



# Material Impact Profiles

**Which materials to prioritize for a 100 percent recycled and renewable supply chain**

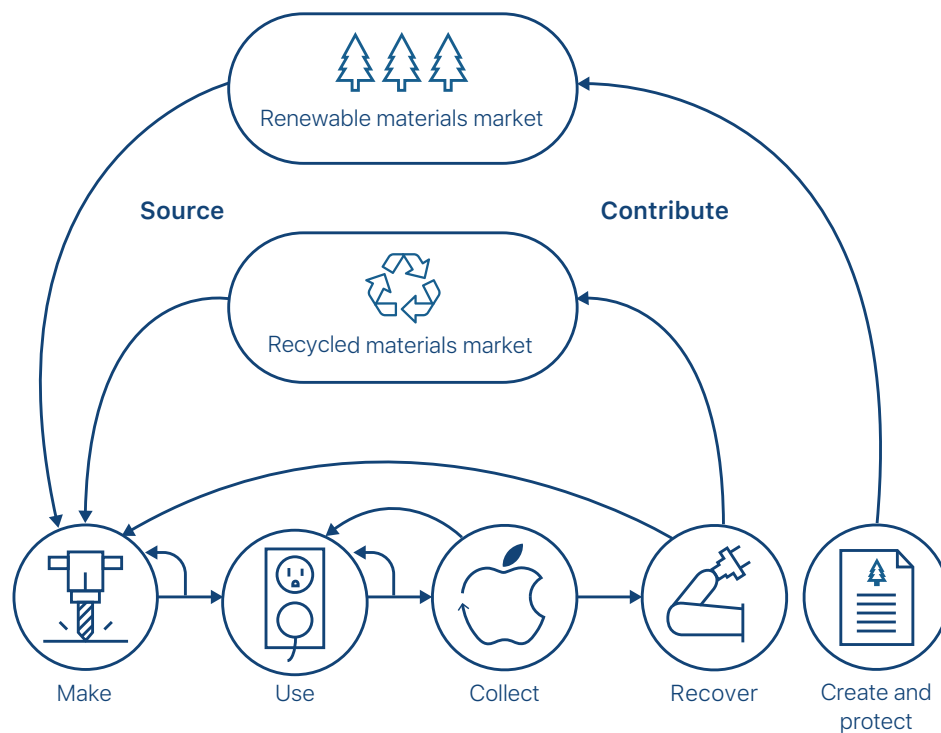
2019

## Our Ambition: An Overview

At Apple, we believe we have a responsibility to leave the world better than we found it. So we established three environmental priority areas where we believe we can make the greatest difference:

- Reduce Apple’s impact on climate change by using renewable energy, driving energy efficiency in products and facilities, and addressing the entire lifecycle of all our products and accessories.
- Conserve precious resources by using materials efficiently, using more recycled and renewable content in products, and recovering material from products at the end of their life.
- Identify, develop, and utilize safer materials in products and processes.

We already have programs in place to ensure that the materials we use in our products are sourced responsibly. We apply strict standards and internationally accepted frameworks, such as the Organisation for Economic Co-operation and Development (OECD) due diligence guidance, to drive progress and protect people in our supply chain. Now, to protect the Earth’s finite resources, we’re also challenging ourselves to one day end our reliance on mining altogether. In the spring of 2017, we made public our commitment to using only recycled and renewable material in our products. It’s an ambitious goal that will require years of collaboration across Apple teams, our suppliers, and recyclers—but our work is already underway.



**Figure 1: How we define a circular supply chain**

The main principles underlying our goal are to make products more efficiently, make them durable, and make them using only recycled or renewable material. And then when necessary, put material back onto the market to be used by us or others. For finite materials such as aluminum or steel, this means both sourcing recycled material and recycling scrap and end-of-life products into raw material for Apple or others to use again. For renewable materials such as the wood fiber in our packaging, our focus is on both responsible sourcing and regeneration of supply that either Apple or others could use.

We have a long way to go, and there are many challenges to our ambition. Technical and economic hurdles can prevent efficient recovery of materials to the same quality as the original primary source. In many cases, achieving our goal will require developing new recovery technologies, new materials, and new ways of doing business.

## Prioritizing Materials

Our supply chain is complex and we use a vast number of unique materials in our products. So we needed a way to identify and prioritize which raw materials would provide the greatest benefit if the majority of global production moved to a recycled and renewable supply base. In 2014, when we first reviewed existing methodologies for assessing impacts, we found that most focused only on the potential for a supply disruption and subsequent negative consequences.

