Observatory of **critical minerals**

2023 Report

Index

REPSOL

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Foreword

The mitigation of climate change through the energy transition is one of the central debates on the agenda of leaders around the world, due to the urgency with which it is necessary to act, as well as the profound implications of the mitigation strategies in the economic system.

The energy transition will bring, to a greater or lesser extent, a change in the paradigm from an economy based on hydrocarbons (coal, oil and natural gas) to an economy based on the exploitation of certain resources that have been called critical raw materials for the energy transition, which are basically mineral resources. The consumption forecasts for these resources in the different energy transition scenarios point to the need to substantially increase their production in relation to current capacities. In the case of certain minerals, this pressing need portends tensions between production and demand with the foreseeable effect on prices and, eventually, supply interruptions. Hence, the contentious topic of energy supply risk (the different steps needed to supply a fuel or a final energy service to end users) will partially shift to technologies and materials supply risk (the different steps needed to build a facility or install a piece of equipment, with inputs of materials, components and services involved at each stage). This shift involves a change in the paradigm of energy security, and all the strengths and weaknesses of each stage of the clean energy supply chains must be considered. Consequently, it is interesting to know the exposure to the risk of supplying critical minerals for the energy transition and the energy transition technologies that will make use of those minerals.

Foreword

The energy transition concerns everyone. Repsol, as a multi-energy producer, is no exception, and wishes to contribute to the public debate in relation to the critical raw materials. It does so through an Observatory of Critical Minerals for the Energy Transition whose first report you have in your hands. The activity of this observatory is based on the monitoring of a supply risk indicator prepared from data from public information sources of recognized solvency, such as the International Energy Agency, the US Geological Survey and the World Justice Project, so that its calculation is transparent and reproducible. This feature of the indicator has the drawback that the frequency with which it can be updated, as well as its own scope in terms of minerals and technologies analysed, are conditioned by those of the aforementioned sources of information.

Given the fact that the sourcing of critical raw materials has become a top concern for governments in the developed world, there are at least as many mineral criticality classifications as jurisdictions. Compared with them, the most innovative contribution of the Repsol observatory is that the supply risk analysis exercise does not end with the minerals, but also extends to the technologies that use them, which can be more or less intensive in their consumption.

Foreword

This first report from the observatory helps to understand what the main causes of mineral supply risk are, namely:

- The demand forecasts vs. mineral reserves,
- The concentration of the mining resources, and
- The country risk of the producing countries.

And it helps to recognize the causes of risk for the user technologies, namely:

- Their intensity of use of the different minerals, each with its own supply risk, and
- The relative cost of each of those minerals; this risk could significantly hamper the competitiveness of some technologies, the most exposed, compared to others less exposed.

Its conclusions invite reflection on the principle of technological neutrality, which should govern the action of policy makers.

Definitions and abbreviations

Definitions

Element: *substance that cannot be decomposed into simpler substances by ordinary chemical processes. Elements are the fundamental materials of which all matter is composed.*

Metal: *any of a class of substances characterized by high electrical and thermal conductivity as well as by malleability, ductility, and high reflectivity of light. Approximately three-quarters of all known chemical elements are metals.*

Mineral: *naturally occurring homogeneous solid with a definite chemical composition and a highly ordered atomic arrangement; it is usually formed by inorganic processes. In this report we refer to "minerals" instead of "elements" to favor coherence with coined terminology.*

Critical Mineral: *any non-fuel mineral, element, substance, or material that has a high risk of supply chain disruption and serves an essential function in one or more energy technologies, including technologies that produce, transmit, store, and conserve energy (Department Of Energy, US).*

Copper equivalent: *CuEq conversion used 5-year average prices for each metal. The conversion is used to emphasize the need for smaller-volume metals, such as platinum, which otherwise appear irrelevant when compared with aluminium, for example.*

Scenarios (IEA)

Announced Pledges Scenario (APS): *IEA's scenario introduced in 2021; illustrates the extent to which announced ambitions and targets can deliver the emissions reductions needed to achieve net zero emissions by 2050. The APS is currently associated with a temperature rise of 1,7ºC in 2100 (with 50% probability).*

Net Zero Emission scenario (NZE): *is a normative scenario that shows a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. The NZE scenario is associated with a temperature rise of 1,5ºC in 2100 (with 50% probability).*

Stated Policies Scenario (STEPS): *IEA's scenario designed to provide a sense of the prevailing direction of energy system progression, based on a detailed review of the current policy landscape. The STEPS is currently associated with a temperature rise of 2,4ºC in 2100 (with 50% probability).*

Sustainable Development Scenario (SDS): *IEA's scenario that outlines one potential path to 2040 to meet the objectives of the Paris Agreement through assumptions about policies aimed at increasing efficiencies and renewable energy sources to limit energy demand growth. Not used since 2021.*

Definitions and abbreviations

Abbreviations

APS	*Announced Pledges Scenario (IEA's scenario)*
CC	*Country Concentration*
Cu_{eq}	*Copper equivalent units*
DLE	*Direct Lithium Extraction*
DOE	*Department Of Energy (US)*
DT	*Depletion Time*
ESG	*Environmental, Social, Governance*
EV	*Electric Vehicle*
GDP	*Gross Domestic Product*
GHG	*Greenhouse Gas*
IEA	*International Energy Agency*
IMF	*International Monetary Fund*
IRA	*Inflation Reduction Act*
NZE	*Net Zero Emissions (IEA's scenario)*
SDS	*Sustainable Development Scenario (IEA's scenario)*
STEPS	*Stated Policies Scenario (IEA's scenario)*
REE	*Rare Earth Elements*
OECD	*Organisation for Economic Cooperation and Development*
OPEC	*Organization of the Petroleum Exporting Countries*
PGM	*Platinum Group Metals*
WEO	*World Energy Outlook*
WJP	*World Justice Project*
USGS	*United States Geological Survey*

Executive summary

The global energy system is amid a major transition to cleaner forms of energy that has accelerated since 2015, when the Paris Agreement was signed. Since then, over 100 countries representing around 80% of global GHG emissions have communicated a net-zero greenhouse gas target.

This transformation involves shifting from a hydrocarbon-intensive to a material-intensive energy system. An energy system powered by clean technologies differs from one fuelled by hydrocarbons in the fact that the former requires more materials than the latter (see Figure 1). For this reason, the deployment of a clean energy system implies an increase in demand for minerals. Those which are considered more relevant in terms of supply risk and severity of supply chain disruption have been called "Critical Minerals" (CMs)[1].

According to the International Energy Agency, an international organization monitoring critical minerals, the demand for minerals like Lithium, used for Electric Vehicles and Battery Storage, could increase by almost 20 times by 2050 in the most ambitious scenario in terms of climate policies (Net Zero Scenario). The same source estimates that Copper demand for clean energy could multiply by 3 with the same assumptions. And for other minerals, like Gallium, Vanadium or Platinum Group Minerals, with low current demand, the increase could be of hundreds of times. In this ambitious scenario (NZE), critical minerals would oust Oil as the main energy-related resource in terms of global trade value before 2050 (critical minerals would represent ~50%, versus fossil fuels ~20%).

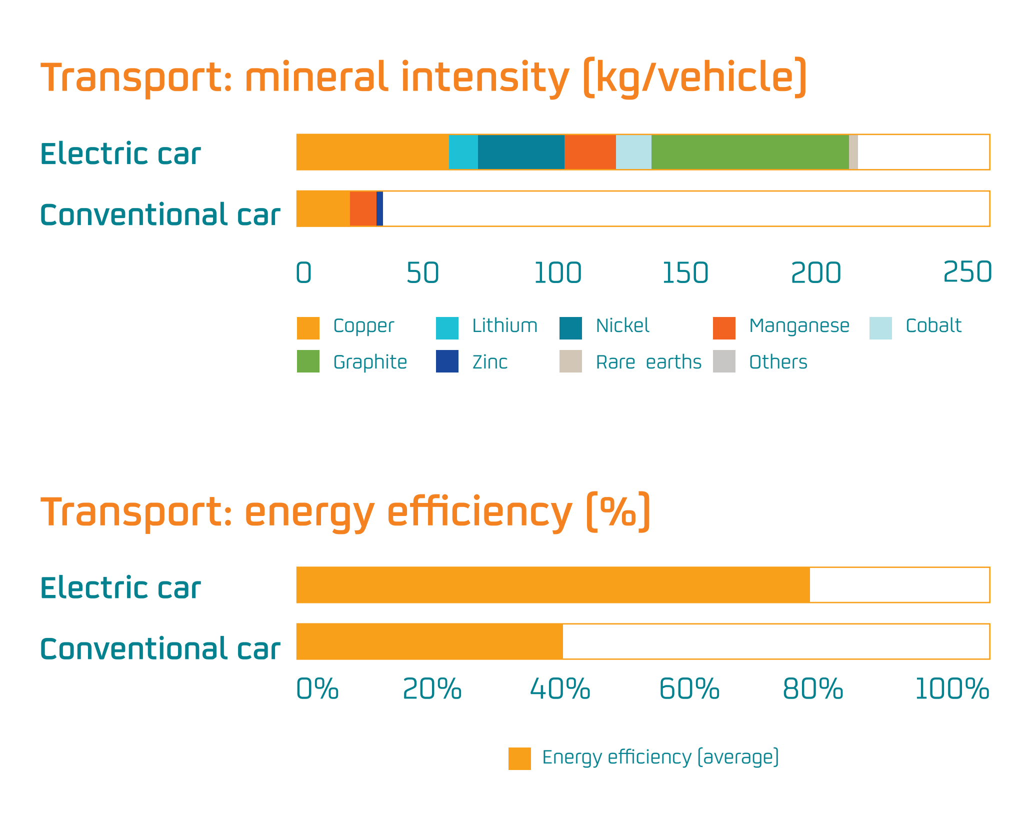


Figure 1: *mineral intensity and energy efficiency of electric vehicle versus internal combustion engine one (source: IEA)*

[1] Hereafter we will refer to "minerals" instead of "chemical elements" to favor coherence with coined terminology, despite the fact that the critical materials are the elements that are contained in the minerals.

Executive summary

To satisfy this growing demand, new investments and mining projects are needed worldwide. The IEA estimates that the average lead time for a mining project is 17 years (from discovery to production), and market tightness can appear in a much shorter period. Another constraint related to the role of Critical Minerals in the Energy Transition is the concentration of mineral reserves, primary production, processing capacity and supply chains. Mineral reserves are diversified to a certain extent, with notable exceptions, but production and processing are progressively more concentrated in a small number of countries, being China the dominant one, which poses another risk to a successful energy transition.

The growth in mineral demand creates another dilemma. For most minerals, increasing supply at the same pace as demand is expected to grow means developing reserves with decreasing ore quality. This fact translates into more energy needed per unit of mineral produced, and therefore more GHG emissions, which has an opposite effect to the one desired.

GHG emissions are not the only ESG concern related to mining and minerals. Minerals like Cobalt present 50% of reserves and almost 70% of production concentrated in the Democratic Republic of Congo (DRC). And between 15 and 30% of DRC's production is obtained from artisanal small-scale mining, which is a rudimentary and hazardous practice against international standards (USGS, Financial Times).

In this complex context, the Observatory of Critical Minerals will regularly monitor the main trends in an attempt to anticipate potential risks that could affect the deployment of one or several energy transition technologies. A methodology has been created (see APPENDIX 2: METHODOLOGY) to develop an index to understand what minerals and technologies are more exposed.

METHODOLOGY (SUMMARY)

Criticality Index is a function of:

- Mineral demand projections
- Mineral reserves
- Country risk
- Country concentration

Technology index is a function of:

- Criticality index
- Technology mineral intensity
- Mineral price

Executive summary

These indicators are based on reliable and open sources of data that get updated regularly (mainly the International Energy Agency, the United States Geological Survey, and the World Justice Project), so they can track changes through time and foresee future constraints.

Our methodology is centred on the primary production of minerals, not on the subsequent supply chain stages (see Figure 2). Thus, bearing in mind the heavy concentration of mineral refining, components manufacturing and assembly capacities in certain countries, notably China, the actual risk could be even more severe.

MAIN SOURCES OF INFORMATION

International Energy Agency:

- The role of critical minerals in clean energy transitions (2021).
- Critical minerals market review (2023).
- World Energy Outlook (annual).

United States Geological Service: Mineral commodity summaries (annual).

