross-culturally validated food insecurity (e.g., Household Food Insecurity Access Scale,[58] Food Insecurity Experience Scale[59]) and water insecurity scales (e.g., Household Water Insecurity Experiences Scale[60]) could be used to measure the impacts on resource security for individuals and households. Some of these data may already be collected by national statistics agencies (e.g., through the United Nations Children's Fund's Multiple Indicator Cluster Surveys or the World Banks' Living Standards Measurement Studies), but often, these are aggregated at regions larger than where mining occurs.[61] Additionally, the Center for Epidemiologic Studies Depression Scale[62] could be used to understand if miners experience worse mental health compared to non-miners in the surrounding area or adjacent regions. Finally, gender equity can be measured using a variety of women's empowerment scales.[63] Some of these, such as indices for women's empowerment in agriculture,[64,65] would need to be tailored to mining.

Sustainability development goal data

Some indicators used to evaluate progress toward the United Nations' Sustainable Development Goals[66] (SDGs) could be disaggregated for use in S-LCA. Having indicators that are evaluated with locally specific data will be important to support S-LCA use in decision making. For instance, SDG Indicator 1.4.2, which measures the proportion of the total adult population with secure land tenure, could provide useful insights into delocalization. Methods for collecting data that support SDG Indicator 1.4.1,[66] access to basic services, could be applied at the local level for evaluation of the access to material resources indicator. Additionally, SDG Indicator 8.7.1, proportion of children aged 5–17 years engaged in child labor, could also support evaluation of this subcategory, although such data are collected at the national level.[66] To obtain local-level estimates, surveys using modules on child labor would need to be conducted in Lualaba.

Remote sensing and imagery

Remote-sensing data at high-resolution are collected globally. Automated techniques can be developed to use these data to identify water scarcity or land use change.[67] In the case of mining, these data could be used to estimate changes in farmland area before and after cobalt mining is established in a community, which would indicate potential decreases in food availability.

IMPLICATIONS FOR S-LCA

S-LCA holds promise as a technique for transparently comparing the social impacts—which are not captured by ELCA—associated with different technology options. Yet, S-LCA currently lacks robust, efficient, standardized ways to collect the inventory data in Phase 2 to support evaluation of indices in Phase 3 or decision-guiding insights from interpretation in Phase 4. Therefore, in this case study, we identified a variety of quantitative and qualitative techniques that could be used in Phase 2 to improve S-LCA (Table 1). These techniques were presented in the context of cobalt mining in the DRC but could be applied to other mining contexts or other operations in which local, site-specific data are crucial to understanding their social impacts. Examples of these contexts include textiles production, in which worker conditions vary greatly by location, and agriculture, which can differ greatly among and within nations, particularly in unregulated regions. We note that low- and middle-income countries, such as the DRC, present a particular challenge given the relative inaccessibility of locally specific data for many S-LCA practitioners.

This case study demonstrates that local impacts are essential to incorporate into S-LCA for a more accurate picture, but collection of site-specific S-LCA data is resource intensive. For instance, it is essential to build strong relationships with local partners, such as local government, universities, non-governmental organizations, and health clinics. The development of these partnerships requires time to establish trust. Additionally, the methods we used (interviews, focus group discussions) can generate robust data, but may be expensive to implement. Surveys, rather than in-depth interview- and focus-group-based methods, are often more efficient for generating empirical data (example modules in Table 1).

To advance S-LCA data collection efforts, researchers, companies, and (non-)governmental agencies must address extant questions about how to fund and conduct these important analyses. For example, where should the resources come from to allow for the development of these relationships and the data collection activities that support meaningful S-LCA? What responsibilities do we as a society and the governments that lead us have to communities along the supply chains we rely upon? What responsibilities do we have to develop frameworks such as S-LCA that can be used alongside tools such as ELCA in decision making and how can we acquire the resources to support our obligations?

We suggest that governmental and scientific agencies that fund research for guiding investments in technology development and possible incentivization have a role to play in supporting the development of robust S-LCA methods. In the United States, these include agencies such as the National Science Foundation, the Department of Energy, and the Department of Defense. Foundations interested in advancing social good and industries that support transparent analyses are also crucial actors. Support from these entities would enable the development and enhancement of public databases such as those available for ELCA, including Ecoinvent[68] (which has an S-LCA component) and the Greenhouse Gases, Regulate Emissions, and Energy Use in Technologies (GREET™) model.[69] Indeed, because industry data are rarely made open access, are often aggregated to a level that masks local or project-specific impacts, and are infrequently audited,[40] publicly accessible data that go beyond or supplement the Social Hotspot Database and are grounded in social science theory and methods are highlighted as a need by UNEP.[70] As a starting point, efforts to connect S-LCA methodology development (including data collection methods and indicators) with SDG data collection[66] and other programs such as the UN's Voluntary Sustainability Standards[71] that emphasize social effects should be bolstered.

