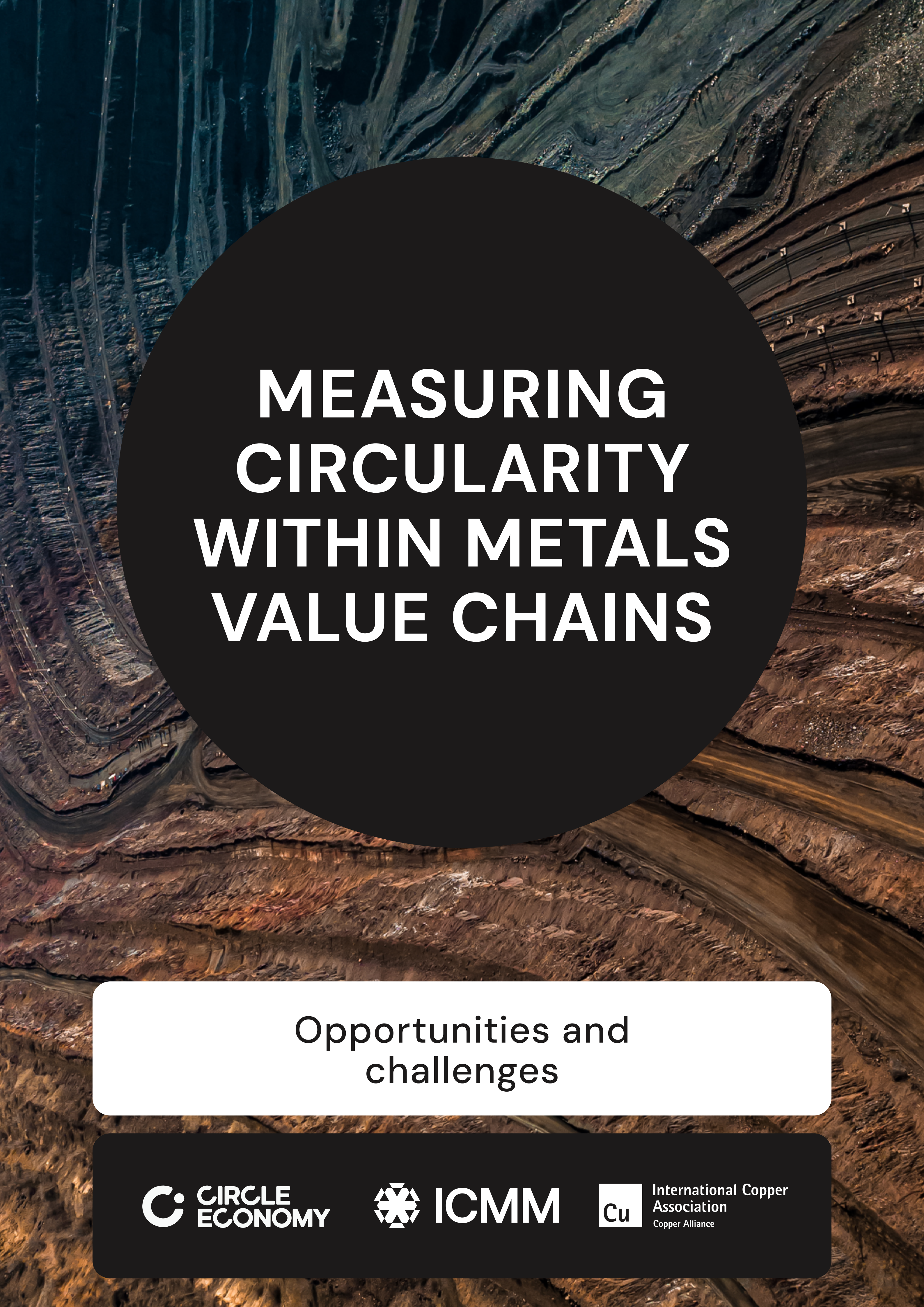


MEASURING CIRCULARITY WITHIN METALS VALUE CHAINS

Opportunities and challenges

CIRCLE ECONOMY

ICMM

International Copper Association
Copper Alliance

1 Executive Summary

The transition to a net-zero future depends on the availability of responsibly sourced metals and minerals. Whether enabling renewable energy, building sustainable infrastructure, or advancing technological interconnectedness, these resources are central to achieving our global climate goals.

