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Solar Photovoltaic and Energy Storage in the Electric Grid

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Table of Contents

About This Paper 3
Introduction 4
An Introduction to Solar PV and Energy Storage in the Electric Grid 6
Metals Used in Solar PV and Energy Storage 7
Primary Mineral Sources 8
Secondary Mineral Sources 9
Market Analysis:
- Market Ability to Meet Demand 10
- Primary Reserves: Lead Minerals and Co-Products 11
- Secondary Reserves: Recycled Metals 12
- The Impact of Innovation on Metal Demand of Primary and Secondary Minerals 13
- Innovation in Solar PV and the National Grid 14

The Effect of Increased Demand for Solar PV and Energy Storage Metals on Supply Chain risk 15
The Importance of Governance in Assessing Supply Chain Risk 18
Conclusion 21
Annex: Country Market Share for Minerals in Scope 22

About Levin Sources 28
References 29

About This Paper

As demand for renewable energy sources, including solar panels, grows, pressure on certain sectors and countries will change. In turn, this may present new and heightened social and economic risks. We believe that, as energy becomes 'greener' at the point of consumption, it is essential to address the consequences at the point of constituent mineral extraction. To be truly 'green', the transition to a low carbon economy must protect the rights of each actor in the supply chain.

In part two of our three-part series analysing the minerals behind the so-called green economy, we investigate 17 minerals used in solar photovoltaic (PV) and lithium-ion battery technologies, and consider the risks to stakeholders associated with their extraction, refining, and recycling. Part one, which identifies risks related to minerals used in lithium-ion batteries for electric cars, is available now. Part three, focussing on the minerals used in wind power, will be released in early 2018.

We welcome your feedback, comments and questions on the contents of this paper. We'd also love to speak with you about this research. If you are looking to drive impact, please do not hesitate to get in touch with our expert team:

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Introduction

Power generation currently accounts for around 40% of global carbon dioxide emissions[1]. The Paris Agreement, signed by 196 ciuntries in 2016, pledges to curb greenhouse gas emissions and keep global temperatures from rising by more than 2 degrees Celsius. Some of the most prevalent polluters in the world, including China, France, Germany, India, Norway and the United Kingdom, have set ambitious carbon emissions reduction targets for implementation before 2050.

To meet national and international emissions targets, low carbon technology in the energy sector will play a significant role. There are many examples of states and political leaders taking up the challenge posed by this target, with many involving solar energy as an important part of their strategy:

- ***The European Union's Renewable Energy Directive requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020, with tailored targets set out for each country[2]. It is also under discussion to implement a Revised Renewable Energy Directive with renewables providing at least 27% of energy in the EU by 2030.***
- ***Last year, China accounted for over half of all the new solar panels installed internationally and further increased its 2020 solar target by 50% to 150 gigawatts (GW) in 2015 [3].***
- ***India has raised its 2022 target for solar power fivefold to 175 GW and is expected to double its renewable energy capacity by that time, once it has managed to overcome some initial difficulties in integrating solar farms with its national grid[4].***
- ***Effectively harnessing energy from wind and solar has prompted the UK National Grid to commit £66 million into the investment of 8 battery energy storage projects which will eventually contribute 201 MW of integrated energy storage for the electric grid[5].***

Last year, solar power became the fastest growing source of new energy, surpassing all other forms of power generation[6]. New solar capacity even overtook net growth in coal for the first time.

"What we are witnessing is the birth of a new era in solar photovoltaics," said Dr Faith Bristol, Executive Director of the International Energy Agency (IEA).

The two major types of technology used to convert solar energy into power are **photovoltaic (PV)**, which converts sunlight into electricity, and **solar thermal technology (CSP)**, which captures the sun's heat for heating or conversion into electricity. **This report examines the minerals commonly used in solar PV**, as it represents more than 98% of all solar power installations worldwide. There are very few indications that a shift towards CSP will take place in the future[7].

Renewable energy accounted for two thirds of new power added to the world's electric grids in 2016, with solar energy representing the largest proportion of this addition[8]. To make full use of new energy technology like solar PV, adaptations to current electric grids, such as the introduction of storage batteries into the grid, are needed. These changes must occur in tandem for an effective transition to renewable-based electricity.

> "What we are witnessing is the birth of a new era in solar photovoltaics"
>
> *- Dr Faith Bristol, Executive Director, International Energy Agency (IEA)*

Solar is becoming a technology-of-choice for domestic and commercial applications around the world.

Introduction (cont.)

Experts initially underestimated the potential growth of solar PV, and have since revised their predictions in light of the observed increase in solar PV use worldwide. The International Energy Agency (IEA) estimates that the global capacity of solar energy will be greater than the current total power capacity of India and Japan combined within five years, and the capacity growth of solar PV will be higher than any other renewable technology up to 2022[9].

However, it is not possible to manufacture green technologies without a carbon footprint, particularly through the extraction of the minerals that are used to build them. In Chile, the **copper** mining sector**,** (a mineral used in many renewable energy technologies) is the largest consumer of energy and the largest source of greenhouse gas emissions in the country. Analysts expect this to increase further as the quality of the ore decreases over time and so the energy required for **copper** production grows[10]. The energy required to produce **copper** alone is expected to be between 1% and 2.4% of total global energy demand by 2050, compared to its current level of 0.3%[11]. For secondary sources of **copper**, the amount of energy needed is less, although the transportation, separation and re-melting of metals also contribute to emissions.

In the transition to a low-carbon economy using renewable energy, it is important to factor in the mineral resources needed to create the technologies. Whether the production of these minerals can meet the demand or not, and the associated human and environmental risks and implications are all considerations that must be identified and addressed.

In this study, we investigate the minerals used in both solar PV technology and the electric storage batteries that will play a crucial role in the future of electric grids. We analyse the impact the growth of these technologies could have on the demand for certain minerals and the supply chain risks connected to these metals.

The energy required to produce copper alone is expected to be between 1% and 2.4% of total global energy demand by 2050, compared to its current level of 0.3%

Solar energy is helping developed countries meet carbon emission goals, but at what cost to the rest of the world?

An Introduction to Solar PV and Energy Storage in the Electric Grid

Solar PV technology uses panels made of semiconductor cells to convert sunlight into electricity.

Solar panels are usually fitted near to the supply point for electricity, such as on roofs or in large groups at ground level. More advanced installations can feed into a central power facility and provide electricity across a much larger area.

The cost of solar PV has dropped by more than 50% over the last decade. This is due to large-scale production and improved technology. In recent years, individual consumers and businesses have installed solar PV as off-grid appliances on their roofs, and by large-scale solar farms, generating megawatts of electricity for commercial use.

The UK government's **Clean Growth Strategy**, released in October 2017, promotes solar energy and draws attention to Clayhill Solar Power Farm and energy storage facility as the first of its kind built in the UK without any subsidies[12]. UK Government awareness-raising campaigns and favourable tax incentives, such as a 5% reduction on VAT for panels installed in residential accommodation, have helped increase public interest in solar PV[13]. More than a million homes in the UK now have solar panels installed on their roofs and connected to small storage batteries[14].

As solar PV is adopted as a source of energy, the electric grid needs to adjust to a more intermittent supply of energy. This necessitates greater investment in energy storage. Currently, pumped-storage hydroelectricity is the most common form of grid-scale energy infrastructure. However, due to the decreasing cost of batteries and comparative flexibility of location and size, experts predict a move towards battery storage. Large solar farms and private homes or businesses can use batteries to store the energy collected from individual installations.