Knowing that more was needed, we worked with Oeko-Institut e.V. to develop Material Impact Profiles (MIPs), which quantify not only the generalized supply impacts of a mined material but also the environmental and social impacts. Using publicly available data, we comprehensively evaluated impacts in the value chains of 45 elements and raw materials commonly used in consumer electronics. We then weighted these MIPs by the quantity of material Apple uses to identify those materials where Apple likely has the best ability to have a positive impact on the planet. Finally, in addition to the weighted score assigned to each material, we considered additional qualitative factors, like whether a material represents unique opportunities for new supply chain models or is significant to the customer experience—such as the glass they touch or the paper packaging they open.

Through this process, we identified a short list of materials on which to focus our initial efforts, and have active projects in aluminum, cobalt, copper, glass, gold, lithium, paper, plastics, rare earth elements (neodymium, praseodymium, dysprosium), steel, tantalum, tin, tungsten, and zinc. We recognize that this transition to 100 percent recycled and renewable material will take many years, and will require entire industries to join in the effort. And as we strive toward this goal, we will continue our work to ensure that materials are sourced and processed in a manner that meets our strict requirements while we also work to protect the rights of those in our supply chain.

## Existing Methodologies

In 2014, during the early phases of the project, Apple evaluated multiple publications on materials' criticality and impacts in material supply chains (see [Appendix A](#)). Various methodologies already existed for measuring the relative importance of raw materials, with some following and others building on traditional supply risk assessments. Governments, for example, had created methods for identifying materials key to national economies and at risk of supply shortages.<sup>1,2,3</sup> Organizations also created sector- and industry-specific assessments for materials that were being used in new ways, such as the U.S. Department of Energy's evaluation of key materials in clean energy technologies.<sup>4</sup> In addition, other companies had developed methodologies targeted to their specific business interests.<sup>5,6</sup> Across methodologies, organizations typically determined a material was "critical" if its supply might be disrupted and if that disruption would significantly impact the organization.<sup>7,8</sup>

Two key groups have looked beyond supply risks in assessing materials. In 2017, Fairphone partnered with The Dragonfly Initiative to prioritize materials for sustainable sourcing efforts, and focused on environmental risks in the assessment.<sup>9</sup> And in 2018, Drive Sustainability, the Responsible Minerals Initiative, and The Dragonfly Initiative released the report *Material Change*, which considers the supply,

environmental, and social impacts of materials.<sup>10</sup> We are encouraged by the increasing engagement on this topic and hope to see further adoption of such initiatives across the industry.

For Apple, assessing only the risk to global supply was not enough. We worked with our partners to create an assessment that includes not only impacts to supply, but also environmental and social impacts throughout the global supply chain. This assessment is designed to evaluate the global landscape, not risks specific to Apple’s supply chain or impacts of sourcing practices on local communities. Our aim was to make these assessments useful to others; shifting to a 100 percent recycled and renewable supply chain requires a global perspective, as we need to shift entire industries to a new way of doing business. It is important to note that these MIPs are not a substitute for the direct assessments of opportunities to improve a company’s specific raw materials sourcing practices or their direct impact, and do not replace evaluation of other factors, such as human rights risks in a specific supply chain. Companies must still perform their own due diligence on their individual supply chains.

H																		He
Li	Be										B	C	N	O	F		Ne	
Na	Mg										Al	Si	P	S	Cl	Ar		
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg								
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu				
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr				

**Figure 2: List of current elements in scope of the methodology (blue)**

## Our Methodology

The MIPs combine three primary focus categories—supply, environmental, and social impacts. Each category is composed of multiple indicators that are used to evaluate 45 mined elements and materials commonly used in consumer electronic products (Figure 2), including those materials (e.g., lead and mercury) that Apple has already restricted or removed from our products.<sup>11</sup> This forms an overall picture of the aggregate impact associated with global extraction and production of each material. We then combine the MIP results with the mass of each material used in our products to help determine our priorities and strategy. The list of materials assessed is reviewed annually and the data for each indicator is updated regularly to ensure that the MIPs reference the most current data sets available. All references, reports, and databases underlying the MIPs can be publicly accessed or licensed, and are detailed in [Appendix B](#).

