2.0 The Context for Lithium and Cobalt Recycling

Key Messages:

- Mineral recycling plays an active role in the global supply chain, with approximately 400 million tonnes of metals recycled worldwide every year.
- Recycling rates for lithium and cobalt, however, are low: for lithium-ion batteries specifically, an increasingly major use for the two minerals, less than 5 per cent are recycled at their end of life.
- Increased lithium and cobalt recycling can contribute to both the circular economy agenda and the UN Sustainable Development Goals (SDGs), most directly impacting goals 7, 8, 9, 12, 13 and 16.

2.1 Background and Terminology

In a simplified mineral supply chain, a given mineral moves along the following points before it reaches the end of its first life: mineral extraction (mining), trading, smelting, refining, manufacturing, sales, and then finally, use by the end consumer. Mineral supply chains can be more complex, with considerably more steps and actors along the process. Regardless of their complexity, however, many metals and minerals end up as permanent waste—oftentimes exported to developing countries—once the consumer is finished using the product (McVeigh, 2018; Vidal, 2013). The circular economy, if widely adopted, could challenge this model, as products are repurposed for secondary (or post-first-life) use. Instead of treating the used products as permanent waste, mineral recycling in a circular economy model involves collecting products containing valuable minerals, sending them to processors, metal recovery specialists and manufacturers and then reaching end users as new products (see Figure 1). Minerals can also enter post-first-life uses through reuse or remanufacturing. Reuse refers to using a product again for either its original purpose or one similar without significant modification. Remanufacturing refers to the process of retrieving the individual components of a product and restoring them to as-new condition (World Steel Association, 2016; Kampker, et al., 2016). Under these models, valuable minerals avoid permanent waste disposal and remain an active part of the world economy.

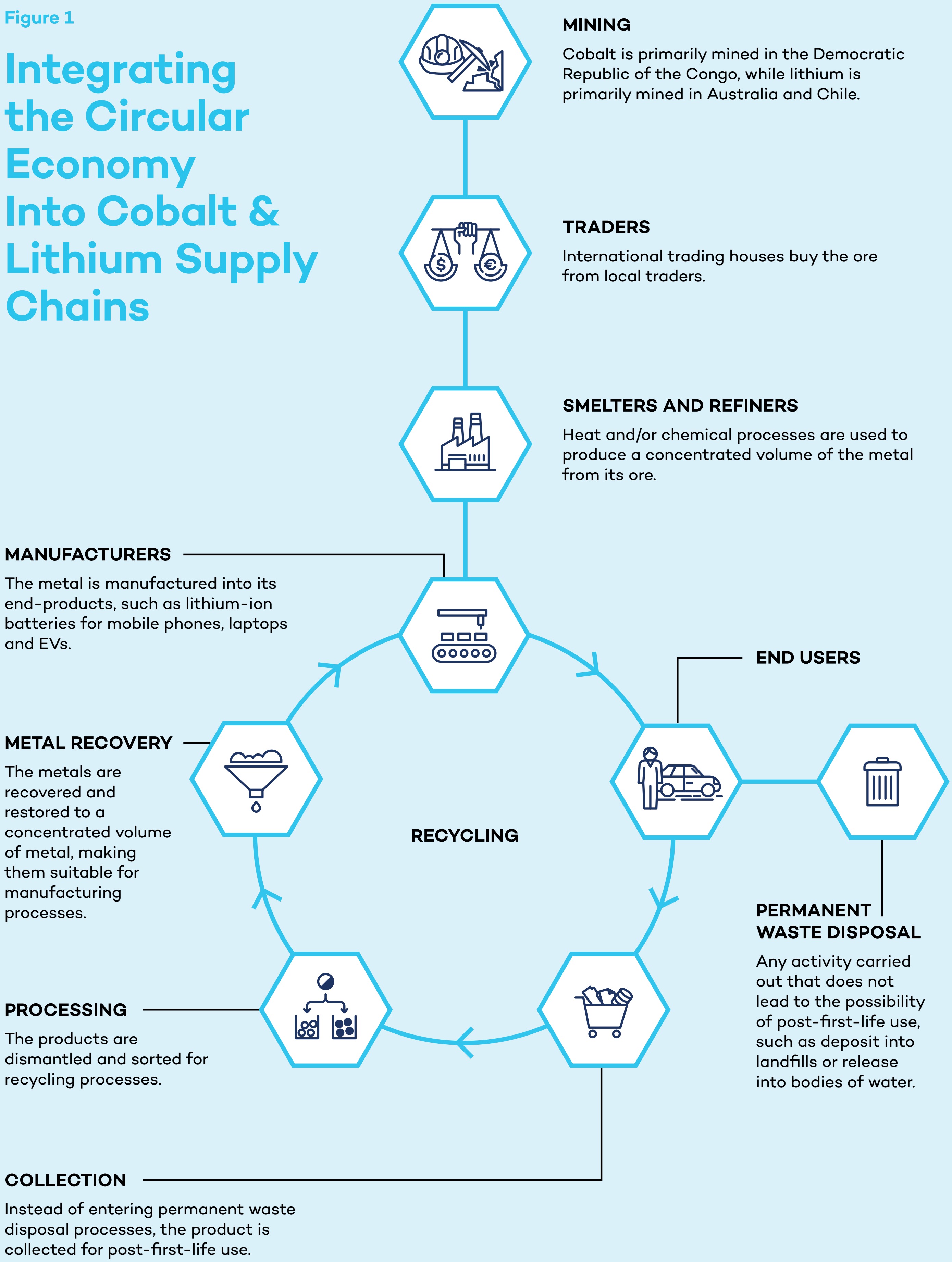
"Mineral recycling already plays an active role in global supply chains. Approximately 400 million tonnes of metal are recycled worldwide every year."