OTHER SOURCES OF INFORMATION

European Commission.

World Bank.

United Nations (CEPAL).

International Monetary Fund.

US Department Of Energy.

Academic papers and specialised sources.

Executive summary

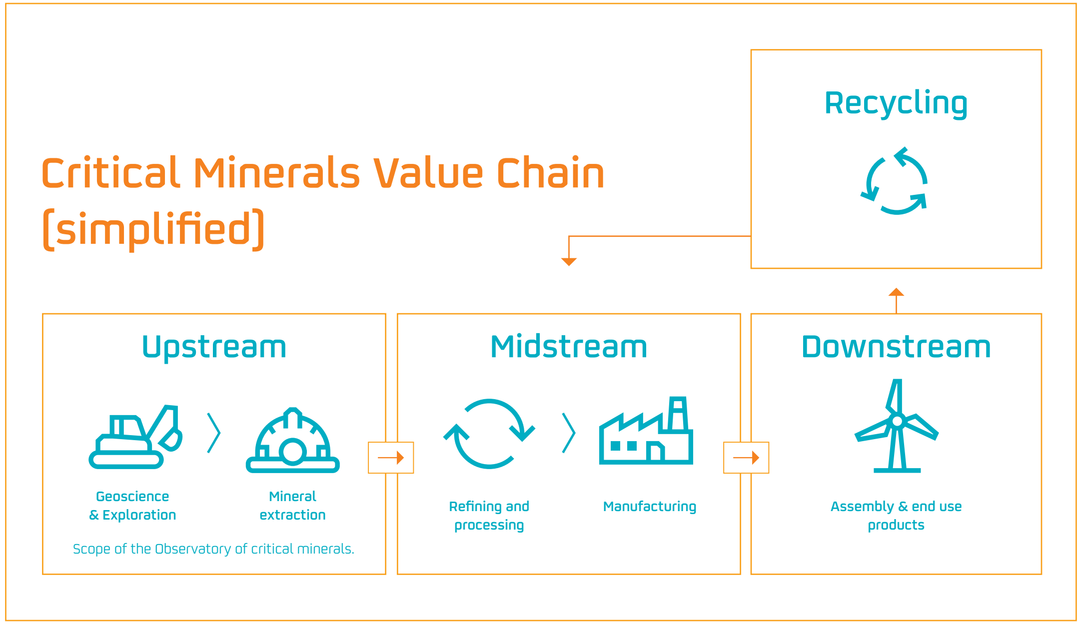


Figure 2: *Simplified critical minerals value chain (modified from The Canadian minerals strategy)*

Likewise, it is also important to bear in mind that mineral demand from sectors other than clean energy could increase faster than it has been assumed (our hypothesis is that they will grow at the same pace as the global GDP), jeopardising the transformation. Recycling and substitutability are implicit in the methodology since the data will be updated yearly, and increases in secondary supply will have an effect in the IEA estimations of future primary production.

If we examine the results obtained (Table 1), that is, the ranking of minerals by their criticality, we will immediately conclude that some findings are somewhat counterintuitive, since they contradict preconceived ideas regarding the preeminent position that we would expect certain minerals to occupy. For example, Lithium, which has a huge presence in the media, but which occupies a fairly low position in our ranking. We can explain this perfectly in light of the IEA's demand projections in relation to mining reserves and their concentration by country. Those minerals whose reserves are scarcer in relation to projected demand are those whose supply is most threatened, especially if the reserves are also highly concentrated, or distributed in locations with high country risk. In our ranking, the first five positions are occupied by Indium, Chromium, Arsenic, Gallium and Germanium; it is no coincidence, in view of this, that China has recently established restrictions on the export of Gallium and Germanium precisely, in response to the restrictions previously imposed by the US on the export of semiconductors.

Mineral	Criticality Index NZE 2040	Mineral	Criticality Index NZE 2040
Indium	0,70	Silver	0,37
Chromium	0,63	Tantalum	0,34
Arsenic	0,58	Selenium	0,34
Gallium	0,58	Molybdenum	0,32
Germanium	0,58	Tungsten	0,32
Boron	0,57	Cadmium	0,32
Magnesium	0,55	Graphite	0,30
Tin	0,49	Manganese	0,29
Niobium	0,49	Vanadium	0,28
PGM	0,46	Copper	0,27
Cobalt	0,45	Zirconium	0,27
Zinc	0,43	Hafnium	0,27
Lead	0,42	Lithium	0,26
Titanium	0,39	REE	0,25
Nickel	0,39	Tellurium	0,19
Silicon	0,38	Aluminium	0,17

Table 1: Criticality index for Net Zero Emissions scenario and 2040

Executive summary

Regarding energy transition technologies, we have faced restrictions on which to include in the scope of the Observatory, as the IEA only publishes data for a small bunch of them.

Technology	Technology Index NZE 2040
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

***Table 2:** : Technology index for Net Zero emissions scenario and 2040*

Nevertheless, this has not been an obstacle for us to draw some striking conclusions (Table 2). The first one is that electromobility is, by far, the most threatened technology due to a combination of high mineral intensity and criticality. The second is that non-manageable renewable technologies, specifically wind and solar, have per se a medium level of exposure, but their real exposure is greater since their deployment must go hand in hand with the deployment of battery storage capacity, whose supply risk is much higher. The third is that bioenergy is the least exposed technology of those analysed, and although the IEA data refer to biomass-fed thermoelectric plants, it is easy to conclude that biofuels are also an instrument of the energy transition that is very little exposed to the risk of supply of critical minerals (they may face other challenges in terms of supply of raw materials, but not minerals).

These conclusions support the mounting evidence, revealed in numerous studies, that certain technologies essential for an accelerated energy transition may not develop as fast as expected by policy makers. Therefore, it is necessary to mitigate the supply risks of critical minerals to the maximum extent possible, developing well-diversified and highly reliable supply chains, from the exploration of mineral reserves to the manufacturing of components and equipment for the generation, transportation and storage of energy.

But, in addition, and with the purpose of ensuring that the energy transition really occurs at the desired pace so that the objectives of the Paris Agreement are met, it is prudent that energy policies be governed by the principle of technological neutrality, so that sufficient incentives are generated for the deployment of those energy technologies less exposed to the supply of critical minerals for the energy transition, in particular biofuels. Beyond energy technologies, there are compensation levers for climate mitigation that should be promoted as well, such as nature-based solutions, which have zero exposure to the supply of critical minerals. In summary, just as climate policies, since their very inception in the 1992 Rio Convention, have been governed by the principle of precaution, which leads us to mitigate climate change even though we do not know with absolute certainty the warming effect of the growing concentration of greenhouse gases in the atmosphere, caution seems to be again the best attitude to approach energy transition policy setting, as the room for development of certain technologies, in which policy makers are relying, is far from being certain.

Mineral

Uses and basic information about the mineral

Criticality Index ranking

Criticality index and nge vs previous year

Position in ranking and change vs previous year

Criticality index breakdown (depletion time & country concentration). And index from previous year

Demand

Production

Reserves

Production Map

Reserves Map

Criticality Index evolution*: from previous year (SDS 2040) to current year (NZE 2040). (*IEA only started using NZE in 2022)

Criticality Index evolution: Different scenarios and years 002

Related Facts

Explanation about criticality index evolution

Results: Mineral sheets

KEY SHEET

(see APPENDIX 1: METHODOLOGY)

Aluminium

Aluminium is used for metallugical applications but also many sectors of the economy (aircraft construction, building materials, consumer durables, electrical conductors, and chemical and food-processing equipment). Aluminium obtained from Bauxite, which is refined into alumina (Bayer process); alumina is then smelted to obtain aluminium (Hall Heroult process).

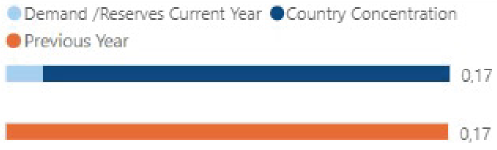
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year
0,17	3,95 %

Ranking	Change vs previous year
32	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
10.357.000	x2	x3

Total Production (USGS)

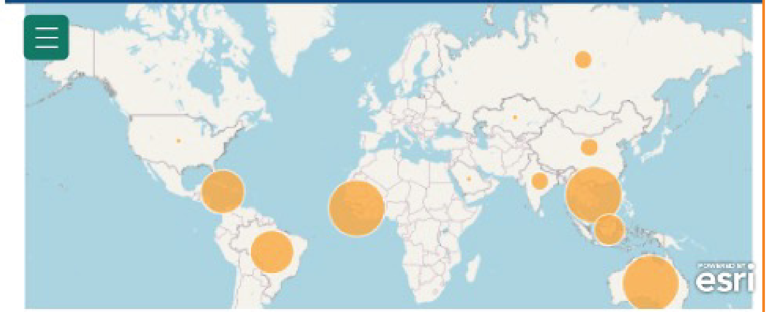
2021 (t)	2022 (t)	Growth
15.360.000	15.200.000	-1,04 %

Total Reserves (USGS)

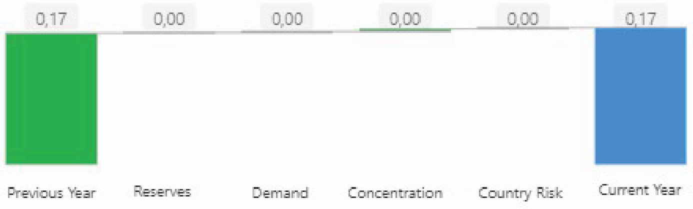
2021 (t)	2022 (t)	Growth
6.400.000.000	6.200.000.000	-3,13 %

Production 2022

Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040

Related Facts

Aluminium index is mainly driven by country concentration and country risk. It has not changed from previous year. Indonesia, the 5th global producer, is considering banning exports of bauxite ore, as it has done with Nickel in 2023.

Results: Mineral sheets

Arsenic

High-purity Arsenic metal is used to produce GaAs, indium-arsenide, and InGaAs semiconductors that are used in biomedical, communications, computer, electronics, and photovoltaic applications. Arsenic may be obtained as a by-product of copper, gold, and lead smelter flue dust, as well as from roasting arsenopyrite, the most abundant ore mineral of arsenic.

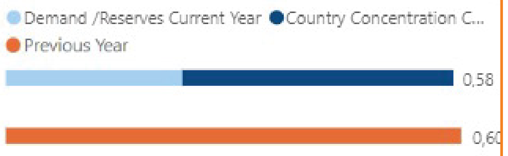
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Critcality Index	Change vs previous year
0,58	-3,04 %

Ranking	Change vs previous year
3	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
0		

Total Production (USGS)

2021 (t)	2022 (t)	Growth
60.000	61.000	1,67 %

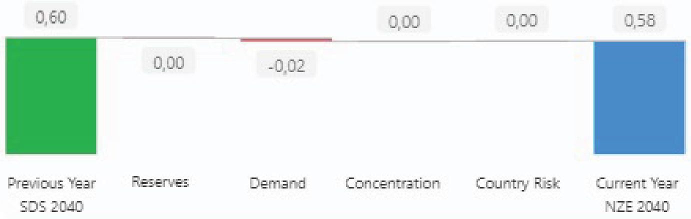
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
1.200.000	1.220.000	1,67 %

Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 ⟶ NZE 2030 ⟶ NZE 2040

Related Facts

Arsenic index responds to both depletion time and country concentration and risk. It has barely changed from previous year.

Results: Mineral sheets

Boron

Boron is used as an abrasive, in the manufacture of hard and chemical-resistant ceramics or wear-resistant tools, in the refractory industry, in light weight cermets, in armour tiles, in radiation protection and shielding, in the nuclear industry in control rods in nuclear reactors.

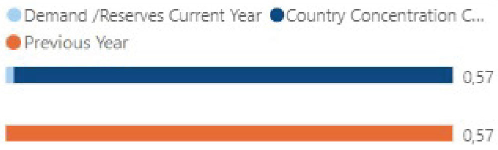
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year
0,57	0,27 %

Ranking	Change vs previous year
6	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
159	x5	x4

Total Production (USGS)

2021 (t)	2022 (t)	Growth
3.086.000	3.020.000	-2,14 %

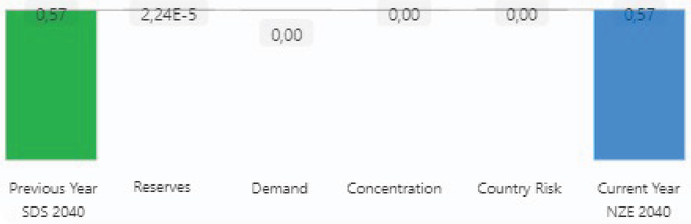
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
1.343.000.000	1.340.000.000	-0,22 %

Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040

Related Facts

Boron index is mainly driven by country concentration and country risk. It has not changed from last year.