CONCLUSION

In sum, technologies that are designed to solve grand challenges such as climate change must consider both their environmental and social impacts to understand their true consequences. To do this, interdisciplinary collaborations that enhance S-LCA are required. These efforts should include social scientists (trained to identify and characterize social impact), natural scientists (trained to identify and measure environmental quality), and engineers who develop technology. With information generated from robust analyses grounded in ELCA and, in the near future, S-LCA, policymakers, industry leaders, and consumers will be able to better estimate both the social and environmental impacts of the technologies they choose.

EXPERIMENTAL PROCEDURES

Resource availability

Lead contact

The lead contact for obtaining resources associated with this manuscript is Jennifer Dunn (jennifer.dunn1@northwestern.edu).

Materials availability

The materials generated in this study are the protocols for in-depth interviews and focus group discussions. These are included in the supplemental information Notes S1 and S2.

Data and code availability

No code or data were generated in the course of preparing this perspectives piece.

Methodological overview

In total, 32 individual interviews and four focus group discussions with 31 participants were conducted by the lead anthropologist. These were completed in July 2019 in the respondents' preferred language (French, Swahili, or Tshiluba) at locations selected by participants.

For key informant interviews and focus group discussions (methods and interview guides for both are in the supplemental information, Notes S1 and S2, respectively), we sought to recruit participants from all cobalt mining stages (i.e., from extraction to sale) as well as community members who may be directly or indirectly impacted by mining activities. Community leaders and other knowledgeable individuals (e.g., staff at non-governmental organizations, church leaders, local researchers, school principals, local officials who oversaw mining activities, community health providers, and land preservation officers) were also purposively recruited for key informant interviews. Interviewees were asked to refer friends, family members, and colleagues who they considered to be good candidates for subsequent interviews or participation in focus group discussions.

In key informant interviews, miners were asked about methods for extracting and processing cobalt, strategies for disposing of waste, and cobalt market operations and trends within the industry. In key informant interviews with non-miners, individuals were asked how their proximity to cobalt mining impacted the well-being of their family and community, personal and local working conditions, community relations, the local environment, and other valued natural resources. Similar topics were explored during focus group discussions; each theme was discussed until consensus was reached or no new perspectives were offered (focus group discussion guide in supplemental information).

For participant observation, the lead anthropologist visited six artisanal cobalt mining sites (Kasulu, Biwaya, Mutoshi, Kawama, Kafwaya village, and Twilizembe). He also visited sites surrounding these mines, including markets where cobalt is sold and restaurants where miners eat.

All interviews were recorded (but not transcribed). Participant observations were described in fieldnotes and complemented by photographs of various mining operations and markets. These observations were used to help contextualize findings from the interviews as well as shape subsequent interviews and focus group discussions. At the end of fieldwork, all notes and photos were reviewed and coded. The coding framework was developed *a priori* based on UNEP's stakeholder subcategories (Table 1) and applied to photographs, fieldnotes, and interviews. For both of the UNEP's selected stakeholder categories (local communities and workers), we present the most relevant generic indicators within each subcategory and suggest potential data sources that could provide more accurate and comparable data for S-LCA analyses. We note that the type of information we gathered would likely be used as foreground (specific to the product under study) rather than more general background data.[3]