Both primary mining and recovery of secondary material through recycling are important in meeting demand for metals. The mining and metals sector should embrace the full breadth of circular economy principles, encompassing both process circularity (sustainable production and operational efficiencies) and product circularity (recovery and reuse of materials). These principles provide a path forward, enabling the value chain to maximise resource value, reduce waste and build a recoverable 'urban stock' of metals.

Urban stock:

Urban stock refers to the minerals and metals in use in our infrastructure and elsewhere or discarded in society.

To accelerate progress, developing metrics to measure circularity is an important step. Such metrics would support companies in tracking and reporting on progress and unlocking the full potential of circularity to drive sustainability and efficiency.

This briefing note describes work by ICMM, the International Copper Association (ICA) and Circle Economy Consulting to begin the process to develop potential headline indicators and key performance indicators (KPIs) to measure circularity across the mining and metals industry. These indicators span different scales, from individual companies to entire value chains. These metrics are prototypes. They are designed to provide a starting point for discussion and now need to be tested and refined by mining and metals companies to ensure they capture the intended information.

By adopting ways to measure, whether these or others, the industry can contribute to the transition to increased circularity, align its practices with global sustainability goals, and ensure its inclusion in critical policy discussions. Unlocking this opportunity will depend on sector-wide collaboration, bold innovation, and robust monitoring systems to secure a just and sustainable future for society and the planet.

Circularity in the Mining and Metals Industry: Process and product circularity

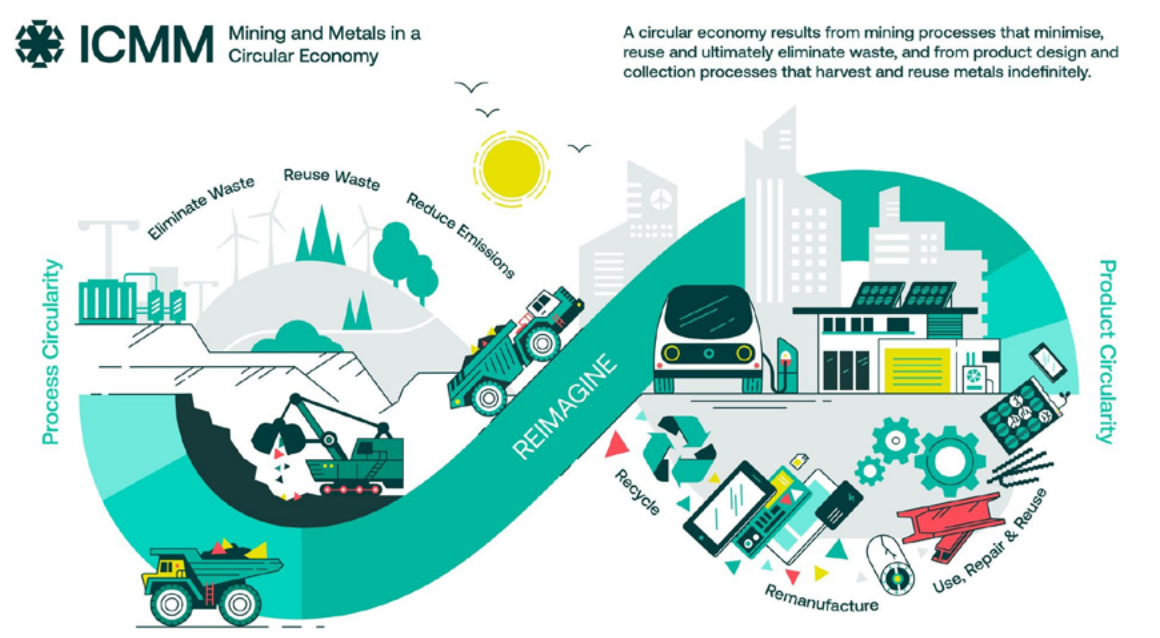


Figure 1. Mining and Metals in a Circular Economy: ICMM's model of process and product circularity