Mineral recycling already plays an active role in global supply chains (for more on how these processes are governed, refer to Box 2 and/or Annex 1). Approximately 400 million tonnes of metal are recycled worldwide every year: in the United States alone, recycling provides approximately 40 to 50 per cent of the national metal supply (LeBlanc, 2018; Mandler, 2017). The main sources of current mineral recycling are post-consumer products and scrap from manufacturing processes (Mandler, 2017). Scrap from the automobile sector, for example, accounted for 106 per cent of the United States' iron and steel scrap supply in 2014, demonstrating that the steel industry recycled more metal than it produced domestically (U.S. Geological Survey, 2018). In addition, approximately 99 per cent of lead-based car batteries are collected and recycled in North America and Europe, making them the most recycled of any major consumer product (Binks, 2015; Gaines, 2014).

The same rates do not apply to lithium-ion battery recycling, or even lithium and cobalt recycling in general. Less than 5 per cent of lithium-ion end-of-life batteries are recycled today (Li-Cycle Corp., 2018). For lithium in general, recycling rates have been deemed "historically insignificant" by the US Geological Survey (U.S. Geological Survey, 2018). Despite projected shortages in lithium supply, forecasts suggest that the recycling infrastructure required to increase lithium recycling rates remains insufficient and will continue to be (Gardiner, 2017). Cobalt has considerably

Figure 1

Integrating the Circular Economy Into Cobalt & Lithium Supply Chains



better rates of recycling than lithium, with an estimated end-of-life recycling rate of 32 per cent (OECD, 2019b). Scrap cobalt accounted for 33 per cent of the overall U.S. supply in 2017, but these rates still lag significantly behind what is economically possible and required to meet the predicted supply shortfalls (U.S. Geological Survey, 2018). This is partly due to the complex and costly processes involved in lithium and cobalt recycling—and lithium-ion battery recycling in particular, which involves a number of stages, including: collection, the burning of flammable electrolytes, the neutralization of the hazardous internal chemistry, the smelting of metallic components, the refining and purifying of high value metals, and finally the disposal of non-recoverable waste (Peterson, 2011).

Despite this complexity, the overall materials recycling sector is projected to triple by 2060 (OECD, 2019b). As such, there are already a growing number of actors in the lithium and cobalt recycling industries. The materials technology and recycling company Umicore, in partnership with Tesla and Toyota, recently invested EUR 25 million in an industrial pilot plant in Antwerp to recover cobalt and nickel from the recycling of lithium-ion batteries (Gardiner, 2017). In 2009, the US Department of Energy awarded USD 9.5 million to Retriev Technologies for the country's first lithium-ion recycling facility, which began operation in 2015 (U.S. Geological Survey, 2018) (for more on this award, refer to Case Study 4). As more electronics and EVs reach their typical end of life, political interests and new business opportunities might increase the demand for more operations such as these to proliferate.

While there are no agreed upon or regulated definitions for lithium and cobalt recycling, it is important to note that the term *post-first-life* use could have a number of meanings. Each of the terms *secondary use*, *reused*, *remanufactured* and *recycled* can be used to describe a product in its post-first-life use. For the purpose of this paper, definitions of key terms are outlined in Box 1.