Results: Mineral sheets

Cadmium

Cadmium is used in batteries, alloys, coatings (electroplating), solar cells, plastic stabilizers, and pigments. Also used in nuclear reactors as a neutron absorber. Cadmium is generally recovered as a by-product from zinc ores and concentrates

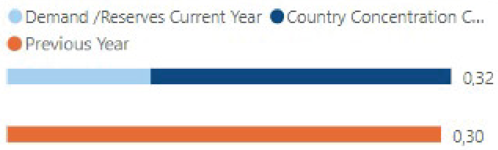
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year
0,32	5,71 %

Ranking	Change vs previous year
22	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
421	x3	x2

Total Production (USGS)

2021 (t)	2022 (t)	Growth
24.700	24.000	-2,83 %

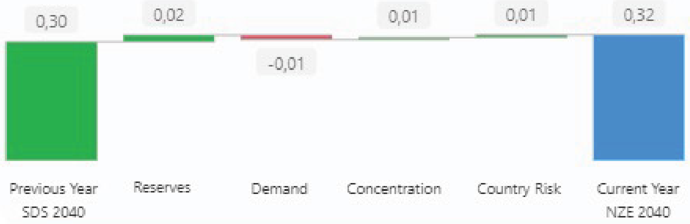
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
1.250.000	1.050.000	-16,00 %

Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040

Related Facts

Cadmium index responds to both depletion time and country concentration and risk. It has barely changed from previous year.

Results: Mineral sheets

Chromium

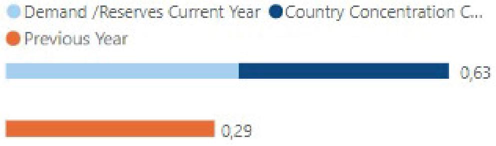
Chromium is used in metallugical applications (used to harden steel, to manufacture stainless steel and to produce several alloys).

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,63	117,26 %	2	24

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
181.109	x5	x4

Total Production (USGS)

2021 (t)	2022 (t)	Growth
42.200.000	41.000.000	-2,84 %

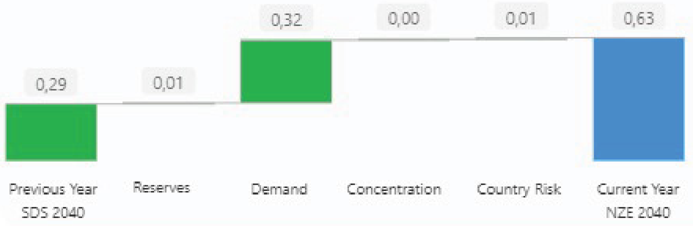
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
570.000.000	560.000.000	-1,75 %

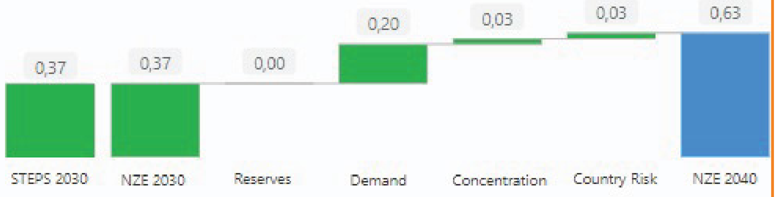
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Chromium index responds to both depletion time and country concentration and risk. It has increased drastically from last year driven by IEA's demand projections, becoming one of the riskiest elements. For this reason, it will be closely monitored in the future.

Results: Mineral sheets

Cobalt

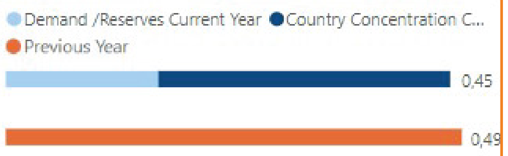
Cobalt is used in battery and metallurgical applications. Most Cobalt is produced in DRC through artisanal and small scale mining (ASM).

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,45	-9,74 %	11	-2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
68.177	x3	x4

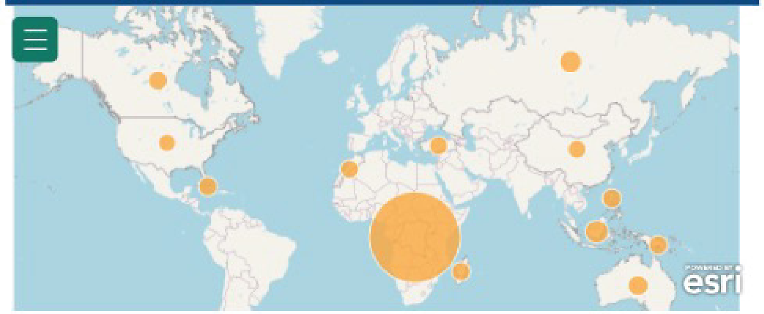
Total Production (USGS)

2021 (t)	2022 (t)	Growth
165.000	190.000	15,15 %

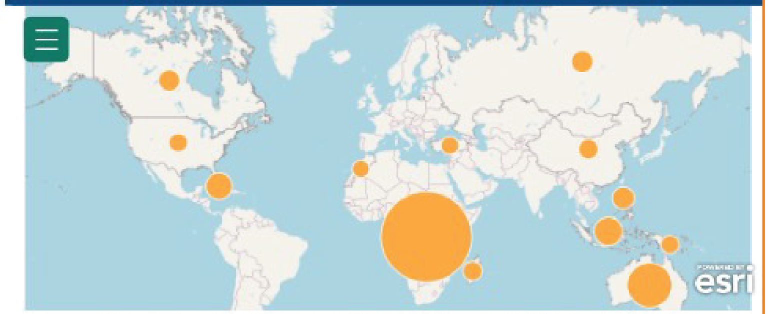
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
7.600.000	8.300.000	9,21 %

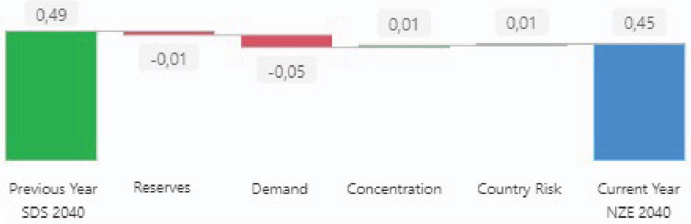
Production 2022



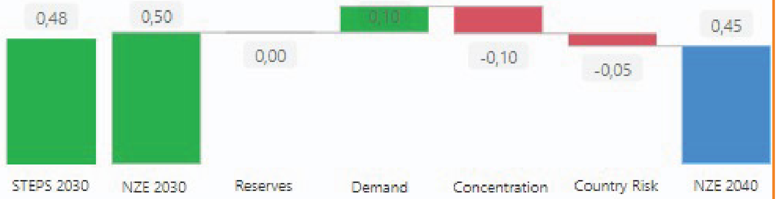
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Cobalt index responds to both depletion time and country concentration and risk. It has improved from previous year due to relaxation in demand proection. Indonesia is considering banning exports of cobalt ore, as it has done with Nickel in 2023. Recent breakthroughs in solid-state and sodium-ion batteries could reduce future cobalt demand. A meeting to decide the future of seabed mining in July 2023 ended with a moratorium (seabed mining could provide resources of nickel, cobalt, manganese and copper).

Results: Mineral sheets

Copper

Most Copper is used in electrical equipment such as wiring and motors. It also has uses in construction (roofing and plumbing), and industrial machinery (heat exchangers).

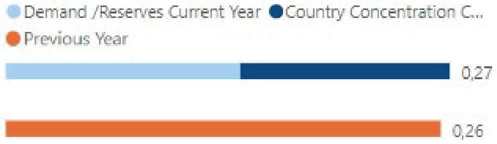
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year
0,27	2,96 %

Ranking	Change vs previous year
26	1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
5.735.860	x3	x4

Total Production (USGS)

2021 (t)	2022 (t)	Growth
21.200.000	22.000.000	3,77 %

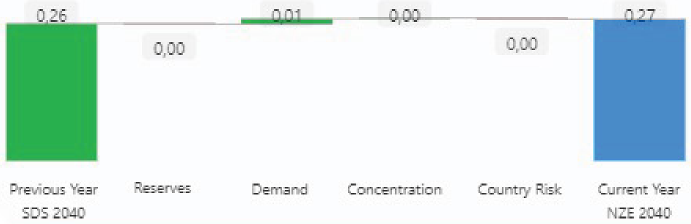
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
880.000.000	890.000.000	1,14 %

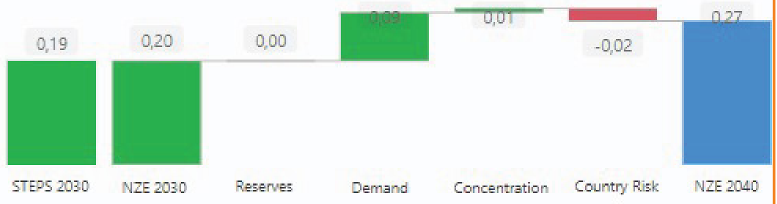
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Copper index responds to both depletion time and country concentration and risk. It has barely changed from previous year.
The world's largest copper producers have recently warned that there is a lack of mines to provide enough copper to keep pace with the energy transition. Mining companies struggle with falling metal prices derived from the weakness of the global economy and cost inflation, which makes executives, investors and banks cautious over financing new projects. A meeting to decide the future of seabed mining in July 2023 ended with a moratorium (seabed mining could provide resources of nickel, cobalt, manganese and copper).

Results: Mineral sheets

Gallium

Gallium is used in integrated circuits and optical device applications (for making semiconductors, used in computers, photovoltaic cells, transistors, aerospace, lasers, etc.). Gallium occurs in very small concentrations in ores of other metals. Most gallium is produced as a by-product of processing bauxite, and the remainder is produced from zinc-processing residues.

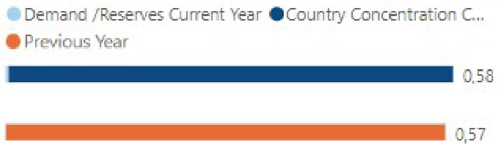
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year
0,58	0,94 %

Ranking	Change vs previous year
5	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
9	x23	x637

Total Production (USGS)

2021 (t)	2022 (t)	Growth
434	550	26,73 %

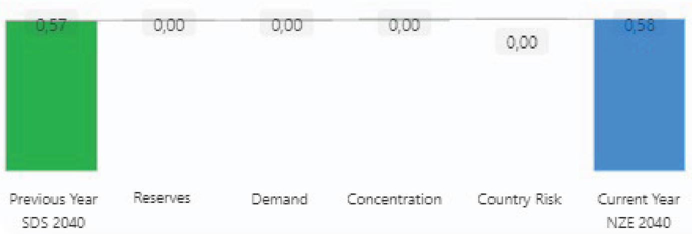
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
1.612.500	1.560.500	-3,22 %

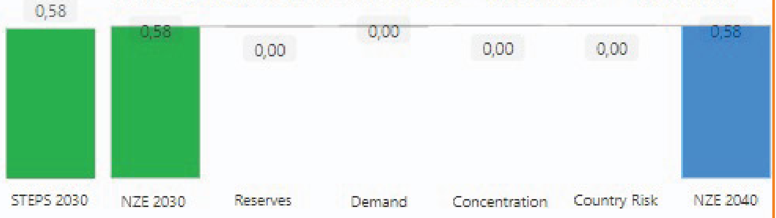
Production 2022

Reserves 2022

Criticality Index Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Gallium index responds almost exclusively to country concentration and country risk. It has not changed from previous year.
Gallium has been object of an export ban by China in July 2023.