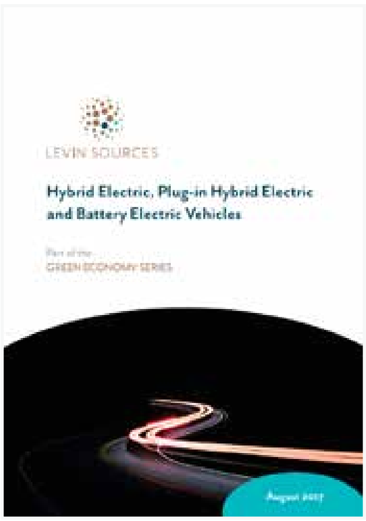
Electric grids with integrated energy storage are imperative for the introduction of increased low carbon energy sources, including solar PV. Due to qualities including their energy efficiency, fast charging ability and low self-discharge rate, lithium-ion batteries represent the most likely solution for governments seeking to shift their power supply to low carbon technology.

For more information on lithium-ion batteries used in electric cars, please see our publication 'Green Economy Series: Hybrid Electric, Plug-In Hybrid Electric, and Battery Electric Vehicles'[15].

The minerals investigated in this study are:

- ***Aluminium***
- ***Cadmium***
- ***Cobalt***
- ***Copper***
- ***Gallium***
- ***Indium***
- ***Iron (and steel)***
- ***Lead***
- ***Lithium***
- ***Manganese***
- ***Nickel***
- ***Silica***
- ***Silver***
- ***Selenium***
- ***Tellurium***
- ***Tin***
- ***Zinc***

These minerals appear **bold** throughout the study to make them easier to identify. Other minerals that are not essential to solar PV and/or lithium-ion battery production, e.g. gold, appear throughout, but do not appear as bold.



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Metals Used in Solar PV and Energy Storage

Although estimates on the exact amount vary, experts predict solar PV will become a critical part of the global energy supply. The quantities of each metal required for solar PV depend on the cell efficiency, utilisation rate, performance ratio and solar irradiation. Manufacturers generally do not disclose the exact amounts of each metal used in their products, but the types of metals and their functions are standard across solar PV panels[16].

In this study, we look at 17 minerals indicated in Table 1 that are generally acknowledged as strategic for solar PV and lithium-ion battery energy storage[17].

Metal	Solar PV	Energy Storage Lithium Batteries
Aluminium (Al)	■	■
Cadmium (Cd)	■	
Cobalt (Co)		■
Copper (Cu)	■	
Gallium (Ga)	■	
Indium (In)	■	
Iron/Steel (Fe)	■	■
Lead (Pb)	■	■
Lithium (Li)		■
Manganese (Mn)		■
Nickel (Ni)	■	■
Silica (Si)	■	
Silver (Ag)	■	
Selenium (Se)	■	
Tellurium (Te)	■	
Tin (Sn)	■	
Zinc (Zn)	■	

Table 1: Metals used in Solar PV and Energy Storage Lithium Batteries

Three prominent technology choices within solar PV technology appear in Table 2: **Crystalline Silicone** (c-si), **Cadmium Telluride** (CdTe) and **Copper Indium Gallium Selenide** (CIGS).

Other technologies include dye-sensitised solar cell (DSSD), **gallium** arsenide (GaAs) and amorphous silicon (a-Si). These technologies do not appear in this study as each represents less than one percent of the market share[18]. These types all have differing quantities and combinations of minerals.

The relative growth of these different technologies will have implications for the demand for the minerals used in their production. For example, c-Si uses larger amounts of **silver** in comparison to the others, **tellurium** is essential to CdTe technology and CIGS needs more **indium**[19].

All type of technology uses mounts of **aluminium**, **nickel**, **copper**, **tin**, and **iron** (in steel) in construction. **Silver** is also used in a paste form in all types solar panel as a conductor. Below, in Table 2, are the additional key minerals for each technology type[20 21 22].

Type of Solar PV	Crystalline Silicone (C-Si)	Cadmium Telluride (CdTe)	Copper Indium Gallium Selenide (CIGS)
Market Share	92%	5%	2%
Efficiency	25.6%	19.6%	22.8%
Lifespan (Approx.)	20 years	10 years	12 years
Key metals	Silica, Lead	Cadmium, Tellurium	Indium, Gallium, Selenium, Copper

Table 2: Properties of different types of Solar PV technology

Primary and Secondary Mineral Sources

Metals used for the production of solar panels and lithium-ion batteries can be sourced through extraction of primary resources in **Large-scale Mining (LSM)** or **Artisanal and Small-scale Mining (ASM)** processes, and through the **recycling** of secondary resources of scrap metal. Please note we do not address stocks and associated risks in this report and recommend that further research on this topic is done.

PRIMARY MINERAL SOURCES

Primary sources are extracted from mineral ore deposits in the earth. Ores are purified into the metals used in solar PV technologies through a series of concentrating, smelting and refining processes. The extraction processes for primary sources depend on many different factors, including the size and type of deposit, the quality of the ore and other minerals present in the ore.

LSM and ASM are two broad categories of mineral extraction which extract minerals from primary sources. LSM is undertaken by large industrial mining companies. It is capital intensive and mechanised. ASM refers to individuals, groups, families, or micro-enterprises extracting minerals with very little or no mechanisation in the extraction process. Activities often take place in an informal or illegal sector of the market. An estimated 40 million people (about the same as the population of Australia) in more than 123 countries around the world practice ASM as part of their livelihood strategy[23].

Within the solar PV and energy storage metals discussed in this study, **copper**, **silver**, **tin**, **iron** and **cobalt** are mined artisanally, although it is possible that others such as bauxite (the primary ore of **aluminium**) are also mined by artisanal miners[24].

Artisanal miners in Sierra Leone, 2016. Levin Sources ©

What is Artisanal and Small-scale Mining?

"Artisanal and Small-scale Mining (ASM) - formal or informal operations with predominantly simplified forms of exploration, extraction, processing and transportation. ASM is normally low capital intensive and uses high labour intensive technology. ASM can include men and women working on an individual basis as well as those working in family groups, in partnership or as members of cooperatives or other types of legal associations and enterprises involving hundreds or thousands of miners." - ***OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas – Supplement on Gold, Second Edition (2012)***[25]

Primary and Secondary Mineral Sources

SECONDARY MINERAL SOURCES

Recycling is the process of converting waste material into a usable resource. This can apply to scrap from industrial processes, as well as old products that are no longer in use. Recycling can reduce pressure on reserves of certain minerals and reduce emissions caused by extracting them, as the process for recycling minerals like **aluminium**, **lead** and **copper** uses significantly less energy than primary extraction. Estimates put the energy saved by obtaining **copper** through recycling rather than mining as between 84 and 88%[26].

The process of recycling minerals usually involves melting down scrap material and remoulding it into a sellable product. The process of collecting products to recycle, as well as the breakdown of components that contain many materials within them, can vary depending on the mineral, the product from which it is being extracted, and the industry standards of the country of operation. Some products are collected and broken down informally by groups of scrap collectors and sold on (common in Mexico), or industrially by large companies[27]. The information, and required due diligence, on the origin of recycled material and scrap available is currently minimal to non-existent. This is an exploitable loophole that is sometimes used to disguise mined material from sources that would not comply with industry standards. This could include mining operations that are linked to serious human rights abuses or mines operating illegally in protected areas. By mixing minerals sourced from primary sources with recycled minerals, or falsely identifying them as recycled, origins can be intentionally obscured.

Cobalt is a mineral of particular concern. Statistics show that 32% of the world's **cobalt** scrap is exported from the Democratic Republic of the Congo (DRC)[28]. The DRC has the world's largest reserves of **cobalt** by a large margin, and has known artisanal mining, prevalent human rights abuses and no clear source of significant secondary **cobalt** scrap. This suggests that much of the 'scrap' export is likely to be mined **cobalt** labelled as scrap to avoid investigation into its origin and make it suitable for sale.

'Mined metals falsely identified as scrap are an exploitable loophole that can be used to disguise mined materials from sources that would not comply with standards.'

Scrap metal in a landfill to be sorted, recycled, and sold.