Institutional Review Board approval

Study activities were approved by the Institutional Review Board at Northwestern University (identification number STU00209861). All individuals provided informed verbal consent prior to being interviewed.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2021.11.007.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. International Standards Organization (1997). Environmental Management-Life Cycle Assessment - Principles and Framework.
2. International Standards Organization (2006). Environmental Management — Life Cycle Assessment — Requirements and Guidelines.
3. United Nations Environment Program (2020). Guidelines for Social Life Cycle Assessment of Products and Organizations 2020.
4. Gómez Vilchez, J.J., and Jochem, P. (2020). Powertrain technologies and their impact on greenhouse gas emissions in key car markets. Transport. Res. Transport Environ. *80*, 102214.
5. Ehrenberger, S.I., Dunn, J.B., Jungmeier, G., and Wang, H. (2019). An international dialogue about electric vehicle deployment to bring energy and greenhouse gas benefits through 2030 on a well-to-wheels basis. Transport. Res. Transport Environ. *74*, 245–254.
6. Dunn, J.B., Gaines, L., Kelly, J.C., James, C., and Gallagher, K.G. (2015). The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction. Energy Environ. Sci. *8*, 158–168.
7. Dai, Q., Kelly, J.C., Gaines, L., and Wang, M. (2019). Life cycle analysis of lithium-ion batteries for automotive applications. Batteries *5*, 48.
8. Dunn, J.B. (2019). Biofuel and bioproduct environmental sustainability analysis. Curr. Opin. Biotechnol. *57*, 88–93.
9. Yang, Z., Wang, B., and Jiao, K. (2020). Life cycle assessment of fuel cell, electric and internal combustion engine vehicles under different fuel scenarios and driving mileages in China. Energy *198*, 117365.
10. Chen, Y., Hu, X., and Liu, J. (2019). Life cycle assessment of fuel cell vehicles considering the detailed vehicle components: Comparison and scenario analysis in China based on different hydrogen production schemes. Energies *12*, 3031.

11. Bicer, Y., and Dincer, I. (2018). Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles. Resour. Conserv. Recycl. *132*, 141–157.

12. Elgowainy, A., Han, J., Ward, J., Joseck, F., Gohlke, D., Lindauer, A., Ramsden, T., Biddy, M., Alexander, M., Barnhart, S., et al. (2016). Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025-2030) Technologies (Argonne National Laboratory).

13. United States Environmental Protection Agency (2010). Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (U.S. Environmental Protection Agency).

14. European Union. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources.

15. Jørgensen, A., Le Bocq, A., Nazarkina, L., and Hauschild, M. (2008). Methodologies for social life cycle assessment. Int. J. Life Cycle Assess. *13*, 96–103.

16. Tokede, O., and Traverso, M. (2020). Implementing the guidelines for social life cycle assessment: past, present, and future. Int. J. Life Cycle Assess. *25*, 1910–1929.

17. Moltesen, A., Bonou, A., Wangel, A., and Bozhilova-Kisheva, K.P. (2018). Social life cycle assessment: An introduction. In Life Cycle Assessment: Theory and Practice, M.Z. Hauschild, R.K. Rosenbaum, and S.I. Olsen, eds. (Springer International Publishing)), pp. 401–422.

18. Chhipi-Shrestha, G.K., Hewage, K., and Sadiq, R. (2015). 'Socializing' sustainability: a critical review on current development status of social life cycle impact assessment method. Clean. Technol. Environ. Policy *17*, 579–596.

19. Wu, R., Yang, D., and Chen, J. (2014). Social life cycle assessment revisited. Sustainability *6*, 4200–4226.

20. Huertas-Valdivia, I., Ferrari, A.M., Settembre-Blundo, D., and García-Muiña, F.E. (2020). Social life-cycle assessment: A review by bibliometric analysis. Sustainability *12*, 6211.

21. Lehmann, A., Zschieschang, E., Traverso, M., Finkbeiner, M., and Schebek, L. (2013). Social aspects for sustainability assessment of technologies—challenges for social life cycle assessment (SLCA). Int. J. Life Cycle Assess. *18*, 1581–1592.

22. Dreyer, L.C., Hauschild, M.Z., and Schierbeck, J. (2010). Characterisation of social impacts in LCA. Part 2: implementation in six company case studies. Int. J. Life Cycle Assess. *15*, 385–402.

23. Ekener-Petersen, E., and Moberg, Å. (2013). Potential hotspots identified by social LCA–Part 2: Reflections on a study of a complex product. Int. J. Life Cycle Assess. *18*, 144–154.

24. Franze, J., and Ciroth, A. (2011). A comparison of cut roses from Ecuador and the Netherlands. Int. J. Life Cycle Assess. *16*, 366–379.

25. Kühnen, M., and Hahn, R. (2017). Indicators in social life cycle assessment: A review of frameworks, theories, and empirical experience: indicators in social life cycle assessment. J. Ind. Ecol. *21*, 1547–1565.

26. United Nations Environment Program (2013). The Methodological Sheets for Sub-categories in Social Life Cycle Assessment (S-LCA).