Results: Mineral sheets

Germanium

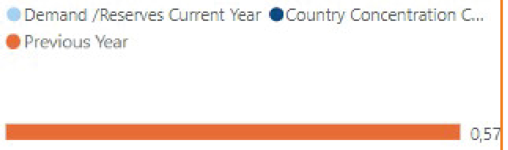
Germanium is used in defense and fiber optics applications. The main uses are electronics and solar applications, fiber-optic systems, infrared optics, and polymerization catalysts. Other uses included chemotherapy, metallurgy, and phosphors. The available resources of Germanium are associated with certain zinc and lead-zinc-copper sulfide ores. Also from coal fly ash. Recoverable germanium in zinc reserves cannot be determined.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,58	0,94 %	4	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
10	x2	x2

Total Production (USGS)

2021 (t)	2022 (t)	Growth
140		

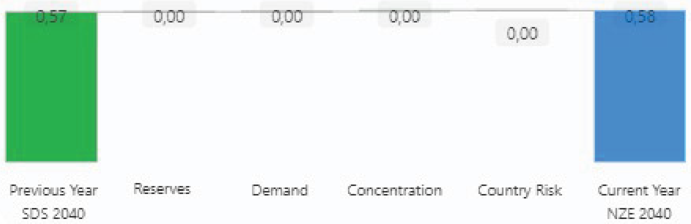
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth

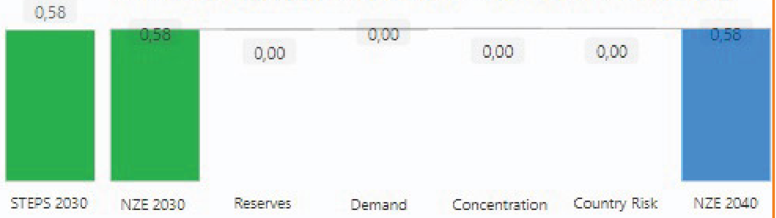
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Germanium production and reserves data provided by USGS not split by country. The index has been linked to the one of Gallium.
Germanium has been object of an export ban by China in July 2023.

Results: Mineral sheets

Graphite

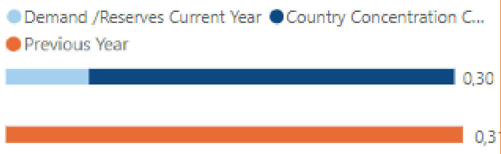
Graphite is mostly used for battery, fuel cells, and lubricant applications.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,30	-4,62 %	23	-2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
587.040	x8	x9

Total Production (USGS)

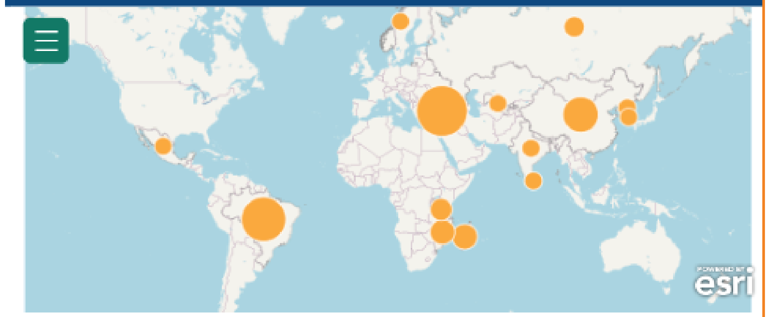
2021 (t)	2022 (t)	Growth
1.130.000	1.300.000	15,04 %

Total Reserves (USGS)

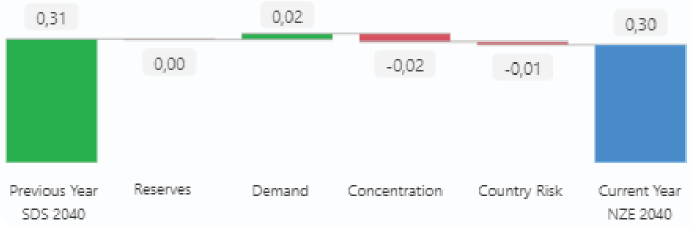
2021 (t)	2022 (t)	Growth
320.000.000	330.000.000	3,13 %

Production 2022

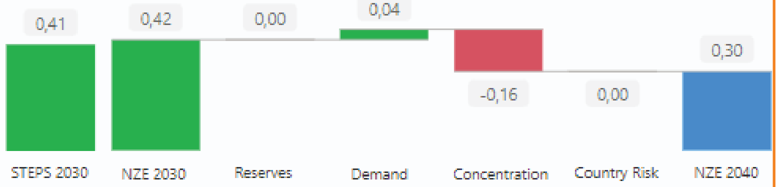
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Graphite index is driven mainly to country concentration and country risk. It has barely changed from previous year despite increase in demand projections and addition of reserves by Russia, that have been cancelled out by a reduction of China's reserves share.

China has threatened on september 2023 to impose an export ban on graphite, which is used in electric vehicle batteries. Recent breakthroughs in solid-state and sodium-ion batteries could reduce future graphite demand.

Results: Mineral sheets

Hafnium

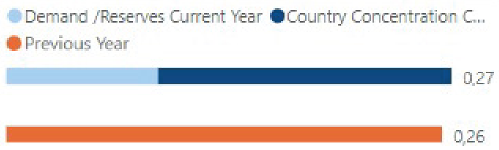
Hafnium is used in ceramics, nuclear control rod and metallurgical applications. Associated with Zirconium production (by-product). No reserves data available.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,27	3,99 %	28	1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
7	x2	x2

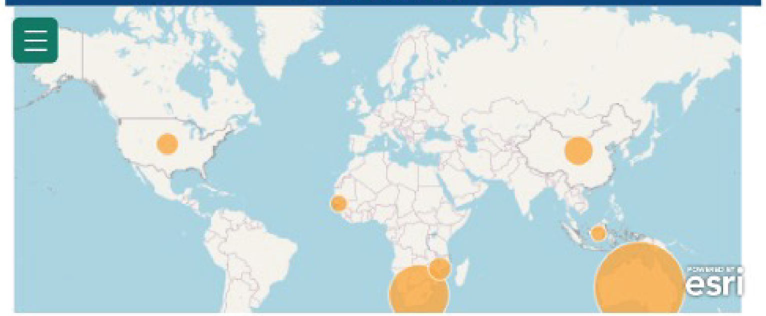
Total Production (USGS)

2021 (t)	2022 (t)	Growth
1.300.000	1.400.000	7,69 %

Total Reserves (USGS)

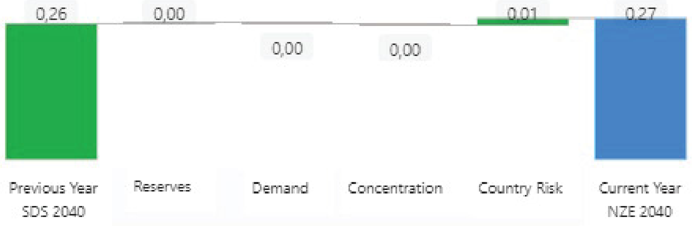
2021 (t)	2022 (t)	Growth
70.000.000	68.000.000	-2,86 %

Production 2022

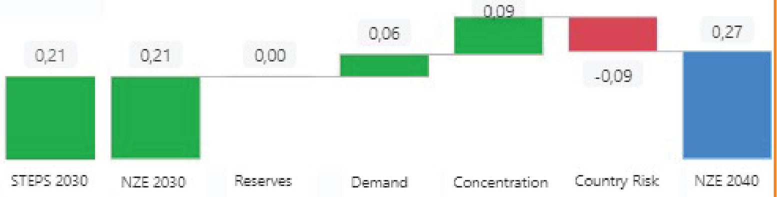


Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Hafnium index responds to both depletion time and country concentretion/risk. Country risk has slightly increased from previous year due to addition of reserves in Senegal.

Results: Mineral sheets

Indium

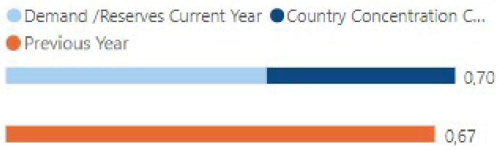
Indium is used for liquid crystal display applications. Indium nitride, phosphide and antimonide are semiconductors used in transistors and microchips. Indium is most commonly recovered as a by-product from the zinc-sulfide ore mineral sphalerite.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,70	4,65 %	1	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
56	x3	x3

Total Production (USGS)

2021 (t)	2022 (t)	Growth
932	900	-3,43 %

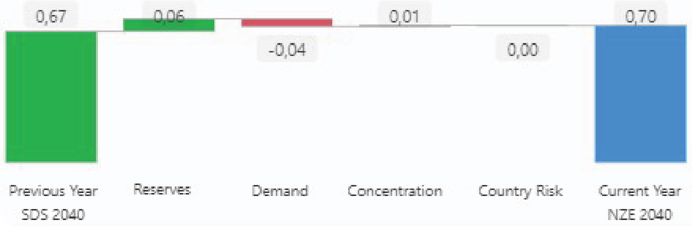
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
12.500	10.500	-16,00 %

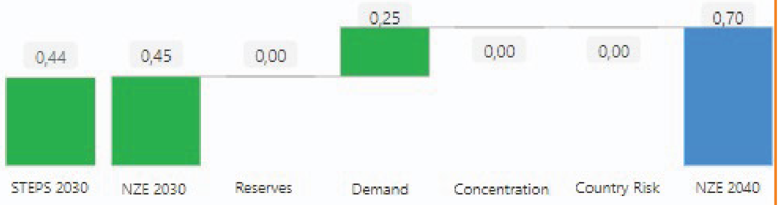
Production 2022

Reserves 2022

Crticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Indium index responds to depletion time and country concentration/risk, but the former has a stronger impact. Depleted reserves have outweighed improved demand figures, increasing the index from previous year and maintaining Indium on top of the ranking.

Results: Mineral sheets

Lead

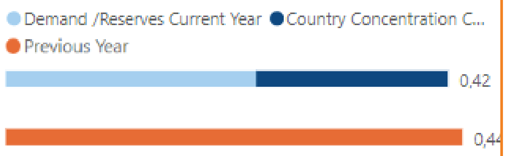
Lead is still widely used for car batteries, pigments, ammunition, cable sheathing, weights for lifting, weight belts for diving, lead crystal glass, radiation protection and in some solders. Lead occurs as the principal metal or a by-product of Zinc, Silver or Copper deposits.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,42	-4,30 %	13	-2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
14.142	x2	x2

Total Production (USGS)

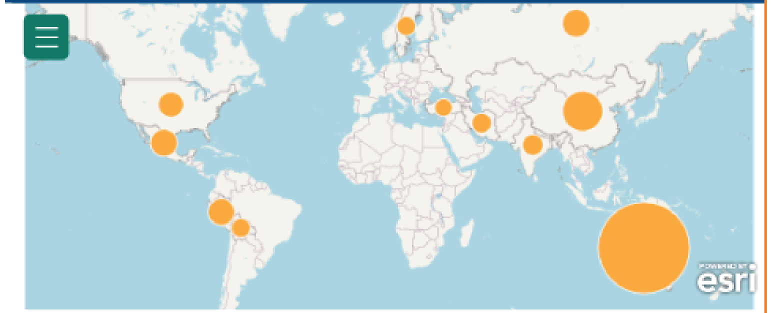
2021 (t)	2022 (t)	Growth
4.550.000	4.500.000	-1,10 %

Total Reserves (USGS)

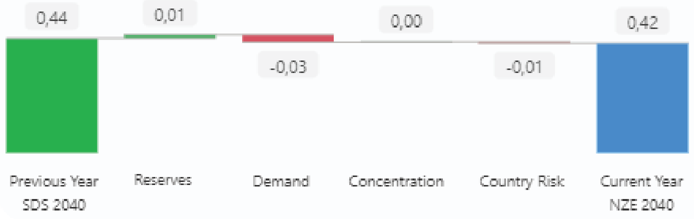
2021 (t)	2022 (t)	Growth
90.000.000	85.000.000	-5,56 %

Production 2022

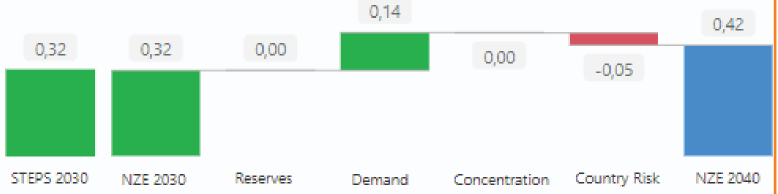
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 ⟶ NZE 2030 ⟶ NZE 2040



Related Facts

Lead index responds to both depletion time and country concentretion/risk. Country risk has slighty decreased from previous year.