Market Analysis

MARKET ABILITY TO MEET DEMAND

Developments in solar and battery technologies will change the quantities and types of minerals needed to produce them. For example, the proportion of the energy sector that will use these technologies could change as new technologies are developed. While it is not possible to make a confident prediction of the precise future demand for the minerals in scope, we can be certain that the metal demand will rise as the International Renewable Energy Agency (IRENA) predicts that, by 2030, the capacity of solar PV installed will increase from 290 to between 1760 and 2130 gigawatts (GW)[29].

Increase in demand for minerals in solar PV has knock-on effects not only on the mineral supply for solar PV, but also for other applications and industries that use these minerals. The Silver Institute predicts that **silver** demand for solar PV could soon equal or exceed the **silver** volumes previously used in the photographic industry, which represented more than 60% of the total **silver** market before the move to digital imagery[30].

A study by Elshkaki and Graedel predicts that the scarcity of resources, in particular **tellurium** and **silver**, will have significant constraining effects on the long-term development of the solar PV industry, and that the risk of scarcity for solar PV minerals was greater than for those used for other renewables, such as wind energy[31]. Although there are attempts to reduce the amount of **silver** used in solar PV by substituting it with copper to lower costs, projections show that if solar PV growth meets estimate levels it will have a significant impact on the market sectors for the minerals used.

IRENA predicts that lithium-ion batteries for energy storage in the electrical will increase from 1GW currently to 250GW by 2030. However, this does not account for the need for lithium-ion batteries in electrical cars, smart phones, laptops and other technologies, all of which are also increasing and will impact supply.

The Royal Society of Chemistry Journal provides a relative supply risk index from 1 (very low risk) to 10 (very high risk) using data from the British Geological Survey on crustal abundance, reserve distribution, production concentration, substitutability, recycling rate and political stability score. This supply risk index rated **nickel**, **lithium** and **cobalt** as "high risk", 6.2, 6.7 and 7.6, respectively, indicating that although there is enough production of those elements for electricity storage lithium-ion batteries, when analysed in the context of other supply risk factors there are still concerns for meeting the demand for lithium-ion batteries.

The grade of **nickel** available also affects the amount of usable supply, for solar PV and lithium-ion technology. Primary **nickel** supply comes from two types of deposits: laterite, which makes up 62% of current production, and sulphide which makes up 38% of current production[32]. Sulphide deposits are rarer but produce higher quality **nickel** and **nickel** sulphate, which goes into electroplating and lithium-ion cathode material for batteries. **Nickel** sulphate represents less than 10% of global **nickel** supply but is the only form of **nickel** currently usable for the battery sector, meaning that it is misleading to analyse overall **nickel** production as all being able to meet battery sector demand[33].

Large-scale solar installation in Región de Antofagasta, Chile.

Market Analysis

PRIMARY RESERVES: LEAD MINERALS AND CO-PRODUCTS

An important factor to consider when analysing both demand and risk of scarcity of a mineral is whether or not it is a 'co-product' mineral produced either primarily or entirely as a co-product of another mineral: the 'lead' mineral.

Co-product minerals are tied to the production of lead minerals and the amount extracted can only be increased through improved technology to make the recovery of the co-product mineral from the lead mineral more efficient, or by increasing the production of the lead mineral.

Factors affecting the supply of co-product metals include:

1. Price of host metal

The values of lead and co-product minerals do not always operate in parallel and therefore price fluctuations of lead minerals can have severe impacts on the scarcity of co-products.

The relationship between co-products and lead minerals is clear in the case of **indium**, the production of which dropped by almost 100 tons from 2015 to 2016 due to the number of **zinc** mine closures that occurred within that time[34].

Glencore's decision to close its **copper** mine in Katanga due to low **copper** prices in 2015 also resulted in the removal of 3% of the world's **cobalt** supply from the market, since these minerals are mined together, and there were similar ramifications to the suspension of operations by a **nickel** and **cobalt** mine in Brazil by Votoranitm Metais.

2. Changes in extraction technology of host metals

Changes in the extraction methods of lead minerals can also prevent the recovery of co-products. For example, the trend in electrolytic refining of **copper** being displaced by acid leaching impacts the supply of **tellurium** because only the former method is able to extract the by-product.

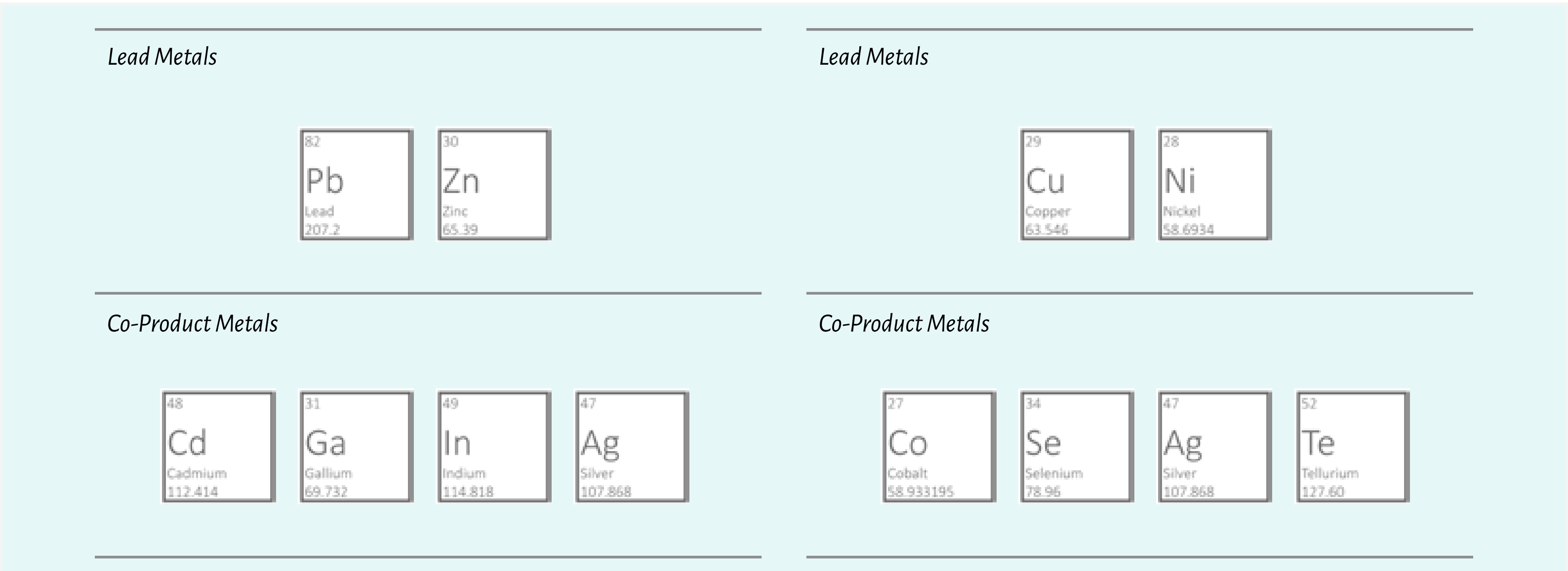


Fig 2 (L+R): Lead metals and the co-product metals tied to their production

For important lead minerals such as **copper**, supply and extraction also dictates the supply of many other minerals which are critical for the move towards renewable energy. **Tellurium**, used in CdTe solar PV, is primarily extracted from **copper** ore, or as a co-product of **zinc** and gold ore deposits. It also takes up only 0.0000001% of the earth's crust and is three times rarer than gold in supply, so its extraction from the by-products of other minerals is more critical[35].

Changes in the extraction methods of lead minerals can also prevent the recovery of co-product minerals. For example, the trend in electrolytic refining of **copper** being displaced by acid leaching impacts the supply of **tellurium** because only the former method is able to extract the co-product.