"Less than 5 per cent of lithium-ion end-of-life batteries are recycled today."

BOX 1. DEFINITIONS OF KEY TERMS

Waste: According to the UN Basel Convention, waste refers to those substances or objects that are disposed of, intended to be disposed of, or required to be disposed of per national law (UNEP, 1989).

Waste disposal operations: Under the UN Basel Convention, disposal can be categorized into operations that lead to the possibility of resource recovery, recycling, reclamation, direct reuse or alternative uses, and those operations that do not (UNEP, 1989).

Permanent waste disposal: Activities carried out that do not lead to the possibility of post-first-life use (Statistics Canada, 2008). This can include deposit into landfills, release into bodies of water, and incineration. (UNEP, 1989).

Post-first-life use: Activities that carry out the agenda of the circular economy to minimize waste, reduce system risks, and optimize resource yields (Standridge & Corneal, 2014). This is the umbrella term for recycling, remanufacturing and reuse processes (Kampker, et al., 2016).

Secondary processes: Processes applied to a product after its first-life use, excluding waste disposal. These can include reuse, processing, metal recovery, recycling and remanufacturing.

Reuse: The complete product is used again—either for its original purpose or for one similar—without significant alterations (World Steel Association, 2016; Kampker, et al., 2016). Like remanufacturing, this process extends the product's life.

Remanufacturing: Retrieving individual components of a product at the end of its first life, restoring the components to as-new condition through manufacturing, usually as the same or a similar end product (World Steel Association, 2016; Kampker, et al., 2016). Like reusing, this process extends the product's life.

Mineral recycling: Sending a product to a post-first-life market in order to retrieve and refine its mineral components, altering the physical form of the product so a new application can be created (Cascade Alliance, 2018; World Steel Association, 2016; Kampker, et al., 2016). The mechanisms to recycle can also be referred to as *resource-recovery technologies*.

2.2 Motivations for Mineral Recycling

Although lithium and cobalt recycling is not currently undertaken at a significant global scale, doing so could contribute to the agendas of both the circular economy and the SDGs. The potential roles and benefits of increased lithium and cobalt recycling are outlined in the sections below as pertaining to both frameworks.

2.2.1 Significance to the Circular Economy

The circular economy is based around three core principles: designing waste out of the system; keeping products and materials in use; and regenerating natural systems (Ellen MacArthur Foundation, 2017). As with the SDGs, the shift to the circular economy will require systemic and transformational change in order to build long-term resilience and sustainability. The definition of the circular economy can be broken into two parts to show how mineral recycling contributes to this agenda: how lithium and cobalt recycling fulfills the goal to decouple economic activity from the consumption of finite resources; and how it contributes to the aim of designing waste out of the global system.

DECOUPLING ECONOMIC ACTIVITY FROM THE CONSUMPTION OF FINITE RESOURCES

Cobalt and lithium are finite, valuable resources. Not only this, both are projected to experience significant supply shortages in the coming decade, due to incoming demand from the electronics and automobile industries (Greenwood, 2018; Holmes, 2018). According to the British Geological Survey, cobalt and lithium are given a supply risk index score of 8.1 and 7.6, respectively, indicating that the relative production of both is concentrated in only a few countries and is subject to disruption and potential instability (British Geological Survey, 2015). Not only are these resources finite, they are also part of supply chains that are identified as risky as compared to other minerals and metals. It is imperative then, that the supply chains of lithium and cobalt are transformed to reduce a reliance on finite resources.

> "The circular economy entails 'gradually decoupling economic activity from the consumption of finite resources, and designing [permanent] waste out of the system.'"

For some markets, including Europe, increased mineral recycling could reduce reliance on imports from foreign primary markets. European lithium and cobalt supplies are mainly imported from Asia, and therefore increased recycling operations could reduce carbon dioxide emissions resulting from transportation of the minerals and cultivate a domestic post-first-life supply of valuable resources (Gaines, 2014). Estimates also suggest that production of an EV lithium-ion battery pack from recycled materials could reduce their total cost from USD 416 to an average of USD 332, based on cost data from 2016 (Ribeiro, et al., 2018). Recycling lithium and cobalt could be a key economic opportunity then for markets to disengage with the consumption of finite resources and maintain a secure post-first-life supply of the critical minerals needed to meet surging demand for clean electrification and digitization.

> "By 2030, approximately 1.2 million EV batteries are expected to reach the end of their first-list. How they are disposed of will influence the success of the SDGs and the circular economy agenda."