### Supply Impacts

To better understand the impacts associated with the availability of materials, we evaluated each material across seven supply indicators. Existing scientific literature has extensively explored risks to the supply of

metallic raw materials.<sup>12</sup> Factors that can indicate restrictions in supply include concentration of production, political risk in producing countries, and the depletion time of reserves. We used the same method to evaluate supply as the British Geological Survey (BGS) in its Risk List.<sup>1</sup> We relied on BGS material data as the primary data source, and supplemented it with data from the United States Geological Survey (USGS).

**Companionality:** *Is global production limited, especially in a way that does not respond to normal market signals?*

Certain materials are extracted mainly as a result of another material's extraction operation, so supply is less responsive to market signals. Increasing demand for the by-product material might not result in increased supply because these materials do not drive the operational planning and production of the mine. Research has shown that supply is sometimes limited by a lack of an incentive to improve recovery of these materials from mining operations, and not because suppliers are unresponsive to a change in price.<sup>13</sup> The companion metal fraction measures how much of the material is mined as a by-product globally,<sup>14</sup> and serves as a proxy for the potential for unpredictable supply disruption because the material is a by-product.

**Geographic Production Concentration:** *Is global production concentrated in only a few countries, or spread across many regions?*

Materials concentrated in fewer geopolitical areas have a greater probability of supply disruptions. As the MIPs focus on impacts related to extraction of raw materials, we chose to look at the countries where ore is extracted and purified. We did not include where the ore is processed through operations such as smelting, refining, and production of semi-finished products, many of which are common to both linear and circular material flows. As an example, the data set for aluminum highlights Australia as the main producing country (32 percent of global bauxite extraction) and not China (where the majority of bauxite is refined into alumina and aluminum). The indicator is assessed by quantifying how much of a material is produced by the top three producing countries, as a percentage of the global market.

**Reserve Concentration:** *Is the total amount of reserves concentrated in only a few countries?*

The concentration of global production does not necessarily match the concentration of reserves (raw ore that can be economically extracted with current technology). To account for this, in addition to production concentration, the MIPs include an indicator covering the concentration of overall reserves, which is assessed by quantifying how much of the proven reserves of a material are within the top three reserve holding countries, as a percentage of the global reserves.

**Global Recycling Rate at End of Life:** *To what extent is the material currently being recycled?*

Recycling can represent a circular supply of material if done correctly, and a higher overall recycling rate can represent a decreased concern for future supply. The Global Recycling Rate at End of Life indicator uses data from the United Nations Environmental Programme and describes the worldwide rate at which a material is recycled, regardless of application and industry.

**Substitutability:** *If the material becomes unavailable, is there a technically viable alternative?*

Substitutability captures the ability of a material to be substituted by other (less critical) materials without compromise to material properties needed for a given application. Those materials with substitutes represent less concern. The indicator follows an assessment from the European Commission.<sup>15</sup>

**Political Stability in Producing Countries:** *What is the potential for a political event to significantly disrupt global supply?*

Consistent with the BGS Risk List, the supply category includes an indicator to evaluate political stability. Weak public governance (e.g., public corruption, inadequate rule of law, or lack of regulations), and lack of governmental capacity to build and sustain economic, social, and political stability can trigger supply constraints of raw materials. This indicator relies on the political stability data set from the World Bank database for governance indicators. Because production may be unequally distributed among the top three

countries, political stability with respect to a material is assessed by an average of the political stability of the top three countries, weighted by each country's share of production.

**Political Stability in Reserve Holding Countries:** *What is the potential for a political event to significantly disrupt global supply?*

Similar to the indicator for producing countries, this indicator assesses the potential of political disruption in the overall world reserves, regardless of whether those regions are currently producing. It is assessed by an average of the political stability of the top three reserve holding countries, weighted by their proportion of the world reserves.

## Environmental Impacts

Apple believes environmental impacts are an important factor to include in our assessment. While earlier assessments had categorized environmental impacts as a mere subset of supply impacts, environmental considerations are evolving, and recent studies have highlighted that environmental impacts should be a standalone component of a material's importance (see [Appendix A](#)).<sup>8</sup> The Yale analytical framework features environmental implications as a third dimension of criticality, equally important as supply impacts and vulnerability to supply restriction.<sup>16</sup> More recently, the OekoRes method for evaluating the environmental hazard potential (EHP) of the current global primary production of a raw material features 11 indicators, including use of toxic substances in processing and mining operations and risk of natural hazards.<sup>17</sup>

When we set out to complete the first set of MIPs in 2014, existing assessments did not adequately capture the environmental impacts of raw material supply chains, so we identified seven life cycle and local pollution impact indicators to evaluate. While the main objective is to capture prevalent environmental impacts of the mining and extraction sector, the availability and robustness of systematic data sets remain a limiting factor.