Market Analysis

SECONDARY RESERVES: RECYCLED METALS

Primary reserves of minerals can also be supplemented by recycling mineral from old products, buildings and electronic waste (e-waste). The recycling rate of a mineral depends on how much they are currently in use and their use in technology that is now obsolete, as well as the difficulty in extracting it from the product it has been used in. Minerals such as **lead**, **aluminium**, **copper**, and **iron** already have very high recycling rates (on average, 90% of all their generated scrap is recycled, excluding waste from nuclear power plants), however these secondary sources only provide between 30-50% of the international demand[36].

The potential for the recycling of **nickel** is also estimated to be high, with secondary sources already covering 72% of demand from renewable technology in 2010 and expected to attain 100% by 2050. This is due to the phase out policy for nuclear and coal power, leading to large quantities of scrap generation from disused technologies containing **nickel**. In contrast, Elshkaki and Graedel (2013) anticipate that the proportion of secondary source minerals for **tellurium** and **indium** will initially be minor due to their relatively low demand in older technology, but that this will change over time to cover a larger proportion of the overall supply[37].

High recycling rates cannot completely replace the need for primary sources of many minerals, and both recycling and mining will need to be used to achieve an adequate supply. For example, although the rate of recycling of **copper** is likely to increase over time, the proportion of **copper** demand that is expected to be covered by secondary sources is only estimated to be 17.5%[38].

Ship breaking is a source of raw materials extraction in the form of scrap recycling

Market Analysis

THE IMPACT OF INNOVATION ON METAL DEMAND OF PRIMARY AND SECONDARY MINERALS

Widespread adoption of new forms of energy technology will also depend at least in part on the innovations made in recycling, mining, and the new technologies themselves.

The mining operations (primary extraction) for minerals for the low carbon economy have significant environmental impacts and use large volumes of energy in the extraction, smelting and refining processes. 10% of global energy consumption in 2013 was used in the extraction and processing of mineral resources. These energy costs along the mineral supply chain also need to be taken into account when considering the real carbon footprint of renewable energy technologies.

One way to address the carbon footprint of mineral extraction is to incorporate renewable energy sources in the mining process instead of fossil fuels. Chile has revised its energy contracts to include renewable sources of energy to power **copper** mines, which reduces some of the greenhouse gases emitted by mining operations[39]. In South Africa, mining companies are moving towards alternative sources of energy including renewables like solar and wind energy to combat the unreliability of the national electricity supply and permit continuous production[40]. It is estimated that around 80% of Africa's mines will soon be located in off-grid areas, and solar PV energy offers a persuasive solution to reduce operating costs and increase energy reliability[41]. China has also linked up solar PV with the rehabilitation of mined out areas by building the world's largest floating solar PV farm on a lake created by a collapsed and flooded coal mine, supplying enough energy to power a large town[42].

Another way to address issues of carbon footprint is innovation concerning the energy efficiency of mineral production methods from primary sources. The total amount of energy required for production depends on the grade of ore, and the energy efficiency and processes used in production. Although in many cases the ore quality of existing reserves will decrease over time which could increase emissions, research conducted on **copper** production in Chile shows that addressing energy inefficiencies could save as much as between 10-60% of energy across the different stages of mineral production[43].

Innovation and growth in recycling is likely to play a key role in accessing the minerals needed for increased demand from renewable technology like solar PV and the grid. Large quantities of valuable and reusable raw materials are currently trapped in retired products like laptops and mobile phones due to the lack of facilities to extract them from e-waste or because consumers are not aware of the facilities. Research into new techniques for recycling scarce minerals is ongoing and innovations around extracting critical materials could reduce the carbon footprint needed for accessing them, as the recycling of minerals usually requires less energy than primary extraction. One of the most successful innovators is Umicore, who is pioneering technology to recycle e-waste to obtain critical minerals from complex wastes including **tellurium**, **selenium** and **indium** along with over 20 other precious and non-ferrous minerals[44].

Recycling alone cannot provide a solution to these changing mineral demands. For several crucial minerals such as **tellurium**, **gallium** and **selenium** there is not enough of the mineral currently in circulation to make secondary sources a viable option, and the recycling of **silica** is very minimal[45]. In the foreseeable future, mining will have to contribute to the supply of raw materials needed for the manufacturing of clean technology alongside recycling.

The carbon footprint of mineral extraction could be reduced by using renewable energy technologies in the extraction process

Market Analysis

INNOVATION IN SOLAR PV AND THE NATIONAL GRID

The three types of solar PV discussed in this paper represent technology that is currently on the market, but do not account for the variations that could occur with the development of new technology that is yet to become commercially available.

Finding less expensive and more readily available minerals as alternatives to high-value and rare minerals could also provide a solution to the scarcity of some minerals that are currently essential to solar PV. One example of this is new research into technology that uses **zinc** and **copper** instead of **gallium** and **indium**[46]. Perovskite solar PV is due to be released onto the market in the next year, and uses much cheaper materials. Its efficiency is said to be similar to the c-Si technology which holds the largest market share at the moment. There is even recent research done on integrating a solar cell into Swarovski crystals which are meant to help direct light to the cell which can lead to further innovations in the design of solar PV[47].

An integrated energy storage in the national grid opens up new possibilities for innovation and development as well, such as the work by the EU funded Project SENSIBLE (Storage ENabled SustaInable energy for BuiLdings and communitiEs) which investigates how to integrate available technologies into power grids to accommodate a hybrid energy storage system[48]. Research conducted at the University of Nottingham in support of SENSIBLE looks into how disused energy storage technology from the automotive industry could be recycled into the national grid and act as an energy storage system for domestic solar PV installations[49].

Connecting low carbon technologies like electric cars to the electric grid in support of renewable wind and solar energy promotes sustainability and a circular economy which is both cost, energy and resource efficient.

> "Solar cells are assumed to have an ultimate efficiency limit of around 30%. The ultimate goal is to break the 30% efficiency limit by utilising new design approaches - this is called a 'super-efficient solar cell'"
>
> *- Johannes Richter, Researcher, Cavendish Laboratory, University of Cambridge*

The Effect of Increased Demand for Solar PV and Energy Storage Metals on Supply Chain Risk

There are a number of risks related to the supply chain of minerals sourced to produce Solar PV, whether these are extracted by ASM, LSM or the recycling of scrap material.

These supply chains all come with challenges and risks relating to their operations, and also can overlap with one another. For example, ASM miners may sell their minerals to LSM companies for processing, and recycled scrap is sometimes refined alongside mined minerals. A non-exhaustive list of supply chain risks is provided below with some illustrative examples from the minerals within the scope of this study. It is worth noting that for companion minerals such as **gallium**, **selenium**, **tellurium**, **indium** and others, the risks associated with the extraction of their host minerals can apply to them as well.

Health and Safety

Mining, processing, dismantling and recycling are all forms of labour that have significant health and safety risks for workers, particularly if insufficient protective equipment and procedures are in place.

The mining of **cobalt**, **cadmium**, **lead**, **silica** can be hazardous due to the release of toxic substances during extraction, smelting and refining. Other health and safety risks in refining include reports of gas leaks in **nickel** refineries in Madagascar which caused respiratory diseases to local residents[50].

Lastly, ship breaking at the end of a vessel's life is a major source of scrap metal for recycled **copper**, **lead**, **nickel** and **iron** (in steel). Ship breaking is well known to employ informal workers with little to no health and safety regulations in countries like India, Pakistan and Bangladesh.

There are reports of accidents, deaths, severe injuries and loss of limbs as well as poisoning of ship breakers by the release of fuel tanks directly into the water and other toxic substances including **lead**, mercury, asbestos and petrochemical by-products.