The infinity loop in Figure 1 illustrates both process and product circularity. These two loops can be shortly described as:

1) Process Circularity: Primary metal entering the market should be produced sustainably, responsibly and with circularity principles built into operations and processes. Examples include waste reduction strategies, by-product recovery, renewable energy integration, water recycling and efficiency programmes.

2) Product Circularity: Metal should be retained when products reach their end-of-life (EoL). This means that products using these materials should be designed with recovery in mind.

While process circularity represents the current focus of most mining companies, there are a range of opportunities for the industry to contribute to product circularity. For instance, different mining and metals companies are involved, to varying degrees, in efforts to support traceability, as well as collect or process secondary materials, which is dependent on various factors including commodity price, logistics of recovery, geography and other contextual factors.

2 Rising Demand for Metals and Minerals and the Need for Improved Circularity

Metals play a fundamental role in shaping modern life and are pivotal in addressing global challenges like climate change, urbanisation and technological progress. Durability and versatility make metals indispensable in advancing new energy solutions, enabling communications systems and building modern, sustainable cities.

These factors are driving an ever-increasing demand for metals and minerals. For example, by 2040 the use of nickel and cobalt is projected to grow 20-fold to support an increasingly electrified world, while total copper demand is expected to double between 2020 and 2050.[1] Meeting these requirements exclusively through new mining projects would require about 145–245 new sites just for five key energy transition materials (copper, nickel, lithium, cobalt, and graphite) by 2030.[2]

Recycling has an important role to play in meeting some of this demand by capturing the value from existing urban stock of materials, but it will need to increase in tandem with primary mining. The International Energy Agency (IEA) estimates that a growth in recycling capabilities could lower the need for new mining activity by 25-40 per cent by 2050 if national climate pledges are to be met, meaning primary mining has a continuing role to play.[3]

Whilst recycling has an important role to play, there are three main challenges with increasing the amount of recycling in the short to medium term:

1. **Insufficient supply from urban stock:** The current urban stock of materials is insufficient to meet the increasing materials needs of the energy transition.
2. **Limited accessibility of materials in use:** Many of these metals are in products that are still in use, so these materials are not available until the product reaches EoL.
3. **Design barriers to recovery:** Much of the current urban stock is not designed for efficient or effective recovery, further complicating recycling efforts.

Recycling and primary mining will both be needed to meet the demand for metal over the coming decades. This underscores the importance of operating responsibly across the value chain, balancing the need to fulfil demand with the goal of minimising harm and maximising benefits. Embedding the principles of circularity at every stage, from extraction to EoL, can help achieve these goals.

3 The Challenge with Measuring Circularity

Process and product circularity both have a role to play in responsibly supplying the materials needed for the energy transition – they are complementary rather than competing. To drive progress, it is useful to be able to measure the current state of circularity.

ICMM and ICA have worked with Circle Economy Consulting to map the current metrics landscape for circularity to understand opportunities for developing a measurement framework for the mining and metals industry to help accelerate action in support of both process and product circularity.

Through this work it became clear that there is no singular metric which can capture circularity in metals value chains. Measuring the impact of product and process circularity requires different indicators, and the diversity of business models also requires flexibility in the selection of appropriate KPIs.

Recycled Content: An illustration of the challenges of using a single metric to measure circularity

Recycled content is a common indicator used in current policy and voluntary frameworks. It is a useful metric to incentivise metal recovery and recycling in some value chains and has been taken up by policymakers looking to increase their national levels of circularity and by downstream companies aiming to demonstrate their commitment to the circular economy.