**Geochemical:** *What is the potential for pollutants or hazardous materials to be released into the environment?*

The first environmental indicator consists of three sub-indicators related to the geochemistry of the mineral host ore: Is the extraction process associated with heavy metals, radioactive substances, or preconditions for acid mine drainage? These three sub-indicators are equally weighted and grouped into one score, assessing the potential release of hazardous tailings into the environment. Tailings are a waste stream generated during mining and ore processing. While most large-scale processing facilities have management systems and storage facilities in place, sites with insufficient tailings management practices exist in a number of countries worldwide and a potential remains for accidental release of tailings containing pollutants such as cadmium, mercury, lead, thorium, uranium, and acidic compounds into the environment.

**Chemical Usage:** *To what extent are hazardous chemicals used in production?*

The second indicator we included in the environmental assessment captures the impacts associated with the use of chemicals during the initial stages of processing and production of the mined ore. The potential for pollution due to the uncontrolled release of process chemicals is a widespread consideration. However, the hazards of the process chemicals vary significantly from material to material and, in some cases, even across production methods for a given material. Therefore, the severity of the impact for a given material was determined by the hazardous nature of the chemicals used in its processing. In cases where different processing methods result in varying degrees of hazards, the score is allocated based on the most common method; if multiple methods are commonly used, the score reflects the most severe method.

**Life Cycle Impacts:** *How carbon- and water-intensive is the material?*

Adding to the site-specific pollution impacts of the geochemical and process chemical usage, this third indicator includes two sub-indicators that cover life cycle metrics—specifically, greenhouse gas (GHG) emissions and water consumption. These sub-indicators are measured throughout the processing of the material, from extraction through refining and processing into a raw material for use in product manufacturing.

Both GHG emission and water consumption are equally weighted into a single score. The GHG emission and water data are drawn from life cycle assessment (LCA) databases (GaBi and ecoinvent) and journal articles. We chose the data source for individual materials based on the comprehensiveness of the database across materials for the given metric, geographic and temporal resolution, alignment with Apple product and corporate LCA methodology, and reliability of the underlying life cycle inventory study. In addition, the water scarcity of producing regions is also taken into account, since consuming a moderate amount of water in an arid region may represent a greater negative impact than high consumption in an area with plentiful supply.

**Specific Recyclability:** *When used in consumer electronics, how recyclable is the material?*

The fourth indicator in the environmental category is related to the specific recyclability of the material once used in consumer electronic equipment. Specific recyclability describes the likelihood that the material will be recovered from electronic waste (e-waste), given standard separation of relevant components during the pre-processing stage, as well as the availability of dedicated smelting and refining processes capable of recovering the material. This indicator is fundamentally different from the Global Recycling Rate at End of Life indicator in the supply category of the assessment, which takes a broader global view at the percentage of the material recycled from all waste streams and not e-waste alone. For example, tungsten is recycled at a rate of 10 to 25 percent globally but is not recycled from electronics in standard e-waste recycling processes. In contrast, ruthenium has a similar global recycling rate but has a high specific recyclability because of its colocation with platinum and other precious metals in printed circuit boards for consumer electronics, and well-developed infrastructure for end-processing of these components and materials.

## Social Impacts

Social impacts, including human rights, are growing more prominent in materials assessments, but we did not find any methodology that would allow us to quantify and compare the potential impact of material extraction activities on a global scale across a large number of materials, although there are various efforts underway.<sup>18,19</sup> Social indicators are the most difficult to quantify. Supply chains are dynamic, as are the conditions under which materials are mined. There is often a lack of reliable or comparable data across a large number of geographies and within a material supply chain itself. The social indicators in the MIPs include the prominence of artisanal mining, the potential for child or forced labor, and the level of corruption and conflict. These indicators do not replace the need for rigorous due diligence within one's own supply chain. Quantifying social impacts is also difficult because such indicators may not sufficiently account for the lives of people living or working in certain conditions. The indicators do not take into account the availability of alternative livelihoods or other factors that may influence whether individuals mine. Beyond these MIPs, our supply chain practices are informed by our rigorous due diligence, insights from third-party expert stakeholders and independent civil society voices, and country and specific mining community data.