Metals extracted from secondary electronic waste (e-waste) can be sold to scrap dealers who bring the material back into the supply chain. Health hazards and toxic pollution risks are reported when landfills of wastes are incinerated as a quick solution to extract metals.

These wastes contain metals and substances such as mercury, **cadmium** (known to accumulate in the human body and damage bone structures and kidneys) and chromium which, if poorly managed, can threaten human health and the environment[51]. Minerals including **silver**, **copper**, **aluminium**, **cadmium** and **lead** are sourced from e-waste, but as solar PV and lithium-ion battery technology advances and becomes even more prevalent, outdated models will become sources of future e-waste, making all of the minerals in scope eligible for this type of extraction in the future[52]. Sorting of such wastes and the sale of metals that are extracted have become a source of income for poor communities in Guiyu, China, Hong Kong, and parts of Ghana where worker safety standards are low and work is carried out by informal labourers[53].

Land Rights

Questions of ownership of land that contains valuable mineral deposits can lead to conflict over territory, which can be further complicated when the land is traditionally owned by indigenous people or considered sacred.

One example can be found in bauxite (which produces **aluminium**) extracted by LSM in Queensland Australia, where poor consideration for indigenous rights over mining land and native title rights has led to a 40-year-long conflict with the Wik and WikWaya peoples[54]. The Aluminium Stewardship Initiative has created an Indigenous People's Advisory Forum (IPAF) to convene actors in the sector around this issue occurring within bauxite exploration, mining and processing[55].

The Effect of Increased Demand for Solar PV and Energy Storage Metals on Supply Chain Risk

Water Rights	**The allocation of local water supply to mining projects can mean that it is diverted away from local residents.** For instance, **lithium** mining projects in Argentina and Chile use huge quantities of water because the extraction method involves evaporation of brine containing **lithium**. **Lithium** extraction has resulted in water shortage in local areas, with residents barricading the highway in protest of lack of water supply to their village in over 50 days. A tonne of **lithium** generally requires around 500,000 gallons of water if extracted from brine[57].
Biodiversity	**Mining practices can interfere with the resilience of ecosystems and threaten biodiversity through deforestation, pollution or diversion of water courses.** One example of this is in New Caledonia which has one of the world's largest reserves of **nickel** as well as an extremely rare terrestrial and marine ecosystem[58]. The mining of **nickel** deposits in New Caledonia has caused carbon emissions, acid rain and siltation which has destroyed unique animal habitats and large areas of coral reef[59]. Across the world, ASM illegally occurs in legally protected areas where mining is not permitted, severely threatening the biodiversity of habitats that are protected for their natural value[60].
Labour Rights	**The contractual agreements (or lack of contractual agreements) for workers in mining, smelting, refining and recycling can fail to provide sufficient job security, meet minimum or living wage standards or give access to a grievance mechanism.** This is prevalent in the informal ASM sector and in informal recycling of e-waste or ship breaking, but also true of some LSM practices as well, such as in Zambian **copper** mines, where workers have been fired for striking about unfair working conditions and miners have been reported to be bribed or threatened to prevent the publicising of accidents and abuse at the workplace[61]. **Forced labour risk:** In the Democratic Republic of the Congo, trafficking and forced labour in **cobalt** and **tin** mining have been reported[62]. Armed forces or rebel groups are reported to force local miners at gunpoint to work without pay, and these groups can also be the only financing options and offer loans at exorbitant rates which lead to bondage work through a cycle of debt that cannot be repaid[63]. **Child labour:** Child labour in ASM and the sorting of e-waste for recycling represent a serious human rights risk[64]. There are reports of **tin** and **cobalt** mined by children in the Democratic Republic of the Congo, as well as child labour in **tin** mining in Bolivia and Indonesia[65].

The Effect of Increased Demand for Solar PV and Energy Storage Metals on Supply Chain Risk

Waste Management

Once the recoverable material has been extracted, its waste product (mine tailings and overburden) must be disposed of safely. The disposal of waste products from the mining process can contaminate areas surrounding the site, having impact on local communities and natural habitats. Waste can contain heavy metals that if left in contact with water sources and the soil can be released into the environment and have a detrimental impact on human and animal health.

For example, the waste disposal practices of one company's **lead** and **zinc** mine in Australia were found in 2016 to be responsible for substantial **lead** poisoning in the nearby river, with more than 90% of the fish stock containing dangerous amounts of **lead**. The waste from the mine was left in large piles and still smouldering, emitting poisonous fumes and polluting surrounding water systems[66].

Acid Mine Drainage: Waste rock from sulphide ores that come into contact with water or metals that have been treated with sulphuric acid in the purification process can generate sulphuric acid which is hazardous for ecosystems and human health. This can lead to contamination of local groundwater and make it undrinkable or unusable for irrigation in farming. The damage done by acid mine drainage can be ongoing for hundreds of years due to its groundwater and streams across great distances. **Silver**, **nickel**, **zinc**, **copper**, and **lead** are examples of metals which can come from sulphide ore.

Pollution

The mining, processing and recycling of metals can use and emit toxic chemical substances that may be harmful to the environment and to human health if these chemicals are released into ecosystems or humans come into contact with high doses, with inadequate protection. Pollutants emitted from mining, processing and refining operations can not only pose a risk to workers that are directly exposed to toxic chemicals, but also to local and regional communities if pollutants are emitted into the air, soil and waters that are in use by them.

Air pollution risks: Dust and fumes from mine sites and stockpiles of ore can cause air pollution. For example, the inhalation of **silica** dust around mining sites can cause silicosis, cancer and increased risk of tuberculosis[67].

Mercury risk: Mercury is used in the amalgamation of **silver** and gold and if not well managed can have severe impact on human health and the environment. Artisanal **silver** and gold miners, as well as those involved in amalgamation, are often exposed to unsafe levels of mercury. Mercury is ranked in the World Health Organisation's top ten chemicals to be a major public health concern due to its toxic effects on vital organs, as well as the digestive, nervous and immune system. When compounded with cyanide, which is also used in the amalgamation process of **silver** and gold, the impact of mercury reaches further from the source.

Mercury entering water bodies and streams can be consumed by fauna, particularly in aquatic and riverine ecosystems if mercury is discharged into rivers. Mercury can remain stored in an organism's tissue for long periods of time. As organisms get consumed by other organisms, the concentration of mercury increases as it moves up the food chain, eventually reaching humans through food systems[68].

Human health risks: mining, smelting and refining processes can release substances which are hazardous to human health, affecting both workers and people in the local community if not managed properly. For example, chronic **manganese** exposure around the mining and processing of **manganese** ores was found to impair growth and lead to skeletal deformities in children living in regions around **manganese** mining in Ukraine[69]. **Cadmium**, **indium** and **selenium** have all been documented to be materials that are hazardous and require handling with appropriate protection from exposure to workers or the environment in their extraction from primary sources or separating from waste material in recycling[70].

The Importance of Governance in Assessing Supply Chain Risk

The governance of the countries where minerals are extracted and refined plays a key role in determining the types of risks that are more, or less, likely to occur in a mineral supply chain.

Governance is here defined as "the form of political regime or the manner by which authority is exercised in the management of a country's social or economic resources for the public good. It can also refer to the capacity of governments to design, formulate and implement policies and discharge functions"[71].

Increased likelihood of risk

Sourcing from countries with poor governance is not in itself a risk, and sourcing from countries with good governance does not mean that the supply chain is risk free. However, sourcing from a country with poor or very poor governance increases the likelihood of certain types of supply chain risk. The sourcing countries of each type of metal and the effectiveness of their governance is therefore an important consideration when doing due diligence a supply chain. For example, the poor enforcement of regulations within Myanmar and political instability suggests that the mining of **tin** there has a high likelihood of human and environmental risk. The governance of countries where metals are sorted in supply chains with secondary sources similarly indicates the likelihood of certain human rights and environmental risks. For example, the low labour rights standards in Bangladesh mean hazardous working conditions are likely in the ship breaking industry.