REPSOL

Results: Mineral sheets

Lithium

Lithium is mostrly used for battery applications (EV, mobile devices...). Also in ceramics and glass, lubricants, metallurgy and other. There are different types of Lithium production: conventional brine extraction, Spodumene (hard rock) lithium extraction, direct Lithium extraction (DLE). DLE is an immature technology that needs to be tested and scaled.

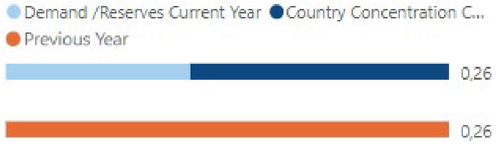
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year
0,26	-0,26 %

Ranking	Change vs previous year
29	1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)		
2022 (t)	Growth 2030	Growth 2040
73.174	x9	x16

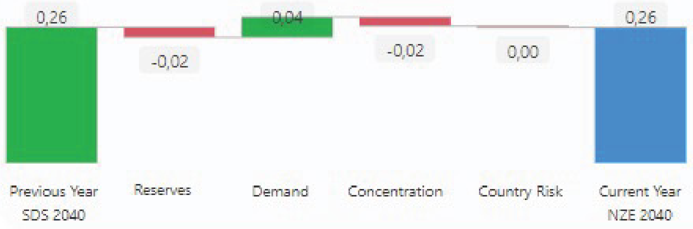
Total Production (USGS)		
2021 (t)	2022 (t)	Growth
107.000	130.000	21,50 %

Total Reserves (USGS)		
2021 (t)	2022 (t)	Growth
22.000.000	26.000.000	18,18 %

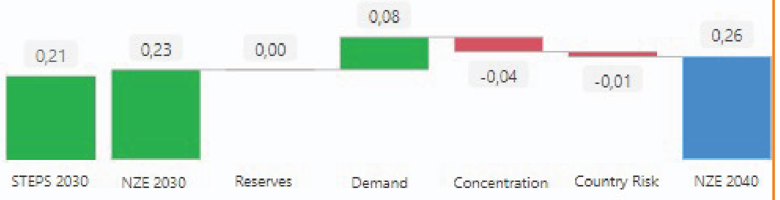
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Lithium index responds to both depletion time and country concentretion/risk. It has not changed from previous year because increased demand projections have been cancelled out by reserves addition in new countries. Chile is currently reviewing the lithium concession system. Namibia and Zimbabwe have banned the export of unprocessed lithium ore. Mexico nationalised its lithium industry in 2022. Oil and gas companies are starting to diversify into lithium investing into Direct Lithium Extraction. Automakers like Tesla are diversifying into lithium refining in order to control the supply of the metal. Recent breakthroughs in solid-state and sodium-ion batteries could reduce future lithium demand.

Results: Mineral sheets

Magnesium

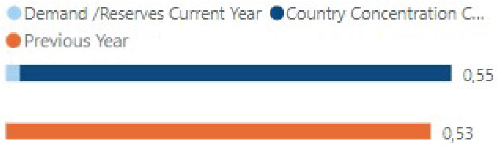
Magnesium is mostly used in metallurgical applications. It is used for aluminium alloys, die-casting (alloyed with zinc), removing sulfur in the production of iron and steel, and the production of titanium in the Kroll process. Magnesium metal can be derived from seawater, natural brines, dolomite, serpentine, and other minerals.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,55	4,99 %	7	-1

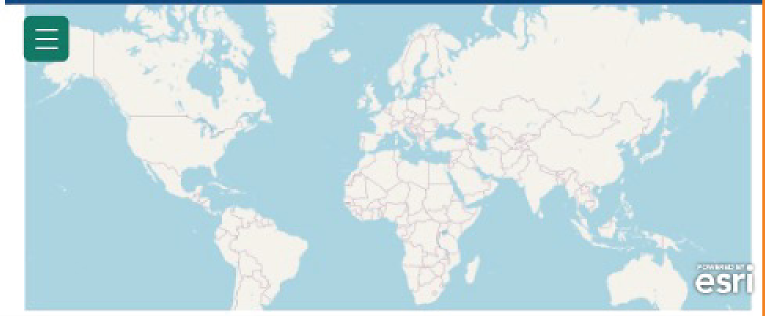
Criticality Index Breakdown



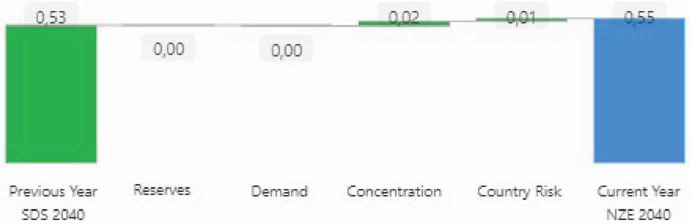
Demand clean technologies NZE (IEA)			Total Production (USGS)			Total Reserves (USGS)		
2022 (t)	Growth 2030	Growth 2040	2021 (t)	2022 (t)	Growth	2021 (t)	2022 (t)	Growth
5.345	x7	x10	10.000	2.000	-80,00 %			

Production 2022

Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040

Related Facts

Magnesium index responds mainly to country concentretion and country risk. It has slightly increased from previous year, driven by an increase of China's share in Magnesium production (USGS dos not provide reserves data per country, and therefore production has been used to calculate concentration and country risks).

Results: Mineral sheets

Manganese

Manganese is used for battery and metallurgical applications. Some common applications for manganese are creating structural alloys, being used as an oxidizing agent, used in welding, and placed into glazes and varnishes and battery manufacturing.

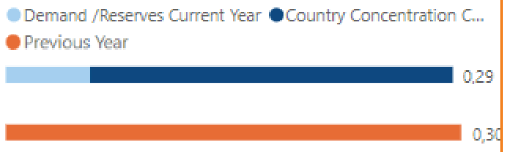
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year
0,29	-4,57 %

Ranking	Change vs previous year
24	-1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
173.753	x5	x9

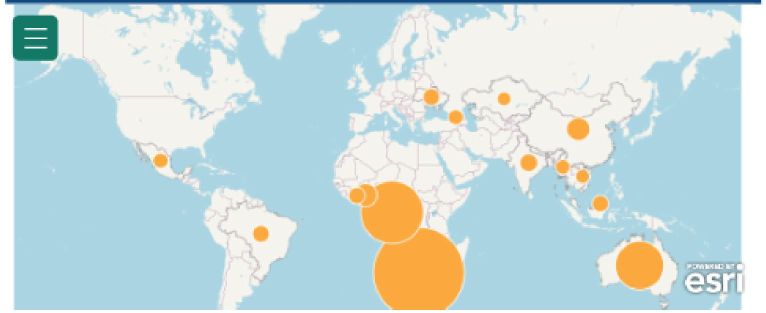
Total Production (USGS)

2021 (t)	2022 (t)	Growth
20.100.000	20.100.000	0,00 %

Total Reserves (USGS)

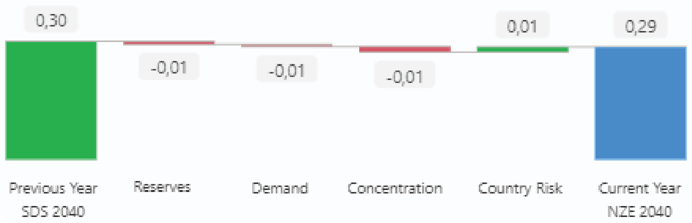
2021 (t)	2022 (t)	Growth
1.500.000.000	1.700.000.000	13,33 %

Production 2022

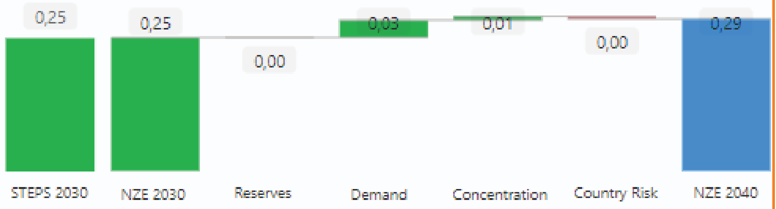


Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Manganese index responds mainly to country concentretion and country risk. It has slightly decreased from previous year.
Recent breakthroughs in solid-state and sodium-ion batteries could reduce future manganese demand. A meeting to decide the future of seabed mining in July 2023 ended with a moratorium (seabed mining could provide resources of nickel, cobalt, manganese and copper).

Molybdenum

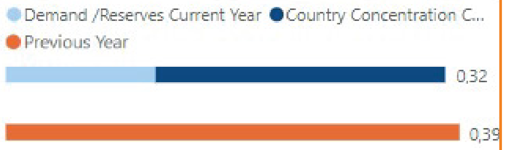
Molybdenum is commonly used for metallurgical applications (steel alloys to increase strength, hardness, electrical conductivity and resistance to corrosion and wear). Molybdenum occurs as the principal metal sulfide in large low-grade porphyry molybdenum deposits and as an associated metal sulfide in low-grade porphyry copper deposits (by-product).

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,32	-16,46 %	20	-5

Criticality Index Breakdown

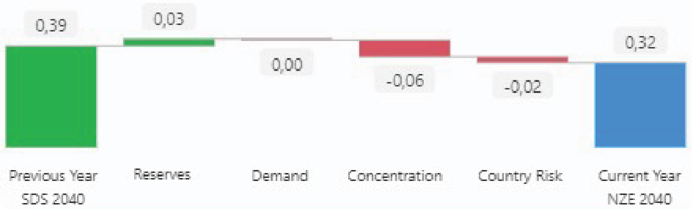


Demand clean technologies NZE (IEA)			Total Production (USGS)			Total Reserves (USGS)		
2022 (t)	Growth 2030	Growth 2040	2021 (t)	2022 (t)	Growth	2021 (t)	2022 (t)	Growth
25.629	x4	x3	255.000	250.000	-1,96 %	16.000.000	12.000.000	-25,00 %

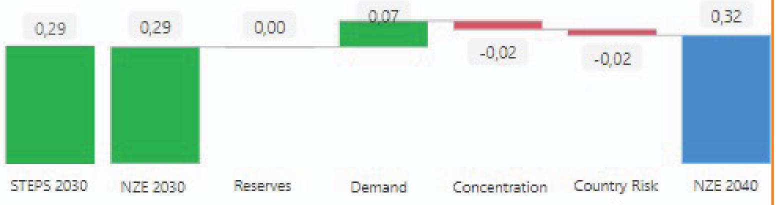
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Molybdenum index responds to both depletion time and country concentretion/risk. It has decreased due to improvements in the second term, namely diversification of reserves, decrease of China's share of reserves, and increase of lower-risk countries' share (US, Chile, Peru); despite depletion of global reserves.

Results: Mineral sheets

Nickel

Nickel is used mostly for battery and metallurgical applications. It is used mainly to make stainless steel and other alloys stronger and better able to withstand extreme temperatures and corrosive environments. Extensive Nickel resources also are found in manganese crusts and nodules on the ocean floor.

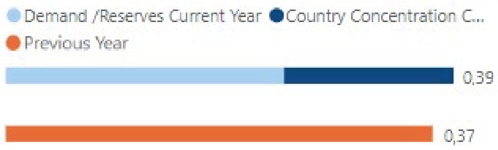
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticaliy Index	Change vs previous year
0,39	6,27 %

Ranking	Change vs previous year
15	2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
456.665	x8	x10

Total Production (USGS)

2021 (t)	2022 (t)	Growth
2.730.000	3.300.000	20,88 %

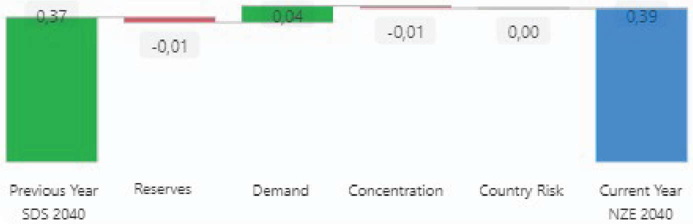
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
95.000.000	100.000.000	5,26 %

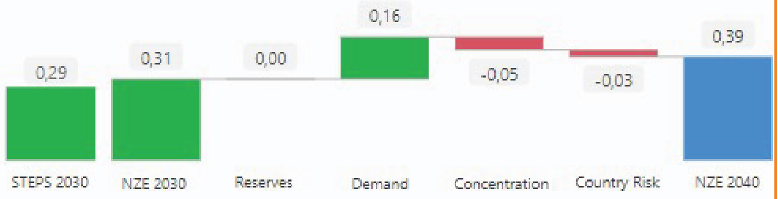
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Nickel index responds to both depletion time and country concentretion/risk. It has increased from previous year due to increase in demand projections. Indonesia has banned in 2022 the export of nickel ore, requiring nickel to be processed domestically for export. A meeting to decide the future of seabed mining in July 2023 ended with a moratorium (seabed mining could provide resources of nickel, cobalt, manganese and copper).