**Artisanal Mining:** *To what extent does the global industry rely on artisanal mining of the material?*

This indicator represents the share of global production dependent upon the prevalence of artisanal-scale mining (ASM). While large-scale mining (LSM) is not free of social impacts, LSM enterprises may be more easily monitored than ASM for certain risks. However, millions of people around the world rely on artisanal and small-scale mining for basic livelihoods, and ASM production may be a significant source for a particular commodity.

This indicator is difficult to quantify across all materials. For those materials where no data was available, Oeko-Institut developed economic models to test whether the lack of data was simply due to low levels of artisanal activity (and therefore low interest in quantification by the community). The premise is that artisanal mining takes place if there is a reasonable return expected from mining the ore. It was found that, for materials with no information on share of artisanal mining, the available ore grades or market prices (or

both) were too low for artisanal-scale mining to be economically viable—and so those materials were given a low score. We believe this indicator can be improved, and we welcome any feedback on our methodology and additional data sets that can provide more direct quantitative measurements in this area.

**Child Labor and Forced Labor:** *To what extent is extraction of the material correlated with child or forced labor practices?*

The Child Labor and Forced Labor indicators are related to the country of origin and often to conditions specific to a particular mining region of that country. The Forced Labor indicator uses data from Walk Free Foundation and the Global Slavery Index, and the Child Labor indicator uses the UNICEF child labour database.<sup>20,21</sup> Both indicators are calculated by the total potential for such conditions from all producing countries. While imperfect, UNICEF data was selected in order to cover a broad range of materials. As in the case of artisanal mining, the Child Labor and Forced Labor indicators do not provide sufficient detail to apply to specific supply chains, and cannot replace supply chain due diligence. However, they do provide a comparison of global impacts across all materials with consistent methodology.

**Corruption and Conflict:** *To what extent is extraction of the material correlated with corruption or local conflicts?*

The Corruption indicator uses the World Bank control of corruption indicator values for the top three producing countries, weighted by their production share. The Conflict indicator relies on county-level data from the 2013 Conflict Barometer of the Heidelberg Institute for International Conflict Research, and a score was awarded based on number of countries affected.

## Scoring

Our analysis produces three scores for each material—one each for supply, social, and environmental impacts (Table 1), where a higher score represents a greater impact. The numerical values are normalized so they can be easily compared and assigned low, medium, and high rankings based on their relative impacts using a quartile analysis. These represent global impacts per unit of material extracted and are not specific to Apple's supply chain or consumption. The MIPs also provide a range of data, from sub-indicator values to qualitative background information and references, to help contextualize the rating. By gathering and organizing diverse data sets, the assessments allow for a data-driven comparison of materials.

## How We're Prioritizing Materials

After using the MIPs to calculate the scores for each material, we weight the results based on the amount of material shipped in Apple products. This weighting helps us identify materials that may not be highlighted as high impact by the methodology (such as aluminum), but are in aggregate highly impactful for Apple due to our consumption. Of course, not all impacts scale by the mass of materials consumed by Apple, but we believe this is the right place to start for our efforts. We also may separately consider human rights or other impacts. Finally, some low-scoring or non-mined materials (such as paper, glass, and plastics) may still be included as a priority due to other consideration factors such as importance to our customers.

With a list of priority materials on which to focus first, we created material-specific working groups and have active projects in aluminum, cobalt, copper, glass, gold, lithium, paper, plastics, rare earth elements (neodymium, praseodymium, dysprosium), steel, tantalum, tin, tungsten, and zinc. Each working group consists of experts from our engineering, procurement, operations, supplier responsibility, and environmental teams, and is tasked with developing a deeper understanding of Apple's specific materials supply chain and closing the loop for the particular material. And as we strive to source increasing amounts of recycled materials, we will continue to ensure that these materials are processed in a way that meets our requirements and protects the rights of all people in our supply chain.





## Acknowledgments

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For inquiries about Apple's 100 percent recycled and renewable material prioritization work, contact Ryan Maloney or email [environment-report@apple.com](mailto:environment-report@apple.com).

**Table 1: Material Impact Profiles**

Every material has some level of social, environmental, or supply impact. The table below shows the global average of 45 elements and raw materials commonly found in consumer electronics—the 2017 methodology results. It includes those materials (e.g., lead and mercury) that Apple has already restricted or removed from our products. Apple used these scores, and weighted them by our consumption of each material (not included in the table below), to inform how we prioritize our work toward our goal of using only recycled and renewable material. The values are listed here as quartiles to describe the relative impacts of each material.