Increased likelihood of disrupted supply

Governance of a primary sourcing countries is an important factor to consider when assessing access to mineral supply and ability to meet demand. The European Commission's criticality methodology for raw materials assesses the importance of materials with regards to the European Union's industrial needs, technology and links to clean technologies[72]. This assessment places a significant weighting on the governance of countries that are primary suppliers of the material, as countries with poor governance have a higher likelihood of the mineral supply being interrupted, for example due to political unrest.

Of the minerals in scope, **cobalt**, **gallium**, and **indium** have been deemed by the EC to be critical raw materials based on criteria assessing their importance, as well as the lack of substitutability for other metals, low recycling rates and high concentration of producing countries with poor governance[73]. The US Department of Energy's critical materials strategy also analyses minerals' importance to clean energy and risk of access to supply, and lists **tellurium**, **lithium**, **gallium, cobalt** and **indium** as near-critical[74]. The US Department of Energy and European Commission's emphasis on sourcing country governance in their assessment of risk in supply of minerals illustrates the importance of its consideration in assessing both social and environmental risk as well as the risk of disrupted access to supply.

Using the country assessments by the Worldwide Governance Indicators (WGI) project and production data from the United States Geological Survey (USGS) 2017 mineral commodity annual report and British Geological Survey, this study has assessed the minerals within scope according to their main sourcing countries and the quality of governance. There would be merit in analysing secondary sourcing countries for these minerals according to effectiveness of governance as well, however the opacity of recycled supply chains makes this difficult and has not been attempted in this report.

The WGI reports governance indicators of countries according to:

- ***voice and accountability***
- ***political stability and absence of violence***
- ***government effectiveness***
- ***rule of law***
- ***control of corruption***

It then gives each country a score between -2.5 and 2.5, -2.5 being the worst and 2.5 being the best. The countries have been grouped into the following categories according to their WGI ranking:

- ***'excellent governance' (a score that is 1.0 or higher)***
- ***'good governance' (a score that is greater than 0.0 and less than 1.0)***
- ***'poor governance' (a score that is greater than -1.0 and less than or equal to 0.0)***
- ***'very poor governance' (a score that is -1.0 or lower)***

This report shows the proportion of each mineral's primary sourcing countries according to rankings of governance given by the WGI, and indicates how governance of sourcing countries could be of importance to these minerals. For example, in the case of **manganese**, 16% of the market share of production comes from Australia, which has a rank of 1.5 by the WGI and fits in the category this report has considered to be 'excellent governance', but also 48% of production comes from countries that have been given a rank that fits in the poor governance category (Brazil, China, Gabon, India, Kazakhstan, Mexico and Ukraine).

The Importance of Governance in Assessing Supply Chain Risk (cont.)

From this data, we can notice how many of the minerals in solar PV and lithium-ion batteries are extracted by countries having poor governance levels, and how for some minerals such as **cobalt**, the majority of primary sourcing comes from very poor governance countries (the DRC).

This assessment was done using the current production data for the minerals and does not take into account mineral reserves. There are many countries with large deposits of certain minerals which are not currently being exploited but which could be in the future. If the demand for solar PV and lithium-ion batteries grows, these reserves will become more lucrative and likely to be developed into producing mines. Some countries are not currently highly ranked in production but have a significant proportion of the mineral's reserves, such as Guinea for bauxite which produces **aluminium**. Guinea is one of the poorest countries in the world as well as categorised as having poor governance[75]. New mining operations opening up in countries with poor governance in order to meet demand could therefore pose new risks in supply chains.

Current data about reserves has also been criticised for being unrepresentative due to the lack of research done on the mineral deposits of poorer countries in comparison to wealthier ones. This means it is likely that our understanding of global mineral reserves is skewed disproportionately in favour of countries that have the resources to research their mineral wealth and that there could be other reserves, particularly of less common minerals like **tellurium** whose total reserves are not yet known.

Shifts in importance of sourcing countries due to exploitation of reserves that are not currently used, or the discovery of new reserves, is also an important factor in understanding whether there is sufficient supply to meet demand, and the risks that are more likely due to the governance level of sourcing countries.

These diagrams show another way of analysing the supply of minerals in solar PV and lithium-ion batteries, and a different dimension to consider in how one can assess likelihood of risks. This analysis is something that should also be taken into account for other stages of the supply chains, such as smelters, refiners, and recyclers, as their operating context similarly affects the types of risks that are likely.

Manganese

Country	Market Share (%)
South Africa	29
China	19
Australia	16
Gabon	13
Brazil	6
India	6
Ghana	3
Ukraine	2
Mexico	1
Malaysia	1
Kazakhstan	1
Other	3

Note: Manganese is used here for example purposes and also appears in the next section, which is organised alphabetically.

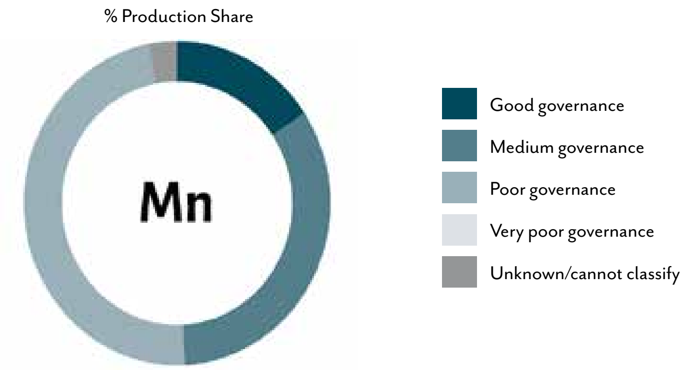
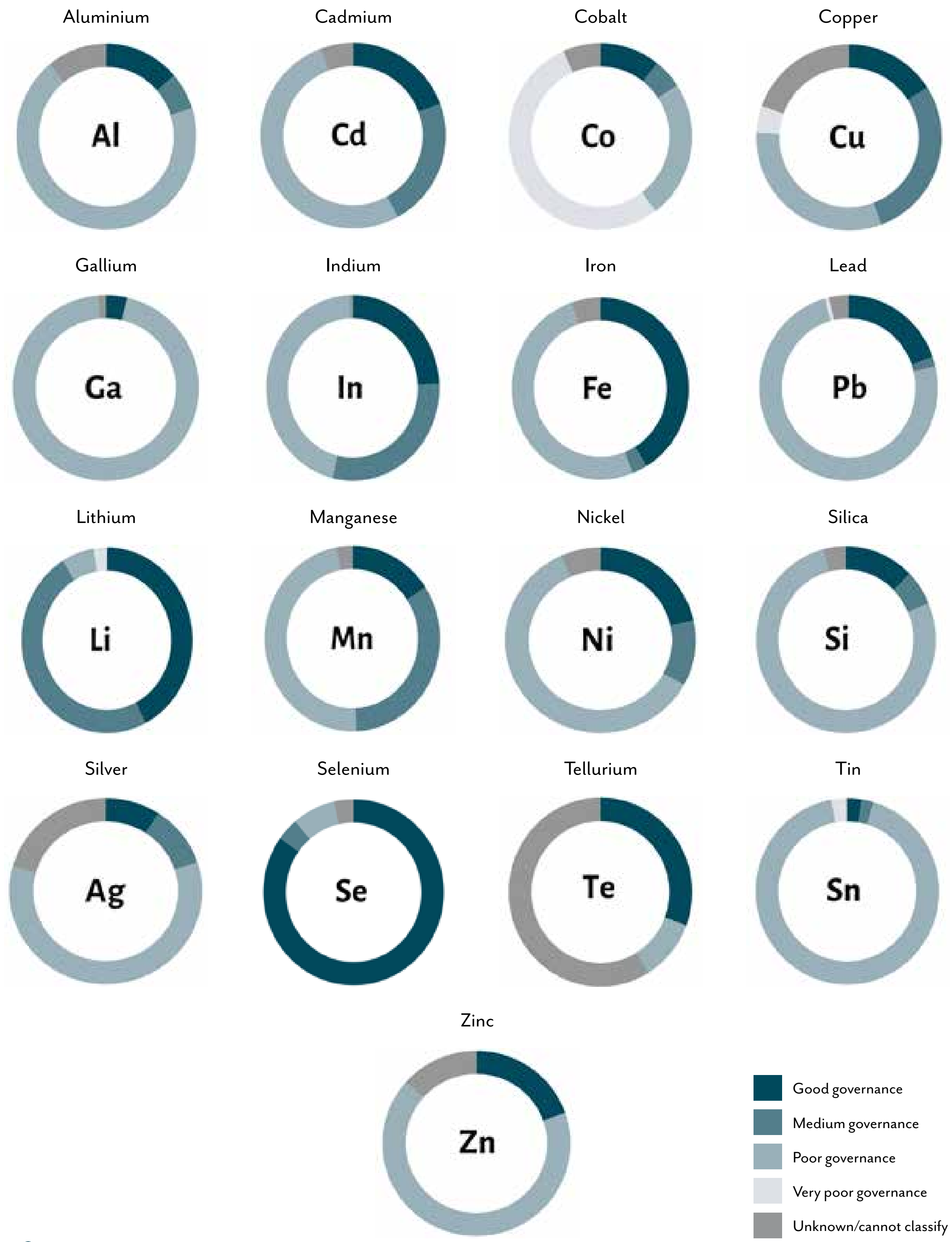