DESIGNING WASTE OUT OF THE SYSTEM

By 2030, approximately 1.2 million EV batteries are expected to reach the end of their first-life (Ribeiro, et al., 2018). How they are disposed of will influence the success of the SDGs – especially SDG 12 for Responsible Consumption and Production – and the circular economy agenda. Annual accumulation of global electronic waste (e-waste) is already an estimated 49.3 million tonnes, and is expected to continue to grow as more electronics reach their perceived end of life (Larmer, 2018; Teck Resources Limited, 2011). The minerals found in this e-waste—lithium and cobalt but also gold, silver, copper and others—often go into permanent waste disposal processes, despite their value. According to current e-waste disposal rates, consumers in the United States alone throw out smartphones worth approximately USD 60 million in gold and silver every year (Larmer, 2018). Beyond this potential loss of value, the disposal of e-waste and scrap batteries can be destructive to the environment, becoming a significant cause of soil contamination and water pollution (Ribeiro, et al., 2018). According to Transparency Market Research, an increase in awareness about the environmentally harmful disposal of batteries at the end of their first life is expected to be a key driver for secondary processes (Transparency Market Research, 2018). Recycling can significantly extend the efficient use of lithium and cobalt, reducing pressure on landfills and incinerators (Natural Resources Canada, 2017). This contributes to goals purported by both the circular economy and the SDGs.

7 AFFORDABLE AND CLEAN ENERGY

2.2.2 Significance to the Sustainable Development Goals

Increased recycling of lithium and cobalt contributes to the attainment of many of the SDGs in both direct and indirect ways, most directly SDGs 7, 8, 9, 12, 13 and 16.

SDG 7: ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL.

As discussed in the introduction, Target 7.2 of SDG 7 for Affordable and Clean Energy aims to increase the share of renewable energy in the global energy mix (United Nations, 2018). Because lithium and cobalt are both critical to the development and deployment of green energy technologies, securing their sustainable and affordable supply—through the integration of mineral recycling—could contribute to this target.

By the end of the first life of most EVs, their lithium-ion batteries still retain 70 to 80 per cent of their initial capacity (Willuhn, 2018). Target 7.3 of SDG 7 is focused on doubling the global rate of improvement in energy efficiency (United Nations, 2018). Reusing, remanufacturing or recycling EV batteries will be imperative to achieving energy efficiency, and is supplemented by the fact that metals recycling requires 80 per cent less energy compared to primary production practices (Ribeiro, et al., 2018).

"By the end of the first life of most EVs, their lithium-ion batteries still retain 70 to 80 per cent of their initial capacity."

This efficiency is demonstrated currently in both the steel and aluminum industries, in which recycling leads to 60–75 per cent and 90–97 per cent energy savings, respectively, when compared to primary mining (Johansson, 2016). While current lithium-ion battery recycling processes remain energy-intensive, more efficient methods are being tested and piloted, which could directly align this practice with SDG 7 (Shi, Chen, & Chen, 2018).

SDG 8: PROMOTE SUSTAINED, INCLUSIVE AND SUSTAINABLE ECONOMIC GROWTH, FULL AND PRODUCTIVE EMPLOYMENT AND DECENT WORK FOR ALL.

Engaging in enhanced lithium and cobalt recycling services could contribute to SDG 8 for Decent Work and Economic Growth by generating sustainable jobs, improving the safety of waste treatment employment, and decoupling economic growth from environmental degradation. Specifically, Target 8.3 aims to promote policies and projects that formalize and grow micro-, small- and medium-sized enterprises (MSMEs), including through access to financial services (United Nations, 2018). Secondary processes are labour-intensive, and entail additional employment creation for collection services, dismantling, processing, metal recovery, manufacturing and sales operations (Drabik & Rizos, 2018). In fact, mineral recycling—especially as it pertains to post-first-life electronics—far surpasses waste disposal in terms of job creation potential (Colorado Association for Recycling, 2011). According to Hummingbird International, materials recycling from e-waste could generate more than 32 times more jobs than are required for traditional disposal operations (Sampson, 2015). The safe and controlled recycling of lithium and cobalt could generate considerable jobs within MSMEs, thereby contributing to Target 8.3.

SDG 9: BUILD RESILIENT INFRASTRUCTURE, PROMOTE INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION AND FOSTER INNOVATION.