However, using this singular metric as a shorthand for wider circularity does not present the full picture. A recycling economy is not equivalent to a circular economy. The growing stock of metals for our growing digital and renewable industries requires increased primary supply alongside recycling. There is a need to both focus on securing the recyclability of the growing stock alongside continued focus on current recycling efforts.

Therefore, recycled content might be one useful metric to understand progress in the recovery of metals, but it should be used in combination with a wider suite of metrics that also focus on other aspects of circularity, including process circularity, and alongside an understanding of metals production and other drivers that may impact source material selection.

4 Developing Potential Indicators for Mining and Metals

In developing indicators at different scales, Circle Economy Consulting developed six criteria to attempt to address the challenges noted above and maximise the value of the proposed indicators. These are all taken or adapted from existing frameworks, standards and publications from recognised institutes.

1. **Defining the circular economy:** Does the indicator cover both process circularity and product circularity?
2. **Relevance to different approaches to circularity:** Could the indicator be applied to companies focussing on both process and product circularity?
3. **Applicability:** Is the indicator applicable to the value chain level and the company level? Is the data available and could the indicators directly apply to other value chains?
4. **Scope:** Does the indicator have a full value chain perspective, covering both inflow and outflow, and energy use?
5. **Potential impact:** Could the indicator describe the positive (and/or negative) impacts on the environment and society?
6. **Potential to inspire:** Could the indicator be easily understood and translated into action?

From these, Circle Economy Consulting, ICMM and ICA developed an indicator framework which tries to capture the circular vision of the mining and metals industry and its value chain.

Headline indicators

The work started by looking at potential 'headline indicators', which are focussed on the entire value chain. Indicators for the entire value chain are key to enable organisations to monitor progress across the sector and allow companies with different business models and ways of improving the circular performance of the value chain to contribute to the same sector-level targets. The indicators presented below emerged from the development and subsequent analysis of a material flow analysis undertaken by Circle Economy (see Annex 1). As these indicators sit at the value chain level, they are influenced by many different actors at different stages. Therefore, measuring and tracking these indicators would most likely need to be coordinated by a third party, with Circle Economy's *Circularity Gap* reports providing an example of how this could be done.

1. Recoverable urban stock (per cent)

Metals in the urban stock need to be recoverable to meet future metal demand. This metric would capture how much of the materials required for the energy transition is in use in some capacity and can be recovered in the future. Ultimately, it will allow tracking of progress towards the goal to grow the proportion of urban stocks which are recoverable.

This urban stock should include minerals and metals in current use in our infrastructure and elsewhere, for example those held in active renewable energy technologies. Further research is required to develop a robust methodology for this metric, as there are likely to be significant uncertainties in any estimates. Additionally, this metric will need to be revisited over time, as something may not be economically viable to recover now but could be in the future depending on market dynamics.

2. Total waste intensity (t/MW/yr)

The industry must mitigate waste production in its operations and explore opportunities to support efforts to do so across the value chain through initiatives to reduce, redesign, reuse and recycle. This metric would measure the total waste generated across the value chain for every additional megawatt (MW) of renewable energy capacity produced. In other words, it answers the question 'For each MW of capacity installed this year, how much waste was generated?'. This metric focusses on metal used for renewable energy creation but could be adjusted for use in different value chains. This indicator supports the goal to minimise waste production along value chains. More work would be needed to refine this indicator, as for some commodities it would be overwhelmingly dominated by tailings and waste rock which might mask progress made in other areas.

3. Circularity metric (per cent)

Aligned with the goal of maximising the circularity of metals and minerals, this metric would measure the proportion of secondary material use relative to total material consumption. Using the methodology from the global *Circularity Gap* reports[4] published by Circle Economy, this metric demonstrates the percentage of circular material used annually in producing, for example, solar panels or wind turbines, supporting the goal to increase the inflow of circular content in key value chains. Similarities exist between the methodology used by Circle Economy and the Circular Material Use Rate indicators that are often used by national statistical bureaus. Care needs to be taken with this metric when applying it to specific value chains that it is not simply displacing secondary recovery from a different value chain rather than seeing an overall increase in the volume of secondary material being recovered.