27. (2013). Social hotspots database. http://www.socialhotspot.org/.

28. (2013). Green delta product social impact life cycle assessment (PSILCA). https://psilca.net.

29. Norris, C.B., and Norris, G.A. (2015). The social hotspots database. In The Sustainability Practitioner's Guide to Social Analysis and Assessment (Common Ground), pp. 52–73.

30. (2015). International migrant stocks migration data portal. http://migrationdataportal.org/themes/international-migrant-stocks.

31. García-Olivares, A., Solé, J., and Osychenko, O. (2018). Transportation in a 100% renewable energy system. Energy Convers. Manag. *158*, 266–285.

32. Burandt, T., Xiong, B., Löffler, K., and Oei, P.-Y. (2019). Decarbonizing China's energy system – modeling the transformation of the electricity, transportation, heat, and industrial sectors. Appl. Energy *255*, 113820.

33. Bartholdsen, H.-K., Eidens, A., Löffler, K., Seehaus, F., Wejda, F., Burandt, T., Oei, P.-Y., Kemfert, C., and Hirschhausen, C.von (2019). Pathways for Germany's low-carbon energy transformation towards 2050. Energies *12*, 2988.

34. Bauer, G., Zheng, C., Greenblatt, J.B., Shaheen, S., and Kammen, D.M. (2020). On-demand automotive fleet electrification can catalyze global transportation decarbonization and smart urban mobility. Environ. Sci. Technol. *54*, 7027–7033.

35. Kelly, J.C., Dai, Q., and Wang, M. (2020). Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. Mitig Adapt Strateg. Glob. Chang. *25*, 371–396.

36. Banza Lubaba Nkulu, C., Casas, L., Haufroid, V., De Putter, T., Saenen, N.D., Kayembe-Kitenge, T., Musa Obadia, P., Kyanika Wa Mukoma, D., Lunda Ilunga, J.-M., Nawrot, T.S., et al. (2018). Sustainability of artisanal mining of cobalt in DR Congo. Nat. Sustain. *1*, 495–504.

37. Cheyns, K., Banza Lubaba Nkulu, C., Ngombe, L.K., Asosa, J.N., Haufroid, V., De Putter, T., Nawrot, T., Kimpanga, C.M., Numbi, O.L., Ilunga, B.K., et al. (2014). Pathways of human exposure to cobalt in Katanga, a mining area of the D.R. Congo. Sci. Total Environ. *490*, 313–321.

38. Federal Institute for Geosciences and Natural Resources (2019). Mapping of the Artisinal Copper-Cobalt Mining Sector in the Provinces of Haut-Katanga and Lualaba in the Democratic Republic of the Congo.

39. Mancini, L., Eslava, N.A., Traverso, M., and Mathieux, F. (2021). Assessing impacts of responsible sourcing initiatives for cobalt: Insights from a case study. Resour. Policy *71*, 102015.

40. European Commission. Joint Research Centre (2020). Responsible and Sustainable Sourcing of Batteries Raw Materials: Insights from Hotspot Analysis, Corporate Disclosures and Field Research.

41. Farjana, S.H., Huda, N., and Mahmud, M.A.P. (2019). Life cycle assessment of cobalt extraction process. J. Sustain. Mining *18*, 150–161.

42. Nuss, P., and Eckelman, M.J. (2014). Life cycle assessment of metals: A scientific synthesis. PLoS One *9*, e101298.

43. Amnesty International, and AfreWatch. (2016). This is what we die for. https://www.amnesty.org/en/documents/afr62/3183/2016/en/.

44. Sovacool, B.K., Turnheim, B., Hook, A., Brock, A., and Martiskainen, M. (2021). Dispossessed by decarbonisation: Reducing vulnerability, injustice, and inequality in the lived experience of low-carbon pathways. World Dev. *137*, 105116.

45. Sovacool, B.K., Ali, S.H., Bazilian, M., Radley, B., Nemery, B., Okatz, J., and Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. Science *367*, 30–33.

46. Karlewski, Lehmann, Ruhland, and Finkbeiner. (2019). A practical approach for social life cycle assessment in the automotive industry. Resources *8*, 146.

47. Tsurukawa, N., Prakash, S., and Manhart, A. (2011). Social Impacts of Artisinal Cobalt Mining in Katanga, Democratic Republic of Congo (Institute for Applied Ecology). https://www.oeko.de/oekodoc/1294/2011-419-en.pdf.