Targets 9.4 and 9.5 of SDG 9 aim to promote sustainability through retrofitting industries for increased resource-use efficiency and enhancing the technological capabilities of industrial sectors in all countries, respectively (United Nations, 2018). One of the key advantages of mineral recycling is that, if operators work proficiently, the minerals can be reused almost endlessly, thereby extending resource-use efficiency (Natural Resources Canada, 2017). Applying current, well-established recycling models—such as those used in the lead-acid battery recycling industry—to lithium and cobalt recycling would contribute significantly to Target 9.4.[3] Moreover, incentivizing lithium and cobalt recycling would foster innovation in industrial sectors, as more actors seek to make the process economically viable and environmentally friendly, ultimately influencing Target 9.5. The Canadian recycling company Li-Cycle, for example, is piloting a project that lowers the cost and increases the sustainability of lithium-ion battery recycling (Li-Cycle, 2019). Projects like these, motivated by the need for lithium and cobalt recycling, would aid in accomplishing SDG 9 for Industry, Innovation and Infrastructure.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

SDG 12: ENSURE SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS.

Targets 12.4 and 12.5 of SDG 12 for Responsible Consumption and Production aim to reduce waste generation and ensure the sound management of chemicals and waste (United Nations, 2018). Primary extraction—or mining—can be associated with higher levels of waste production when compared to recycling processes. The levels of waste can be very significant; in the European Union (EU), for example, mines have generated more waste than households (Johansson, 2016). If poorly managed, lithium and cobalt mining, like other forms of mining, can also cause environmental and health problems related to the waste generated. Beyond waste, mining can also place considerable demands on the local resource base; lithium extraction, for example, can use up to 500,000 gallons of water per tonne of lithium extracted (Katwala, 2018). This can create tensions at the local level and can also be associated with water pollution due to toxic chemical leakage; incidents of hydrochloric acid polluting water sources in Tibet have been associated with nearby lithium mining (Katwala, 2018). Due to the finite, non-renewable nature of these minerals, continued consumption at current (and expected) demand levels could create considerable waste, exacerbate grievances regarding natural resource use, and jeopardize global supply chains and production patterns.

13 CLIMATE ACTION

SDG 13: TAKE URGENT ACTION TO COMBAT CLIMATE CHANGE AND ITS IMPACTS.

As discussed in the Introduction, climate change mitigation measures are essential to accomplishing the commitments set out by both SDG 13 for Climate Action and the Paris Climate Agreement. Renewable energy sources—like solar and wind—will contribute greatly to mitigation by providing options for lowering greenhouse gas emissions from the overall energy system, while still satisfying the global demand for energy services (IPCC, 2011). At the same time, these energy sources require significant mineral and metal inputs, cobalt and lithium among them (Arrobas, et al., 2017). In the face of impending projected supply shortages of both minerals and failing any significant substitution, recycling has the potential to contribute to a stable supply of lithium and cobalt, thereby enabling these energy sources and their required infrastructure (Greenwood, 2018; Holmes, 2018).

[3] This is not to say, however, that the same recovery processes should be used in both lead-acid and lithium-ion recycling, but that the collection infrastructure and services of lead-acid batteries should serve as a model to increase and scale up lithium-ion battery recycling.

In the past two decades, mines around the world have been impacted by significant climate events, including rainfall variability, droughts and floods, and extreme storms (Pearce, Ford, Prno, & Duerden, 2009). Increased mineral recycling will also contribute to the adaptation-related targets of SDG 13, by reducing a reliance on mines vulnerable to climate change. In addition, the mining sector is water- and energy-intensive. A greater reliance on the recycling industry could serve to reallocate some of these resources to nearby communities in their adaptation and development efforts.

SDG 16: PROMOTE PEACEFUL AND INCLUSIVE SOCIETIES FOR SUSTAINABLE DEVELOPMENT, PROVIDE ACCESS TO JUSTICE FOR ALL AND BUILD EFFECTIVE, ACCOUNTABLE AND INCLUSIVE INSTITUTIONS AT ALL LEVELS.

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

While mining can bring socioeconomic benefits and prosperity to local communities and regions, if poorly managed and governed it can be associated with fragility, conflict and violence. Approximately 50 per cent of world reserves of cobalt are located in the Democratic Republic of Congo (DRC), the 6th most fragile and 17th most corrupt state in the world (U.S. Geological Survey, 2018; The Fund for Peace, 2018; Transparency International, 2017). Although a lot of cobalt extraction takes place in a safe environment and contributes positively to socioeconomic development, some cobalt mines in the south of the DRC have employed young children and been associated with extortion, abuse, and dangerous working conditions with minimal safety equipment (Amnesty International & African Resources Watch, 2016; Amnesty International, 2017). In the case of lithium, an estimated 54 per cent of world reserves are located in what is known as the Lithium Triangle—a region intersecting Chile, Argentina, and Bolivia (Dickson, 2018). Most of the primary extraction takes place without issue; however, some of the mines in the area have become embroiled in ongoing grievances and local conflicts over land and water rights (Environmental Justice Atlas, 2018; Environmental Justice Atlas, 2017; Environmental Justice Atlas, 2015). Moreover, recent reports have focused on concerns in the Lithium Triangle—especially in Bolivia—surrounding an uneven distribution of mining benefits and lack of community consultation and buy-in, a cause for potential fragility and tension if not governed responsibly (Draper, 2019).