Potential KPIs: Individual business metrics

Whilst headline indicators are useful for measuring progress across a whole value chain, it is key that individual companies have KPIs they can track to understand their part in supporting to value chain wide approach. The following five suggestions serve as a useful starting point for companies seeking to demonstrate their progress in both process and product circularity.

These metrics are a starting point for discussion and have not yet been tested by companies – each has challenges which are highlighted below. For these reasons, the metrics should not be taken as ready to use – more work is required to test and refine the metrics. It is also likely that no company would use all five metrics. The selection of metrics by a company would depend upon their individual balance of process and product circularity and could also be influenced by commodity.

1. Waste generation (T/T)

Aim: Measures the waste generated per tonne of ore produced. Highlights reductions in specific waste streams at mine sites, including tailings, relative to the output of metal products.

Importance: Among other innovations, mining companies are increasingly using novel technologies and adopting best practices to reduce waste. Innovation in on-site operations is key to improving process circularity.

How: Rather than reporting on waste production in general, this metric is best used within (a) well-defined scope(s), for example, for assessing reductions in tailings production or hazardous waste streams. Allocation methods based on revenue would distribute waste across various commodities coming from the same ore. Reporting should focus on the waste production per unit of product produced, rather than absolute waste volumes. To account for differences in the value of minerals and other products, companies could also report on waste produced per revenue generated. Clear definitions are needed on the units of measurement, as there are different metrics used e.g. tonnes of concentrate, tonnes of cathodes etc.

Further considerations with this metric: Contextual information is crucial for this metric. Tailings and waste rock will make up an overwhelming majority of the waste at many mine sites, and so companies may wish to measure this metric twice, once with these included and once without, or to apply this metric on specific waste streams individually to provide enough context. Ore grades must also be factored in, as declining ore grades means more tailings for the same amount of output. This is a particular challenge for copper, where ore grades are generally declining and even at the same site, this metric might appear to get worse over time despite efforts by companies to divert tailings from storage. Therefore, companies may wish to explore adjusting this metric to account for changing ore grades.

Expected user: Mining and metal companies pursuing process circularity through operational improvements.

The challenge with comparing commodities

Metrics should not be compared from metal to metal due to the differences in their natural attributes. Ore grade is a key example of this, with current deposits of copper containing around 0.2–0.8 per cent copper[5], compared to iron, where ore grades can be around 60 per cent.[6] As a result, the waste production of copper compared to iron is much higher and comparison between these two metals can be misleading.

	Steel	Copper	Aluminium
Tailings (kT)	7,955	19,213	2,127
Processed ore (kT)	6,458	157	730
Ton of waste per ton of ore	**1.2**	**122.5**	**2.9**

Table 1. Demonstrating tailings production differences between varied commodities

Rather, the ambition should be to promote improvements over time in metrics at an individual mine or company level, accounting for the specific attributes of the site and the commodity being mined.

2. Share of renewable energy or electricity consumption (per cent)

Aim: Demonstrate the share of renewable energy or electricity used in mining and processing operations at site-level.

Importance: The use of renewable energy is widely considered to be a prerequisite for a circular economy. This indicator highlights reductions in emissions coming from power use, aligning with net zero targets.

How: Report the proportion of renewable energy or electricity consumed at a mine site compared to total energy consumption. The definition of renewable energy or electricity should be made clear, including whether it includes biofuels for example.

Further considerations with this metric: Progress against this metric will be heavily influenced by jurisdiction. In certain countries or regions, grids may already be largely or entirely renewable, and so a higher score here will be more easily achieved without effort from the company. In other places, and particularly at remote operations, renewable power may be much harder to source. Therefore, it should be considered within the context of the operation's location.

Expected user: Mining and metal companies pursuing process circularity through operational improvements. This metric could also apply to smelters, recycling facilities and other sites.