48. Whitehead, T.L. (2005). Basic Classical Ethnographic Research Methods: Secondary Data Analysis, Fieldwork, Observation/Participant Observation, and Informal and Semi Structured Interviewing (TL Whitehead Associates).

49. Davies, C. (1999). Reflexive Ethnography: A Guide to Researching Selves and Others (Routledge).

50. DeWalt, K.M., and DeWalt, B.R. (2011). Participant Observation: A Guide for Fieldworkers, 2nd edition (Rowman & Littlefield).

51. (2002). Journal Officiel de la RDC. leganet.cd/JO.htm.

52. (2018). Journal Officiel de la RDC. http://www.leganet.cd/JO.htm.

53. Oyono, P.R. (2011). La tenure foncière et forestière en République démocratique du Congo [RDC]: Une question critique, des vues centrifuges. Revue compréhensive de la littérature (L'Initiative des Droits et Resources).

54. (2011). Services d'assistance et d'encadrement du small scale mining. http://www.saesscam.cd/SAESSCAM/pages/creation.php.

55. Lauwerys, R., and Lison, D. (1994). Health risks associated with cobalt exposure — an overview. Sci. Total Environ. *150*, 1–6.

56. International Labor Organization. C154 - collective bargaining convention, 1981 (No. 154). https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C154.

57. (1994). OECD Employment database. http://www.oecd.org/employment/emp/onlineoecdemploymentdatabase.htm.

58. Coates, J., Swindale, A., and Bilinsky, P. (2007). Household Food Insecurity Access Scale (HFIAS) for Measurement of Household Food Access: Indicator Guide (v. 3) (Food and Nutrition Technical Assistance Project, Academy for Educational Development).

59. Cafiero, C., Viviani, S., and Nord, M. (2018). Food security measurement in a global context: The food insecurity experience scale. Measurement *116*, 146–152.

60. Young, S.L., Boateng, G.O., Jamaluddine, Z., Miller, J.D., Frongillo, E.A., Neilands, T.B., Collins, S.M., Wutich, A., Jepson, W.E., and Stoler, J. (2019). The Household Water InSecurity Experiences (HWISE) Scale:

development and validation of a household water insecurity measure for low-income and middle-income countries. BMJ Glob. Health *4*, e001750.

61. (2019). The DHS program demographic and health survey (DHS). https://dhsprogram.com/what-we-do/survey-Types/dHs.cfm.
62. Radloff, L.S. (1977). The CES-D scale: A self-report depression scale for research in the general population. Appl. Psychol. Meas. *1*, 385–401.
63. Santoso, M.V., Kerr, R.B., Hoddinott, J., Garigipati, P., Olmos, S., and Young, S.L. (2019). Role of women's empowerment in child nutrition outcomes: A systematic review. Adv. Nutr. *10*, 1138–1151.
64. Malapit, H.J., Pinkstaff, C., Sproule, K., Kovarik, C., Quisumbing, A.R., and Meinzen-Dick, R.S. (2017). The abbreviated Women's Empowerment in Agriculture Index (A-WEAI). IFPRI discussion paper 1647. https://ssrn.com/abstract=3012806.
65. Malapit, H.J., Sproule, K., Kovarik, C., Meinzen-Dick, R., Quisumbing, A.R., Ramzan, F., Hogue, E., and Alkire, S. (2014). Measuring Progress toward Empowerment Women's Empowerment in Agriculture Index: Baseline Report (International Food Policy Research Institute).
66. (2014). United Nations SDG indicators metadata repository. https://unstats.un.org/sdgs/metadata/.
67. López-Tapia, S., Ruiz, P., Smith, M., Matthews, J., Zercher, B., Sydorenko, L., Varia, N., Jin, Y., Wang, M., Dunn, J.B., et al. (2021). Machine learning with high-resolution aerial imagery and data fusion to improve and automate the detection of wetlands. Int. J. Appl. Earth Obs. Geoinf. *105*, 102581.
68. (2021). Ecoinvent. https://www.ecoinvent.org/.
69. Argonne National Laboratory. Greenhouse Gases, Regulated Emissions and Energy Use in Technologies Model greet.es.anl.gov.
70. United Nations Environment Program and Society of Environmental Toxicology and Chemistry (2009). Guidelines for Social Life Cycle Assessment of Products.
71. (2009). United Nations voluntary sustainability standards. https://unfss.org/home/about-unfss/.