Results: Mineral sheets

Niobium

Niobium is used for metallurgical applications (including stainless steel, improving strength particularly at low temperatures. Used in jet engines and rockets, beams and girders for buildings and O&G rigs and pipelines).

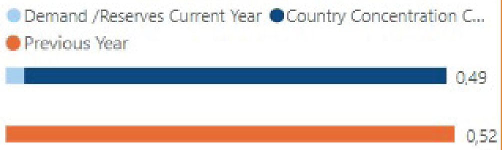
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year
0,49	-6,23 %

Ranking	Change vs previous year
9	-2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
171	x14	x18

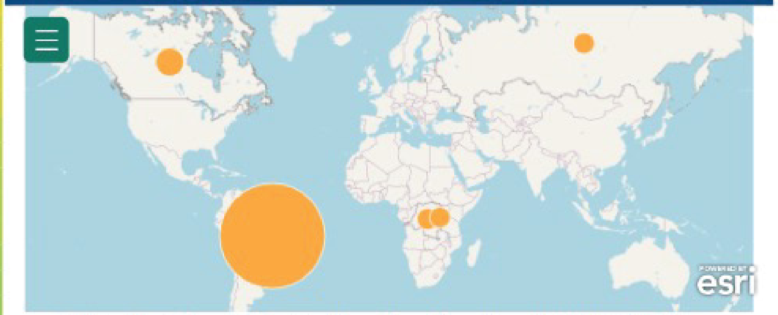
Total Production (USGS)

2021 (t)	2022 (t)	Growth
87.600	79.000	-9,82 %

Total Reserves (USGS)

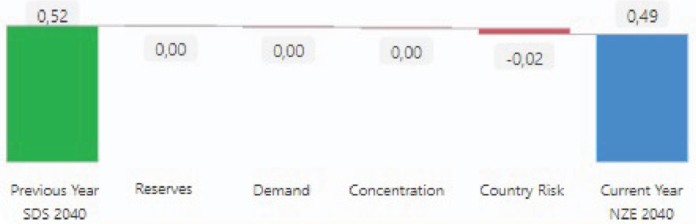
2021 (t)	2022 (t)	Growth
17.000.000	18.000.000	5,88 %

Production 2022

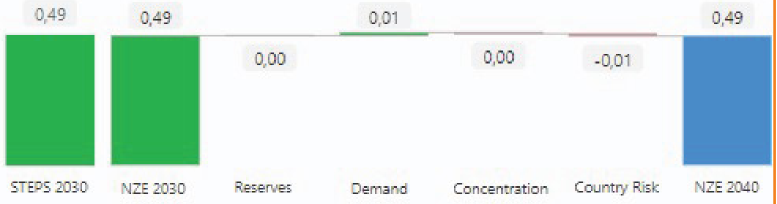


Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Niobium index responds almost uniquely to country concentration/risk. It has slightly improved from previous year due to changes in country risk, driven by the increase of reserves share of US and Canada.

PGM

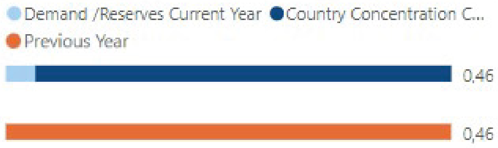
Platinum Group Metals are used in jewellery, anticancer drugs, industries, dentistry, electronics, catalytic converters, electrolysers and fuel cells. PGM can be principal metals; but Platinum and Iridium can be produced as a by-product of Neckel mining or processing.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

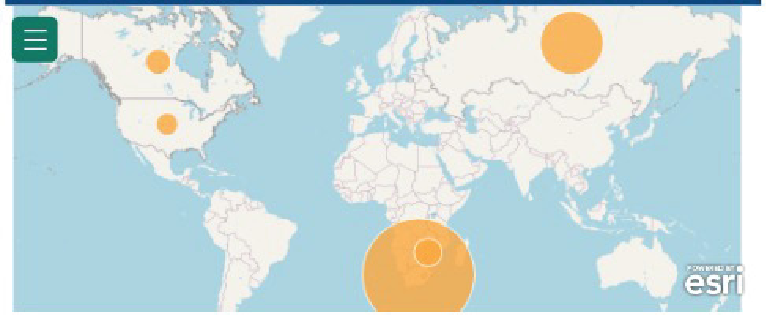
Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,46	0,66 %	10	0

Criticality Index Breakdown

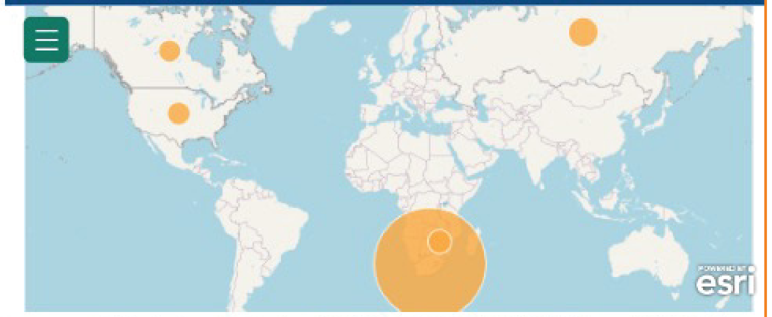


Demand clean technologies NZE (IEA)			Total Production (USGS)			Total Reserves (USGS)		
2022 (t)	Growth 2030	Growth 2040	2021 (t)	2022 (t)	Growth	2021 (t)	2022 (t)	Growth
1	x57	x135	406	400	-1,48 %	70.000	71.000	1,43 %

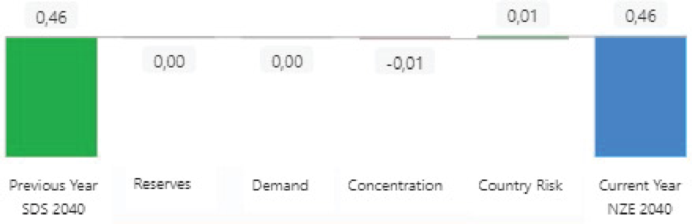
Production 2022



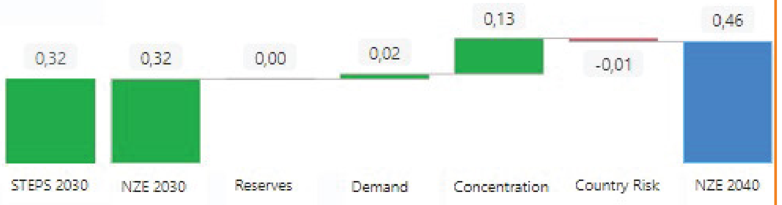
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

The index for Platinum Group Metals responds mainly to country concentration/risk. It5 has barely changed from previous year.

Results: Mineral sheets

REE

The largest use of Rare Earth Elements is in magnets (43.2%), followed by catalysts (17.0%), polishing powders (11.2%), metallurgical (7.1%), glass (6.4%), battery alloys (3.6%), ceramics (3.0%), phosphors (0.5%), pigments (0.3%) and other products (7.6%). Rare earths are relatively abundant in the Earth's crust, but minable concentrations are less common than for most other mineral commodities.

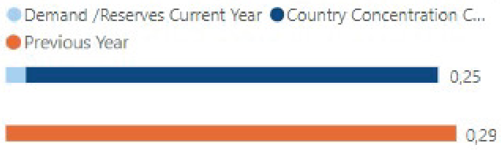
Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year
0,25	-13,82 %

Ranking	Change vs previous year
30	-6

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
12.658	x5	x5

Total Production (USGS)

2021 (t)	2022 (t)	Growth
290.000	300.000	3,45 %

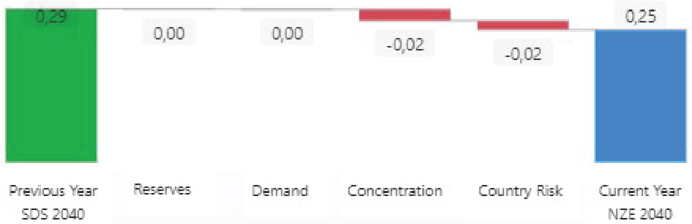
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
120.000.000	130.000.000	8,33 %

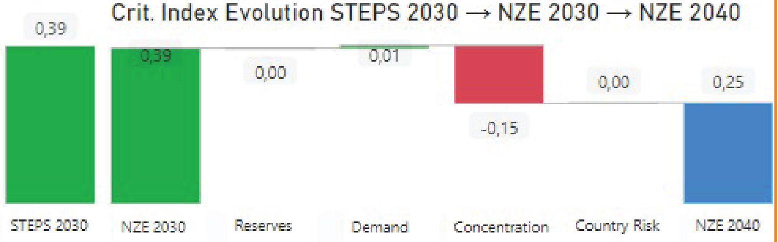
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

The index for Rare Earth Elements responds mainly to country concentration/risk. It has improved thanks to changes in concentration and country risk (increase of reserves in US and Australia, decrease of reserves share of China).

Results: Mineral sheets

Selenium

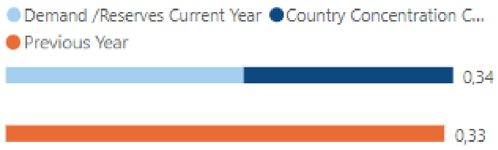
Selenium is used extensively in electronics, such as photocells, light meters and solar cells. The second largest use of selenium is in the glass industry. Selenium is recovered as a by-product of the electrolytic refining of copper, where it accumulates in the residues of copper anodes.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,34	2,09 %	19	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
76	x3	x2

Total Production (USGS)

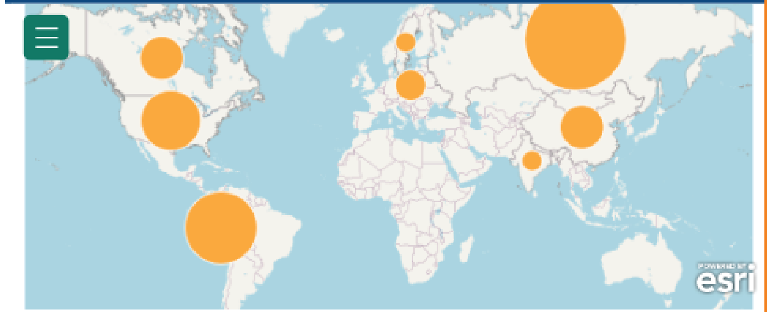
2021 (t)	2022 (t)	Growth
3.100	3.200	3,23 %

Total Reserves (USGS)

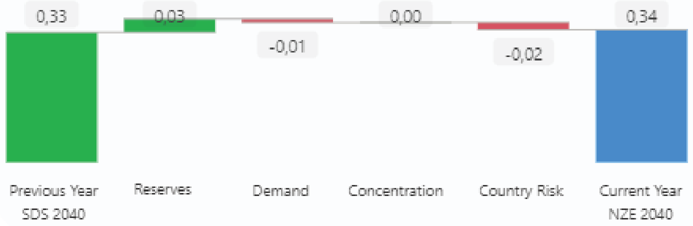
2021 (t)	2022 (t)	Growth
100.000	81.000	-19,00 %

Production 2022

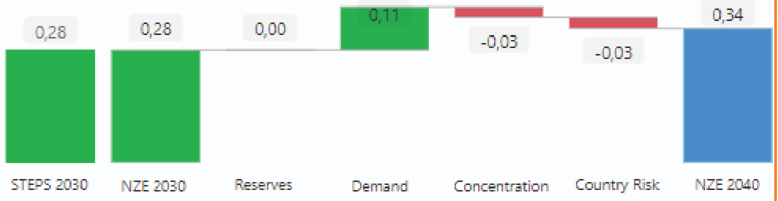
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Selenium index responds to both depletion time and country concentretion/risk. It has barely increased from previous year.