3. Material recovery from legacy tailings (per cent)

Aim: Measure the value derived from legacy tailings and the volume of tailings re-treated.

Importance: The massive volume of legacy tailings are deposits of potentially valuable metals, particularly where past extraction methods were less efficient so the remaining ore grade in tailings remains high. Recovery of these residual resources can be economically attractive for mining companies while enabling them to contribute to product circularity and other sustainability goals.

How: Report two metrics: 1) material recovery from legacy tailings relative to the portion of relevant commodities present in the tailings, and 2) amount of tailings treated relative to the total volume of legacy tailings, in the scale of millions of cubic kilometres. These metrics combined reflect progress in capturing additional value from tailings and mitigating environmental and social risks presented by legacy tailings.

Further considerations with this metric: No two tailings deposits are the same – each has a different composition. This means that some tailings have a higher recoverability potential than others. Additionally, legislation around recovery of tailings varies by jurisdictions – in some cases it is considered a hazardous waste and so it can be challenging to access the permits necessary to allow recovery.

Expected user: Mining and metal companies aiming to drive product circularity through legacy stock.

4. Recovery potential of metal added to stock (per cent)

Aim: Report on contributions to creating a circular urban stock.

Importance: Ensuring that metals added to the urban stock are recoverable is critical for future circularity. Mining companies can provide enabling services, helping other actors in the value chain recover metals. Examples of enabling services include traceability services and advanced metal sorting services.

How: Measure the metal recovery facilitated by a company (e.g. tracing through digital product passports) relative to market size. Market size is defined as the annual global addition to urban stock. This way, this metric resembles the global market share of a company for this particular business model.

Further considerations with this metric: This metric will be influenced by commodity – the recovery of some commodities is harder than others, especially where metals are alloyed or used in very small quantities. Jurisdiction can also have an influence with regulations either supporting or hindering recovery of materials.

Expected user: Mining and metal companies contributing to urban stock growth, particularly those diversifying into additional service offerings to customers and other value chain actors.

5. Actual recovery of EoL metal (per cent)

Aim: Demonstrate a company's role in recovering EoL metal.

Importance: Growing urban stock offers significant potential for EoL recovery. Mining companies may be able to diversify into services focusing on recovering metals and other resources from post-consumer material flows, supporting product circularity by closing the metal loop.

How: Measure the amount of metal recovered by a company in relation to market size. This metric applies beyond the energy sector to all global urban stock applications.

Further considerations with this metric: Data availability and quality may be an issue with this metric.

Expected user: Mining and metal companies diversifying to product circularity through urban stock focussed operations.

6. Conclusion and next steps

What can be measured can be managed. Circle Economy Consulting, ICMM and ICA's attempts to develop an indicator framework reveal the complexities of measuring circularity across value chains, and within the mining and metals industry. Our work highlights that circularity is best measured using a range of metrics that a) cover both process and product circularity, b) consider the broader value chain, and c) can be appropriately selected by companies to account for their specific operation, location, and business model.

These attempts provide a foundation for tracking progress and addressing the challenges facing the mining and metals industry in maximising the value of operations, minimising waste or negative impacts, and contributing to the production of a responsibly produced urban stock of metals.

To this end, this report suggests three headline indicators and five KPIs which, with further testing and refinement, may serve as practical tools for measuring and improving both process and product circularity across scales, from whole value chains to individual companies. We hope that the indicators in this report will provide a foundation for further discussions on measuring circularity in the industry, and across broader value chains.

We also encourage policymakers to prioritise the inclusion of mining companies in circular economy strategies, ensuring that both increasing recovery of metal as well as ensuring the input into the system of responsibly mined materials are accounted for. Collaboration is essential to operationalising these metrics and ensuring the mining and metals industry plays its full part in a sustainable, equitable future.