Fig 3: An example governance-market/production share table

The Importance of Governance in Assessing Supply Chain Risk (cont.)



For a full breakdown of sourcing countries and their market share, please see page 23 for 'Annex: Country Market Share for Minerals in Scope'

Conclusion

We don't know which technology types will prevail as dominant, whether it will be one of the solar PV types that are currently commercially available, new technology that is still in development stages, or whether there will be many types that continue to hold shares in the solar market as it grows.

Although we can analyse the metal demand based on current technology and the quantities that are used at the moment, we also don't know how this will change as research is done into substitution of more costly or rare minerals for cheaper more prevalent ones. However, it is clear that moving towards a low carbon economy will impact demand for certain minerals as the market demand for the technology needed to harness renewable energy sources like solar PV increases.

To facilitate a smooth transition to low carbon technology and better prepare for the new needs of solar PV and lithium-ion battery storage, the following should be considered:

- ***The role of mineral sourcing in climate change is crucial to consider. Mineral sourcing is both a challenge due to the energy needed in the extraction, but also a necessary part of the solution in providing the supply of raw materials that are needed for the transition to solar PV technology and the grid that supports them.***

- ***The growing demand from solar PV and lithium-ion energy storage technology will likely put a strain on the current production of certain minerals. It is likely that to meet this demand, increased primary production, use of secondary reserves and innovation in the technology itself will all provide part of the solution.***

- ***There are existing human and environmental risks within the supply chains of the minerals needed for solar PV and lithium-ion batteries. If the demand for these minerals increases, it is possible that the prevalence of these risks will also grow, and they need to be better understood, and ideally prevented or mitigated.***

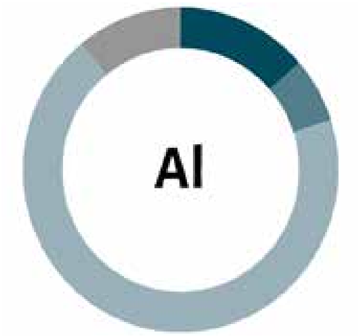
- ***The governance of the countries which produce, process and recycle the minerals impacts the possibility of disrupted supply chains and also the likelihood of human and environmental risks in the mineral supply chain.***

For more on Levin Sources, and to find out how to get in touch, see page 29.

Annex: Country Market Share for Minerals in Scope

Aluminium

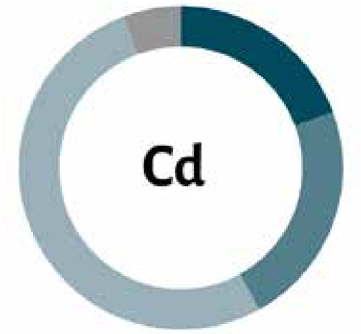
% Production Share



Country	Market Share (%)
China	54
Russia	6
Canada	6
India	5
UAE	4
Australia	3
Norway	2
Bahrain	2
USA	1
Iceland	1
Brazil	1
Saudi Arabia	1
South Africa	1
Qatar	1
Other	11

Cadmium

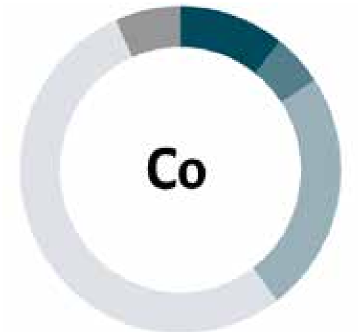
% Production Share



Country	Market Share (%)
China	31
Republic of Korea	19
Japan	8
Kazakhstan	6
Russia	6
Mexico	5
Canada	5
Peru	3
Netherlands	3
USA	2
Poland	2
Australia	2
Bulgaria	1
Other	6

Cobalt

% Production Share



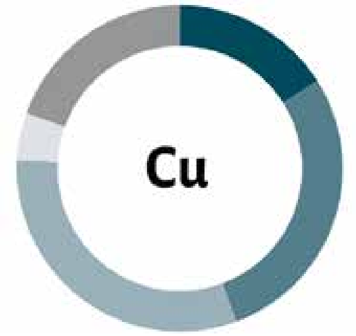
Country	Market Share (%)
DRC	54
China	6
Canada	6
Russia	5
Australia	4
Zambia	3
Cuba	3
Philippines	3
Madagascar	3
New Caledonia	3
South Africa	2
USA	1
Other	7

Good governance
Medium governance
Poor governance
Very poor governance
Unknown/cannot classify

Annex: Country Market Share for Minerals in Scope

Copper

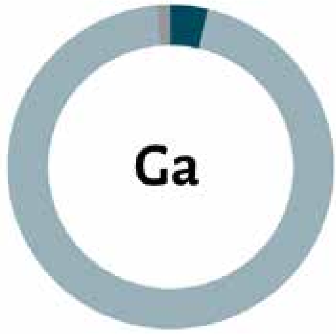
% Production Share



Country	Market Share (%)
Chile	28
Peru	12
China	9
USA	7
Australia	5
DRC	5
Zambia	4
Canada	4
Russia	4
Mexico	3
Other	19

Gallium

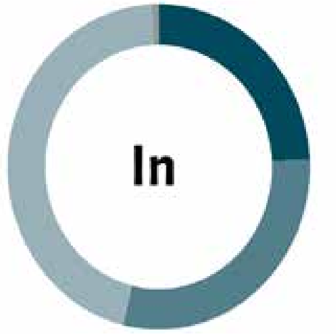
% Production Share



Country	Market Share (%)
China	92
Russia	3
Germany	3
Japan	1
Other	1

Indium

% Production Share



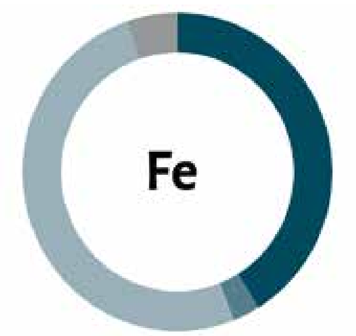
Country	Market Share (%)
China	44
Republic of Korea	30
Japan	11
Canada	10
Belgium	4
Peru	1
Russia	1
Other	<1