Material	Supply	Environmental	Social
Aluminium	1st Q	1st Q	2nd-3rd Q
Bismuth	4th Q	2nd-3rd Q	2nd-3rd Q
Boron	4th Q	1st Q	1st Q
Cerium	2nd-3rd Q	2nd-3rd Q	2nd-3rd Q
Chromium	2nd-3rd Q	1st Q	4th Q
Cobalt	2nd-3rd Q	2nd-3rd Q	4th Q
Copper	1st Q	2nd-3rd Q	2nd-3rd Q
Dysprosium	2nd-3rd Q	4th Q	2nd-3rd Q
Gadolinium	2nd-3rd Q	4th Q	2nd-3rd Q
Gallium	4th Q	2nd-3rd Q	2nd-3rd Q
Germanium	4th Q	4th Q	2nd-3rd Q
Gold	1st Q	2nd-3rd Q	4th Q
Indium	2nd-3rd Q	4th Q	2nd-3rd Q
Iridium	4th Q	2nd-3rd Q	2nd-3rd Q
Iron	1st Q	1st Q	2nd-3rd Q
Lead	1st Q	1st Q	2nd-3rd Q
Lithium	2nd-3rd Q	2nd-3rd Q	1st Q
Magnesium	2nd-3rd Q	1st Q	2nd-3rd Q
Manganese	2nd-3rd Q	2nd-3rd Q	2nd-3rd Q
Mercury	2nd-3rd Q	2nd-3rd Q	4th Q
Molybdenum	2nd-3rd Q	4th Q	2nd-3rd Q
Natural graphite	2nd-3rd Q	2nd-3rd Q	2nd-3rd Q
Neodymium	2nd-3rd Q	4th Q	2nd-3rd Q
Nickel	1st Q	2nd-3rd Q	4th Q
Niobium	2nd-3rd Q	4th Q	2nd-3rd Q
Palladium	2nd-3rd Q	2nd-3rd Q	4th Q
Phosphorous	2nd-3rd Q	4th Q	1st Q
Platinum	2nd-3rd Q	2nd-3rd Q	2nd-3rd Q
Praseodymium	2nd-3rd Q	4th Q	2nd-3rd Q
Rhenium	2nd-3rd Q	4th Q	1st Q
Rhodium	4th Q	2nd-3rd Q	2nd-3rd Q
Ruthenium	4th Q	2nd-3rd Q	2nd-3rd Q
Scandium	2nd-3rd Q	2nd-3rd Q	2nd-3rd Q
Silicon	1st Q	1st Q	2nd-3rd Q
Silver	1st Q	2nd-3rd Q	4th Q
Sulphur	2nd-3rd Q	1st Q	2nd-3rd Q
Tantalum	2nd-3rd Q	2nd-3rd Q	4th Q
Terbium	2nd-3rd Q	4th Q	2nd-3rd Q
Tin	2nd-3rd Q	1st Q	4th Q
Titanium	1st Q	1st Q	2nd-3rd Q
Tungsten	2nd-3rd Q	2nd-3rd Q	4th Q
Vanadium	4th Q	2nd-3rd Q	2nd-3rd Q
Yttrium	2nd-3rd Q	4th Q	2nd-3rd Q
Zinc	1st Q	2nd-3rd Q	4th Q
Zirconium	2nd-3rd Q	1st Q	1st Q

# Appendix A

Existing materials assessments identified in  
Apple's literature review

Author (Year)	Goal	Scope	Supply	Environmental	Social	Vulnerability
U.S. National Research Council (2008)	Assess the U.S. non-fuel raw material supply.	Country	x			x
European Commission (2010, 2014)	Assess supply risks of raw materials critical for the E.U. economy.	Country	x			x
U.S. Department of Energy (2011)	Identify materials essential to high-growth clean energy technologies.	Industry	x			x
Zepf et al. (2014)	Assess materials critical to the energy supply chain.	Industry	x	x		x
British Geological Survey (2015)	Indicate relative risk to the supply of elements and elemental groups key to the U.K. economy.	Country	x			x
Graedel et al. (2015)	Create a methodology to quantify the criticality of metals for broad use.	All	x	x	(x) Human Health	x
Bach et al. (2016)	Integrated method to assess resource efficiency of products.	Industry	x	x		x
European Commission, European Innovation Partnership (EIP) on Raw Materials (2016)	Provide quantitative data ("Raw Materials Scoreboard") to support the goals of the EIP and monitor progress toward a circular economy.	Country	x	x	(x) Safety	x
Fairphone (2017)	Identify hotspots to prioritize materials for sustainable sourcing initiatives.	Industry	x	x	x	x
Manhart et al. (2018) Research commissioned by German Environment Agency (UBA)	Methodology to assess the EHP of primary raw materials (OekoRes I and II).	All		x		