Results: Mineral sheets

Silicon

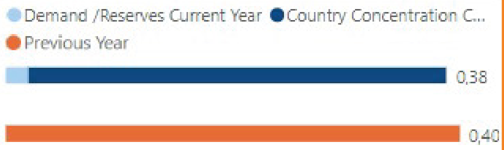
Silicon is a semiconductor in solid-stat, and therefore used in devices in the computer and microelectronics industries. For this, hyperpure silicon is needed. The silicon is selectively doped with tiny amounts of boron, gallium, phosphorus or arsenic to control its electrical properties. Also used in Solar PV and EV industries.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,38	-3,80 %	16	-3

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
765.097	x3	x3

Total Production (USGS)

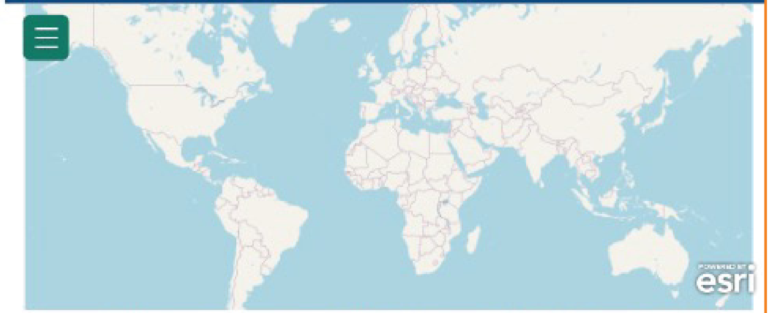
2021 (t)	2022 (t)	Growth
9.150.000	8.800.000	-3,83 %

Total Reserves (USGS)

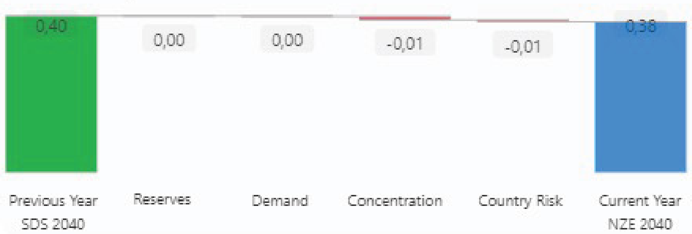
2021 (t)	2022 (t)	Growth
2.300.000.000	2.300.000.000	0,00 %

Production 2022

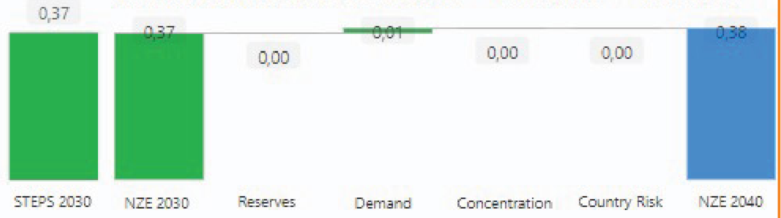
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Silicon index responds mainly to country concentration/risk. It has slightly improved from previous year driven by the reduction of China's share of global production (USGS does not provide reserves data per country, and therefore production data has been used to calculate country concentration and risk)

Results: Mineral sheets

Silver

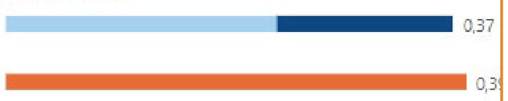
Silver main use is in jewlery. It is also used in dental alloys, solder and brazing alloys, electrical contacts and batteries. At least 80 percent of the world's Silver is produced as a by-product of mining for other metals such as Gold, Copper, Lead, Zinc, and Uranium.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,37	-4,19 %	17	-3

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
3.855	x2	x1

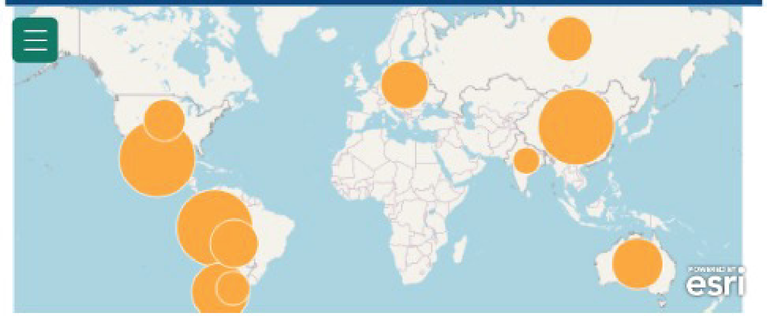
Total Production (USGS)

2021 (t)	2022 (t)	Growth
25.000	26.000	4,00 %

Total Reserves (USGS)

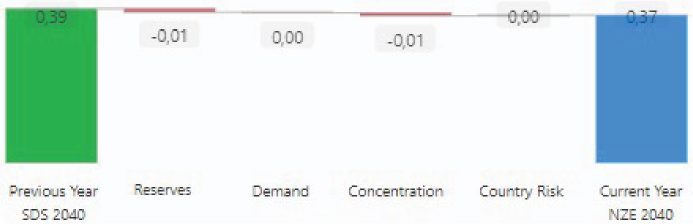
2021 (t)	2022 (t)	Growth
530.000	550.000	3,77 %

Production 2022



Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040

Related Facts

Silver index responds to both depletion time and country concentration/risk. It has slightly decreased from previous year.

Results: Mineral sheets

Tantalum

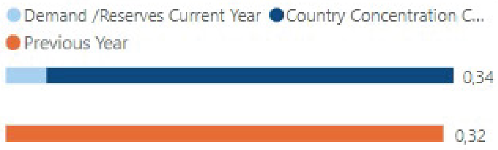
Tantalum is mostly used in high-temperature applications (capacitors and metallurgical applications). Tantalum Can be principal mineral or produced as a by-product of Niobium or Tin.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,34	6,07 %	18	2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
39	x11	x9

Total Production (USGS)

2021 (t)	2022 (t)	Growth
1.840	2.000	8,70 %

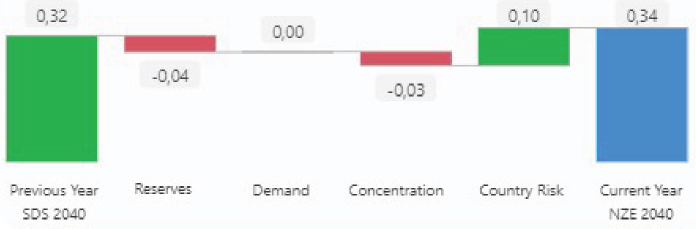
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
134.000	319.000	138,06 %

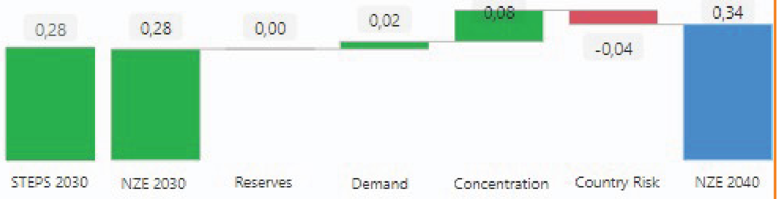
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Tantalum index responds mainly to country concentration/risk. Addition of new reserves has contributed to reduce the reserves and concentration terms, but this has been outweighed by the increase country risk, since the new reserves are located in China.

Results: Mineral sheets

Tellurium

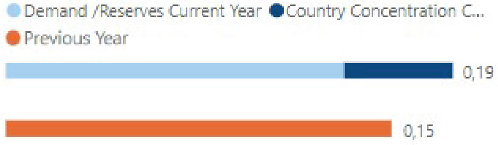
Tellurium is used for metallurgical applications, solar cells, and thermoelectric devices. Tellurium production is mainly a by-product of Copper processing.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,19	26,68 %	31	1

Criticality Index Breakdown



Demand clean technologies NZE (IEA)		
2022 (t)	Growth 2030	Growth 2040
423	x3	x2

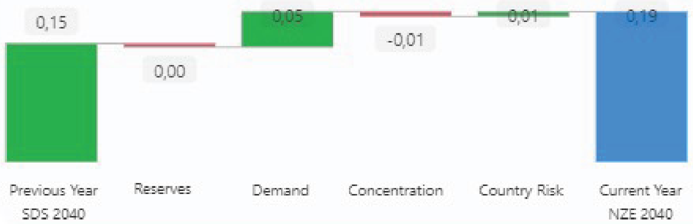
Total Production (USGS)		
2021 (t)	2022 (t)	Growth
610	640	4,92 %

Total Reserves (USGS)		
2021 (t)	2022 (t)	Growth
31.000	32.000	3,23 %

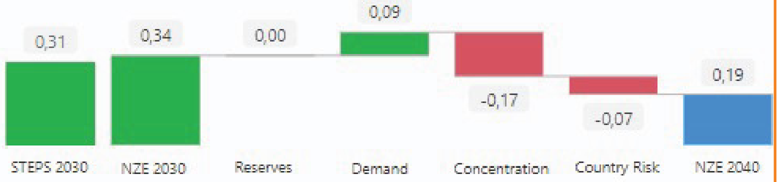
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Tellurium index responds mainly to depletion time. It has increased from previous year due to higher demand projections.

Results: Mineral sheets

Tin

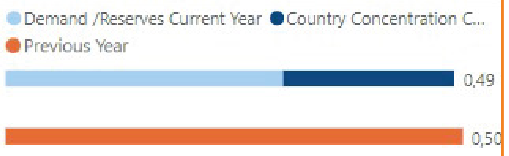
Tin is mostly used for metallurgical applications. A niobium-tin alloy is used for superconducting magnets.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,49	-2,14 %	8	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
1.269	x3	x3

Total Production (USGS)

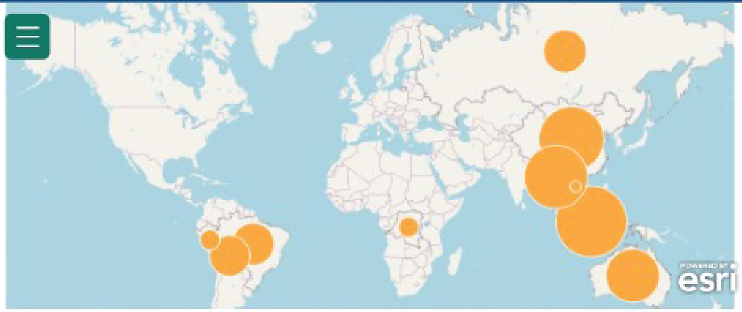
2021 (t)	2022 (t)	Growth
305.000	310.000	1,64 %

Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
4.900.000	4.600.000	-6,12 %

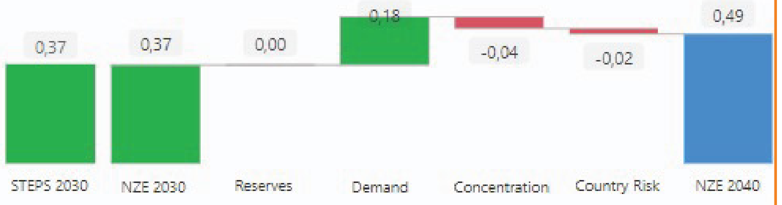
Production 2022

Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)

Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Tin index responds to both depletion time and country concentration/risk. It has barely changed from previous year. Indonesia is considering banning exports of tin ore, as it has done with Nickel in 2023.

REPSOL

Titanium

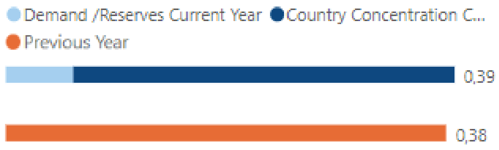
Titanium is used in many sectors, mainly for metallurgical and pigment applications. Other sectors include aerospace and marine; industrial; consumer and architectural; jewellery; medical; nuclear waste storage.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,39	1,85 %	14	2

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
4.720	x4	x4

Total Production (USGS)

2021 (t)	2022 (t)	Growth
240.000	250.000	4,17 %

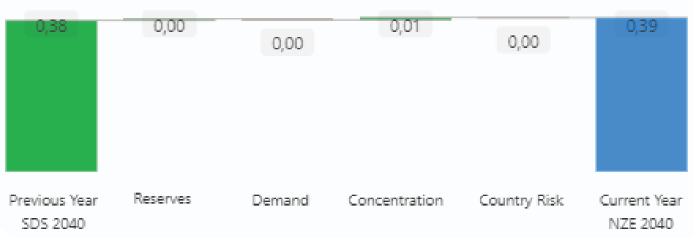
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
21.000.000	19.500.000	-7,14 %

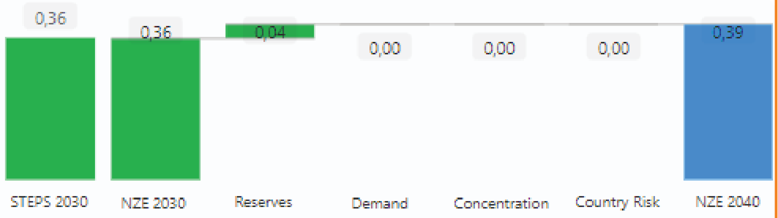
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Titanium index responds mainly to country concentration/risk. It has barely changed from previous year.