Increased conflicts in both locations could put a strain on the primary supply chains of lithium and cobalt, jeopardizing the national programs toward the achievement of SDG 16. Increased recycling of these two minerals could relieve some of the pressure on primary extraction sites and thus reduce conflict pressures. Moreover, competition caused by successful mineral recycling may present an incentive for mining companies to address supply chain issues in order to strengthen their reputation and gain back market shares. However, it is important to note that mineral and battery recycling has also been associated with child labour and dangerous working conditions in some impoverished areas of Bangladesh, India, and China (Gaines, 2014). This lack of transparency will be explored further in Section 3.

BOX 2. WASTE DISPOSAL AND RECYCLING GOVERNANCE MECHANISMS

In recent decades, a range of governance mechanisms have been developed on waste disposal and mineral recycling processes for electronics and batteries. While the designation of who is responsible for secondary processes varies based on sector, the “polluter pays” and its derived principle of “extended producer responsibility” (EPR) have increasingly gained traction. EPR requires targeted producers to assume some or full administrative, financial, and/or physical responsibility for collection, recycling, and waste disposal operations (OECD, 2001). Cobalt and lithium recycling is (and will continue to be) shaped by these national and international regulations, policies and international conventions, some of which are listed below. These governance mechanisms are expanded upon further in Annex 1.

The European Union:

The EU Batteries Directive, the EU Raw Materials Initiative, and the EU Waste of Electrical and Electronic Equipment (WEEE) Directive govern the waste disposal operations for lithium-ion batteries, and the mineral contents they contain. For these Directives, targets are set by the EU and interpreted into national law by each member state.

Canada and the United States:

Neither Canada nor the United States has adopted national laws to govern the recycling of WEEE. However, recycling regulations on a provincial and state level are spreading in both countries; all 10 Canadian provinces have implemented programs and regulations for waste batteries, and 28 US states have adopted WEEE recycling laws.

China:

China is the largest EV market in the world and generates the highest amount of WEEE globally (Bloomberg News, 2018; Doyle, 2017). In response to these demands, China has announced some pilot programs to repurpose and recycle EV batteries in 17 major regions and cities (Reuters, 2018). China has also adopted several national regulations for the collection and recycling of some WEEE product groups, including TVs, computers, refrigerators, washing machines and air conditioners—steadily growing the recycling sector.

Asia:

The recycling governance landscape for WEEE and waste batteries for the rest of Asia is highly diverse. Some countries in Southeast Asia, South Asia and Western Asia have started to promote and adopt legislation, while other countries—including Sri Lanka and Bangladesh—have no formal governance mechanisms. The informal recycling sector remains dominant in many countries in the region.

Latin America:

Seven countries in Latin American enforce national regulations on WEEE, apply the EPR principle and are active in implementing formal recycling systems: Bolivia, Chile, Colombia, Costa Rica, Ecuador, Mexico and Peru. While there is progress in many countries to adopting specific legislation for WEEE and waste batteries, challenges remain with respect to establishing and enforcing formal collection infrastructure and recycling systems.

Africa:

Historically, few countries in Africa have implemented regulations to govern WEEE. Instead, many countries host a large, informal recycling sector, in which government control and oversight is minimal. However, the interest to adopt regulations to formally govern WEEE is increasing. Ghana, Madagascar and Kenya, for example, have formally passed draft bills on WEEE into law, with other countries, including Cameroon, Nigeria, South Africa and Zambia, following suit.

International Mechanisms:

The UN Basel Convention was adopted in 1989 to protect human health and the environment against the adverse effects of hazardous wastes, household wastes and incinerator ash (Basel Convention, 2011). The Convention defines what can be counted internationally as waste and aims to uphold the core objectives of reducing the generation of hazardous wastes, promoting their environmentally sound management, and restricting the transboundary movements of wastes (Basel Convention, 2011).