Annex

Material flow analysis of renewable energy value chain

To understand aspects of circularity that indicators may wish to demonstrate, a material flow analysis was undertaken by Circle Economy Consulting to understand the movement of value and the production of waste across renewable energy value chains, specifically wind turbines and photovoltaic cells. This analysis stretched from extraction to use and dismantling, aiming to understand which indicators could be suitable to measure circularity across the whole value chain.

The results, outlined in Figure 2 on the next page, show three main factors that should be considered when attempting to increase levels of circularity in renewable energy value chains.

1. Mining waste dominates waste production across entire value chains

Tailings and waste rock are by far the largest waste flows through the value chains. Tailings account for 31 per cent and waste rocks account for 68 per cent of the total waste produced which adds up to 99 per cent of the entire value chains. Indicators must be attentive to this significant waste stream when attempting to measure circularity. For certain metrics, companies may wish to either exclude waste rock and potentially tailings from the assessment so focus lies more on other material flows, or they may wish to present the metric twice – once with and once without these waste streams.

2. The availability of secondary resources is limited

Regardless of current efforts to increase recycling, relatively little secondary input is available, via reuse, remanufacturing and recycling. Recycled inputs represent three per cent of the assessed value chains. Increasing the share of recycled content, as well as responsible practices within the recycling industry, should remain a focus but will be limited by the fact that the demand of the assessed metals far outweighs the potential supply of secondary materials.

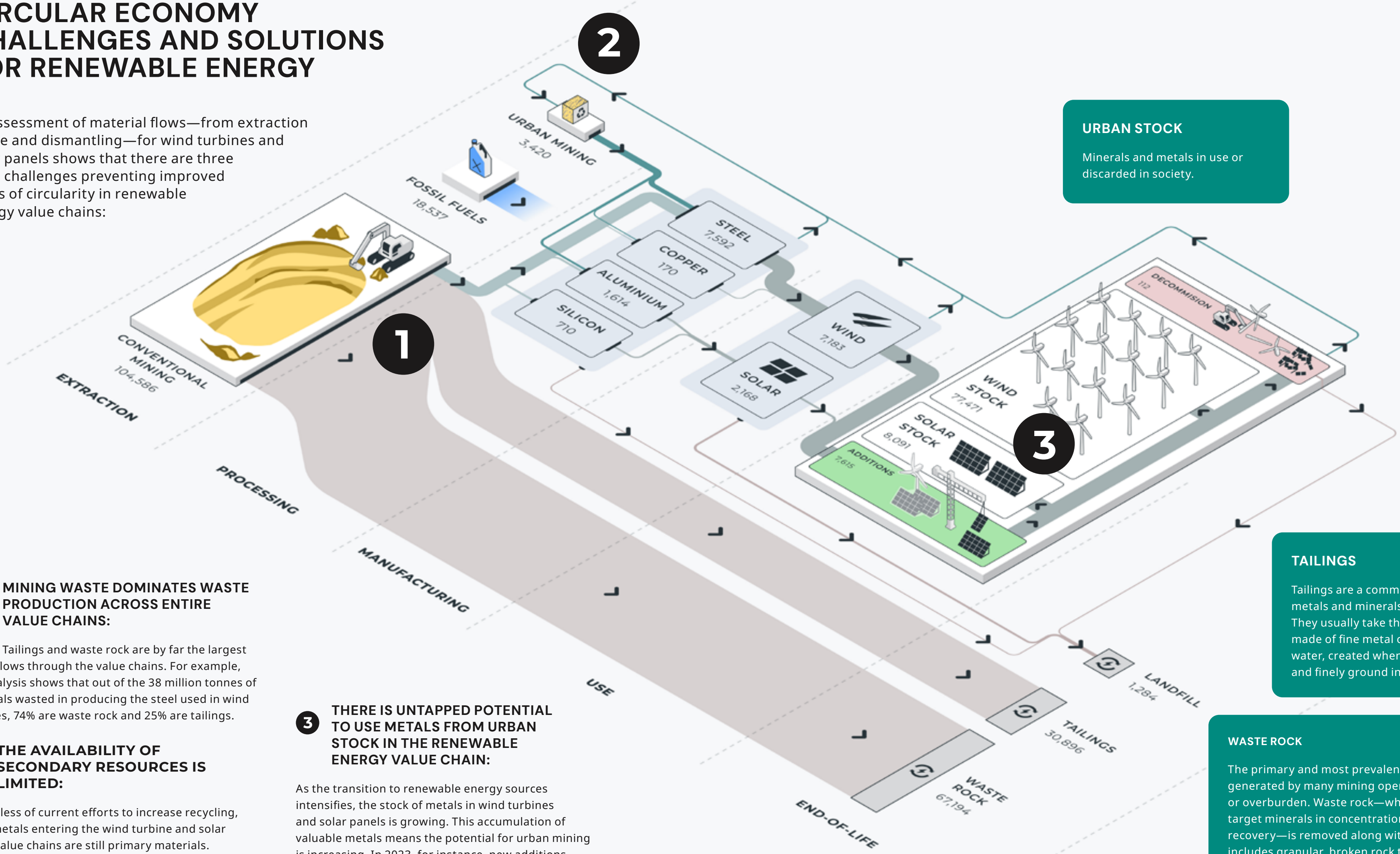
3. There is untapped potential to use metals from urban stock in the renewable energy value chain