Good governance
Medium governance
Poor governance
Very poor governance
Unknown/cannot classify

Annex: Country Market Share for Minerals in Scope

Iron

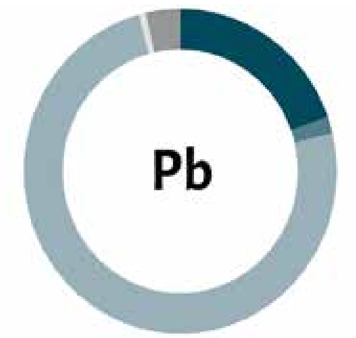
% Production Share



Country	Market Share (%)
Australia	36
Brazil	19
China	16
India	7
Russia	4
South Africa	3
Ukraine	3
Canada	2
USA	2
Sweden	1
Kazakhstan	1
Iran	1
Other	5

Lead

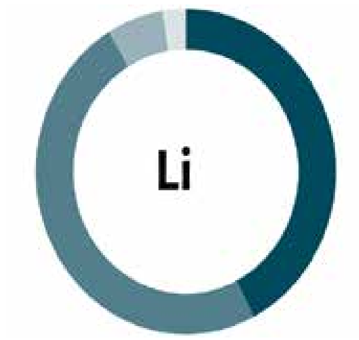
% Production Share



Country	Market Share (%)
China	50
Australia	10
USA	7
Peru	6
Mexico	5
Russia	5
India	3
Bolivia	2
Sweden	2
Turkey	2
Iran	1
Kazakhstan	1
Poland	1
South Africa	1
North Korea	1
Iceland	1
Macedonia	1
Other	4

Lithium

% Production Share



Country	Market Share (%)
Australia	40
Chile	33
Argentina	16
China	6
USA	2
Zimbabwe	2
Brazil	1
Portugal	1
Other	<1

Good governance

Medium governance

Poor governance

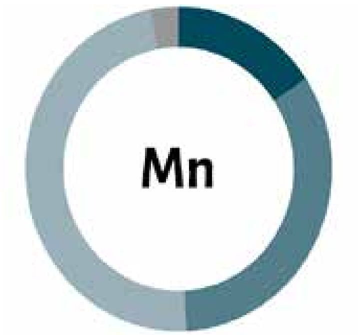
Very poor governance

Unknown/cannot classify

Annex: Country Market Share for Minerals in Scope

Manganese

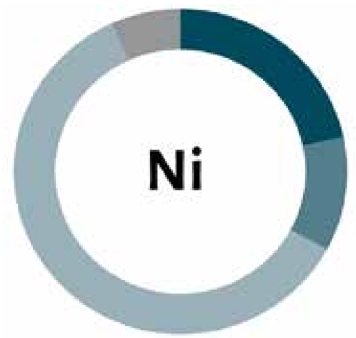
% Production Share



Country	Market Share (%)
South Africa	29
China	19
Australia	16
Gabon	13
Brazil	6
India	6
Ghana	3
Ukraine	2
Mexico	1
Malaysia	1
Kazakhstan	1
Other	3

Nickel

% Production Share



Country	Market Share (%)
Philippines	22
Russia	11
Canada	11
Australia	9
New Caledonia	9
Indonesia	7
Brazil	6
China	4
Guatemala	3
Cuba	2
South Africa	2
Madagascar	2
Colombia	2
USA	1
Other	4

Silica

% Production Share

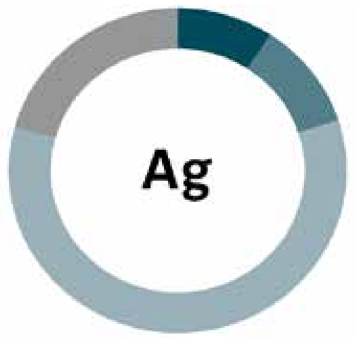
Country	Market Share (%)
China	64
Russia	10
USA	6
Norway	5
France	2
Brazil	1
Spain	1
Bhutan	1
Iceland	1
Malaysia	1
Ukraine	1
India	1
Canada	1
Other	4

Good governance
Medium governance
Poor governance
Very poor governance
Unknown/cannot classify

Annex: Country Market Share for Minerals in Scope

Silver

% Production Share



Country	Market Share (%)
Mexico	21
Peru	15
China	13
Chile	6
Australia	5
Poland	5
Russia	5
Bolivia	5
USA	4
Other	21

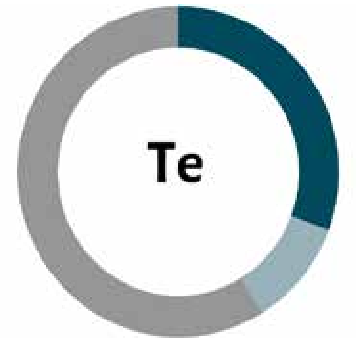
Selenium

% Production Share

Country	Market Share (%)
Japan	33
Germany	29
Belgium	9
Canada	7
Russia	6
Finland	4
USA	4
Poland	4
Peru	2
China	N/A*
Other	4

Tellurium

% Production Share



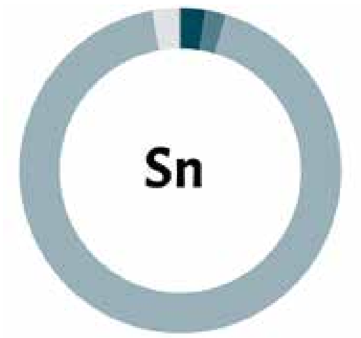
Country	Market Share (%)
USA	13
Russia	9
Sweden	8
Japan	8
Canada	3
China	2
Other	59

- Good governance
- Medium governance
- Poor governance
- Very poor governance
- Unknown/cannot classify

Annex: Country Market Share for Minerals in Scope

Tin

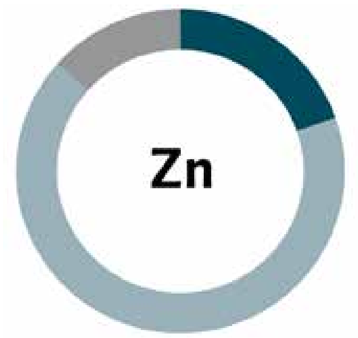
% Production Share



Country	Market Share (%)
China	36
Indonesia	20
Myanmar	12
Brazil	9
Bolivia	7
Peru	6
Australia	3
Vietnam	2
DRC	2
Malaysia	1
Nigeria	1
Rwanda	1
Laos	<1
Thailand	<1
Russia	<1
Other	<1

Zinc

% Production Share



Country	Market Share (%)
China	38
Peru	11
Australia	7
USA	7
Mexico	6
India	5
Bolivia	4
Kazakhstan	3
Canada	3
Sweden	2
Ireland	1
Other	13

Good governance
Medium governance
Poor governance
Very poor governance
Unknown/cannot classify

Levin Sources

"Our goal is to drive raw materials through systems where good governance and better business are the norm, building resilient futures for us all."

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Levin Sources is a consultancy and social venture that moves more raw materials through systems where good governance and better business are the norm.

For more than seven years, we have been at the forefront of responsible mining and sourcing, with unique expertise in issues surrounding raw material sustainability and artisanal and small-scale mining.

We are a core team of strategists, researchers, project managers, educators and communicators with multidisciplinary abilities and a collective expert knowledge in sustainable supply chains, extractives, minerals science & engineering, biodiversity and conservation, human rights and vulnerable groups, responsible business conduct and good governance.

We are proud of our global network and the complementary skills and experience of our team. We deploy these assets to find innovative and practical solutions to complex issues in mineral global supply chains.

We are trusted by the full diversity of players in the minerals system, from Fortune 500 companies and SMEs to industry associations and certification bodies to NGOs and civil society to governments in fragile states and in G20 economies.

For more information on our projects, publications, team and services, please visit us at www.levinsources.com, or click the button below.

Find out more

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