# Appendix B

## Data sources for assessment

Supply Impacts	
Indicator	Primary Data Source
Companionability Companion metal fraction	Nassar, N. et al. (2015): Supplementary Materials for By-product metals are technologically essential but have problematic supply. <i>Science Advances</i> , April 2015, 1(3), 1-10.
Production concentration Percentage of world supply from top three producing countries	United States Geological Survey: Mineral Commodity Summaries 2017.  British Geological Survey: World Mineral Production 2010-2014. Keyworth, 2016.
Reserve distribution Percentage of world reserves in top three reserve holding countries	United States Geological Survey: Mineral Commodity Summaries 2017.
Global recycling rate at end of life Percentage of material recycled globally	United Nations Environment Programme: Recycling Rates of Metals. A Status Report. Paris, 2011.
Substitutability Potential to substitute a material	European Commission: Study on the review of the list of critical raw materials – Critical raw material factsheets. Brussels, 2017.  European Commission: Study on the review of the list of critical raw materials – Non-critical raw material factsheets. Brussels, 2017.
Political stability in producing countries Political stability of top three producing countries (average, weighted by percent of global production)	World Bank: Worldwide Governance Indicators (WGI), 2017.
Political stability in reserve holding countries Political stability of top three reserve holding countries (average, weighted by percent of global production)	World Bank: Worldwide Governance Indicators (WGI), 2017.

Environmental Impacts		
Indicator	Sub-indicator	Primary Data Source
Geochemical pollution	Concerns associated with heavy metals in ores and tailings (Pb, Cd, Hg)	Reuter, M.A. et al.: The Metrics of Material and Metal Ecology. Amsterdam, 2005.
	Concerns associated with radioactive substances (thorium or uranium) in ores and tailings	Numerous scientific reports, e.g., World Nuclear Association: Naturally Occurring Radioactive Materials (NORM). Information from website. Updated January 2014.
	Preconditions for acid mine drainage	Reuter, M.A. et al.: The Metrics of Material and Metal Ecology. Amsterdam, 2005.
Chemical usage	Use of chemicals during extraction and beneficiation	Numerous scientific reports, e.g., Schmidt, S. (2012). From Deposit to Concentration: The Basics of Tungsten Mining. Part 1: Project Generation and Project Development International Tungsten Association (ed.).
Life cycle metrics	Greenhouse gas emissions	GHG and water consumption: GaBi, ecoinvent, numerous journal articles, e.g., Nuss, P.; Eckelman, M. J. (2014): Life Cycle Assessment of Metals: A Scientific Synthesis. In: PLoS ONE 9 (7).
	Water impact index	Water scarcity metrics: Boulay et al. (2017): The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). International Journal of Life Cycle Assessment.
Specific recyclability	Recyclability of material from end-of-life electronics	Numerous scientific reports, e.g., Buchert, M. et al.: Recycling critical raw materials from waste electronic equipment. Oeko-Institut e.V., 2012.



<b>Social Impacts</b>	
<b>Indicator</b>	<b>Primary Data Source</b>
<b>Share of artisanal mining</b> Percentage of world production from artisanal mining	Numerous scientific reports, e.g., Dorner, U. et al.: Artisanal and Small-Scale Mining (ASM). POLINARIS working paper no. 19. Hannover, 2012.
<b>Forced labor</b> Potential presence of forced labor in supply chain (based on country risk)	Walk Free Foundation (2016): The Global Slavery Index, 2016.
<b>Child labor</b> Potential presence of child labor in supply chain (based on country risk)	UNICEF child labour database, May 2016.
<b>Corruption</b> Corruption potential of top three producing countries (average, weighted by percent of global production)	World Bank Worldwide Governance Indicators (WGI), 2017.
<b>Conflict relation</b> Number of countries affected by mineral-related conflict	Heidelberg Institute for International Conflict Research, Conflict Barometer, 2013.

## References

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