As the transition to renewable energy sources intensifies, the stock of metals in wind turbines and solar panels is growing. We need to ensure that the system is in place to capture the value of this increasing potential of urban stock. New additions represent 8.9 per cent within just one year to the current stock of metals in the entire value chain.

Reflecting on these three factors highlights the need for circularity metrics to focus on waste reduction, notably tailings, building a secondary stock of resources, and the use of urban stock in the renewable energy value chain. These reflections were key in shaping the potential headline indicators and KPIs discussed in this report.

CIRCULAR ECONOMY CHALLENGES AND SOLUTIONS FOR RENEWABLE ENERGY

An assessment of material flows—from extraction to use and dismantling—for wind turbines and solar panels shows that there are three main challenges preventing improved levels of circularity in renewable energy value chains:



URBAN STOCK

Minerals and metals in use or discarded in society.

TAILINGS

Tailings are a common by-product of the metals and minerals recovery process. They usually take the form of a liquid slurry made of fine metal or mineral particles and water, created when mined ore is crushed and finely ground in a milling process.

WASTE ROCK

The primary and most prevalent form of waste generated by many mining operations is waste rock, or overburden. Waste rock—which consists of rock and target minerals in concentrations too low for economic recovery—is removed along with the ore. Waste rock includes granular, broken rock that ranges from fine sand to large boulders, depending on the nature of the formation and mining methods employed.

1 MINING WASTE DOMINATES WASTE PRODUCTION ACROSS ENTIRE VALUE CHAINS:

Tailings and waste rock are by far the largest waste flows through the value chains. For example, our analysis shows that out of the 38 million tonnes of materials wasted in producing the steel used in wind turbines, 74% are waste rock and 25% are tailings.

2 THE AVAILABILITY OF SECONDARY RESOURCES IS LIMITED:

Regardless of current efforts to increase recycling, most metals entering the wind turbine and solar panel value chains are still primary materials. Relatively little secondary input is available, via reuse, remanufacturing and recycling, for example. We estimate recycled inputs represent just 8.3% of aluminium in the wind turbine value chain, for example.

3 THERE IS UNTAPPED POTENTIAL TO USE METALS FROM URBAN STOCK IN THE RENEWABLE ENERGY VALUE CHAIN:

As the transition to renewable energy sources intensifies, the stock of metals in wind turbines and solar panels is growing. This accumulation of valuable metals means the potential for urban mining is increasing. In 2023, for instance, new additions represented 11% of the copper currently installed in the stock of solar panels, according to our analysis.

Figure 2. The material flow analysis for solar and wind value chains, suggesting three key areas with opportunities for increased circularity

Endnotes

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3. Recycling of Critical Minerals, IEA, 2024
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