Results: Mineral sheets

Tungsten

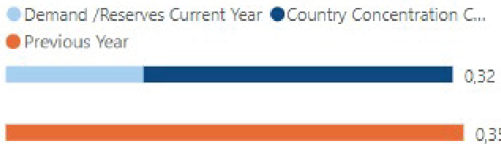
Tungsten is mostly used for metallurgical applications. Uses are as electrodes, heating elements and field emitters, and as filaments in light bulbs and cathode ray tubes. Also used in heavy metal alloys such as high speed steel, from which cutting tools are manufactured. And in the so-called 'superalloys' to form wear-resistant coatings.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,32	-9,05 %	21	-3

Criticality Index Breakdown



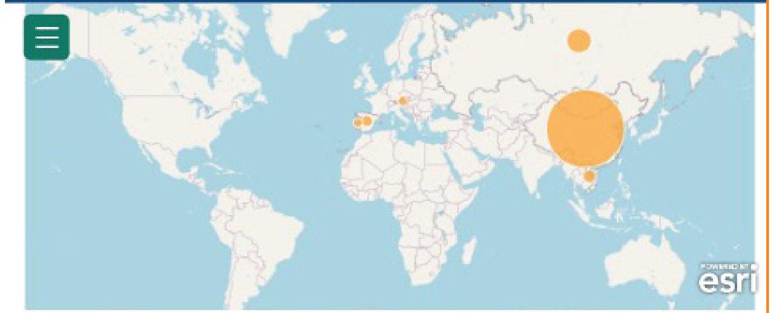
Demand clean technologies NZE (IEA)		
2022 (t)	Growth 2030	Growth 2040
73	x2	x2

Total Production (USGS)		
2021 (t)	2022 (t)	Growth
83.800	84.000	0,24 %

Total Reserves (USGS)		
2021 (t)	2022 (t)	Growth
3.700.000	3.800.000	2,70 %

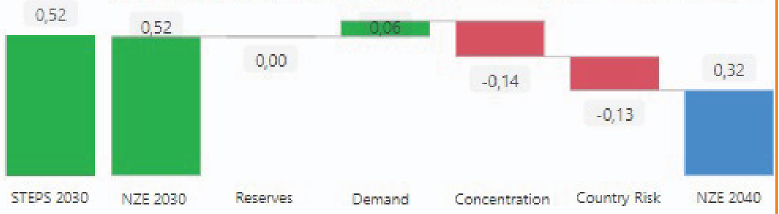
Production 2022

Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)

Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Tungsten index responds to both depletion time and country concentration/risk. It has slightly decreased from previous year due to demand and country risk improvements (lower demand projection and lower share of reserves in China).

Results: Mineral sheets

REPSOL

Vanadium

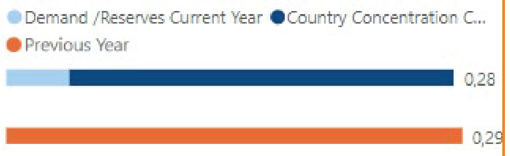
Vanadium is mosty used in battery and metallurgical applications. About 80% of the vanadium produced is used as a steel additive. Vanadium-steel alloys are very tough and are used for armour plate, axles, tools, piston rods and crankshafts.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,28	-2,65 %	25	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
10	x4798	x67053

Total Production (USGS)

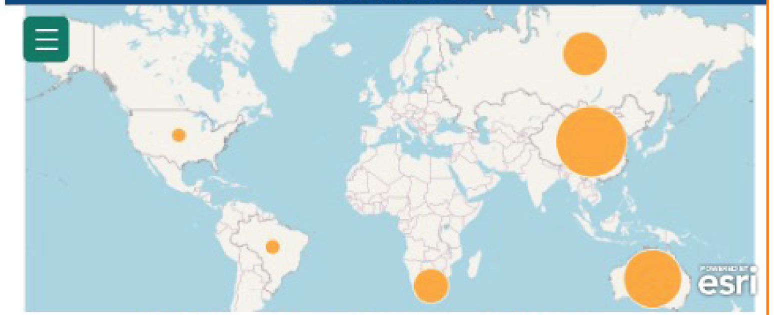
2021 (t)	2022 (t)	Growth
105.000	100.000	-4,76 %

Total Reserves (USGS)

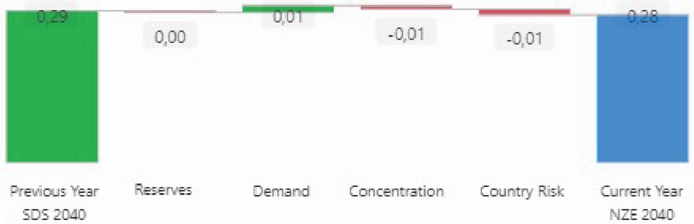
2021 (t)	2022 (t)	Growth
24.000.000	26.000.000	8,33 %

Production 2022

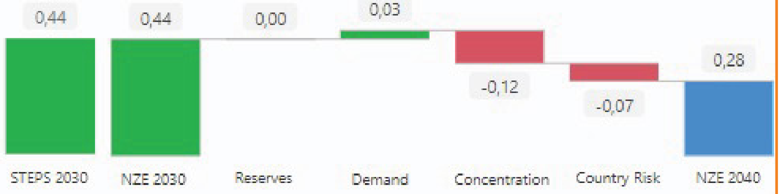
Reserves 2022



Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Vanadium index responds mainly to country concentration/risk. Despite increase of demand projection by the IEA, the net change of the index is negative, since some new reserves have been added and they are located in Australia.

Results: Mineral sheets

Zinc

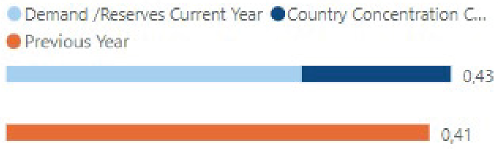
Zinc is mosty used for metallurgical applications. About 3/4 of zinc is consumed as metal, mainly as a coating to protect iron and steel from corrosion (galvanized), as alloying metal to make brass, as zinc-based die casting alloy, and as rolled zinc.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f
(demand/reserves, concentration, country risk)

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,43	6,67 %	12	0

Criticality Index Breakdown



Demand clean technologies NZE (IEA)

2022 (t)	Growth 2030	Growth 2040
584.508	x4	x3

Total Production (USGS)

2021 (t)	2022 (t)	Growth
12.700.000	13.000.000	2,36 %

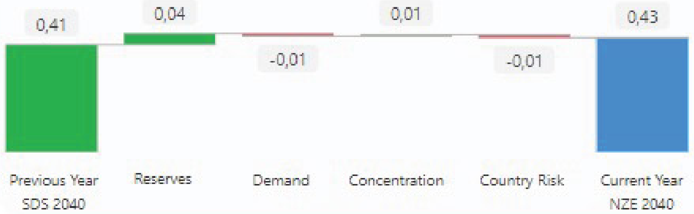
Total Reserves (USGS)

2021 (t)	2022 (t)	Growth
250.000.000	212.900.000	-14,84 %

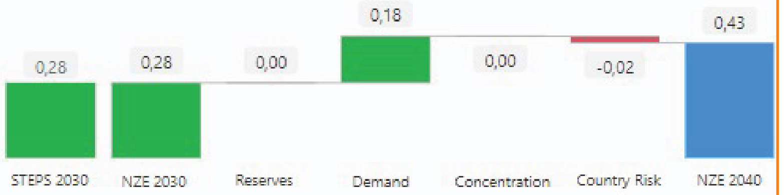
Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)



Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Zinc index responds mainly to depletaion time. It has increased from previous year, mainly due to reserves depletion in China, Mexico, Kazakhstan and other countries. This has affected in turn the concentrantion and country risk. Demand projections have also been reduced.

Results: Mineral sheets

Zirconium

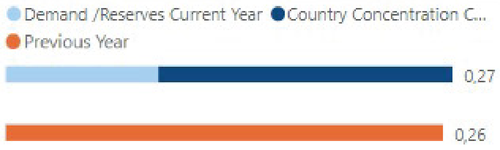
Zirconium is mostly used for metallurgical and nuclear applications. Zirconium is used in ceramics, foundry equipment, glass, chemicals, and metal alloys. Zircon sand is used for heat-resistant linings for furnaces, for giant ladles for molten metal, and to make foundry moulds. Zirconium is a by-product obtained after mining and processing of the titanium minerals ilmenite and rutile, as well as tin mining.

Mineral	Criticality Index
Indium	0,70
Chromium	0,63
Arsenic	0,58
Gallium	0,58
Germanium	0,58
Boron	0,57
Magnesium	0,55
Tin	0,49
Niobium	0,49
PGM	0,46
Cobalt	0,45
Zinc	0,43
Lead	0,42
Titanium	0,39
Nickel	0,39
Silicon	0,38
Silver	0,37
Tantalum	0,34
Selenium	0,34
Molybdenum	0,32
Tungsten	0,32
Cadmium	0,32
Graphite	0,30
Manganese	0,29
Vanadium	0,28
Copper	0,27
Zirconium	0,27
Hafnium	0,27
Lithium	0,26
REE	0,25
Tellurium	0,19
Aluminium	0,17

Criticality Index = f *(demand/reserves, concentration, country risk)*

Criticality Index	Change vs previous year	Ranking	Change vs previous year
0,27	4,20 %	27	1

Criticality Index Breakdown



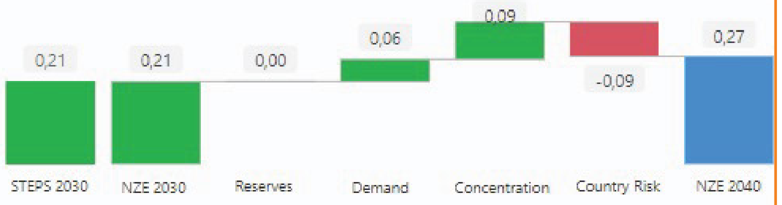
Demand clean technologies NZE (IEA)			Total Production (USGS)			Total Reserves (USGS)		
2022 (t)	Growth 2030	Growth 2040	2021 (t)	2022 (t)	Growth	2021 (t)	2022 (t)	Growth
684	x24	x19	1.300.000	1.400.000	7,69 %	70.000.000	68.000.000	-2,86 %

Production 2022

Reserves 2022

Criticality Index Evolution Year "n-1" vs Year "n" (NZE 2040)

Crit. Index Evolution STEPS 2030 → NZE 2030 → NZE 2040



Related Facts

Zirconium index responds to both depletion time and country concentration/risk. It has slightly increased from previous year due to the presence of reserves in Senegal.

Results: Mineral sheets

Technology

Basic information about the technology

Technology Index and position in ranking

Mineral intensity
(%, main minerals)

Total mineral intensity and Technology Index (combined seffect of mineral intensity and criticality index)

Technology Index ranking

Technology Index evolution for different scenarios and years

Related Facts

Explanation about the Technology Index

Results: Technology Sheets

KEY SHEET (see APPENDIX 1: METHODOLOGY)

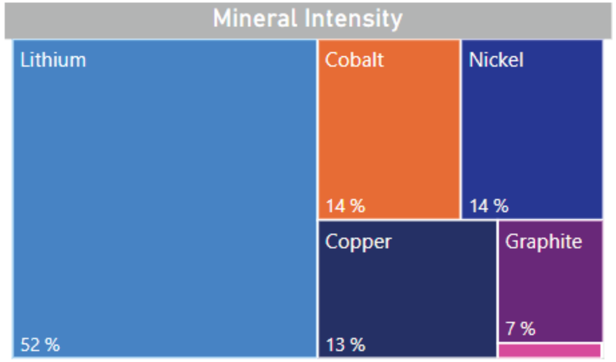
Battery Storage

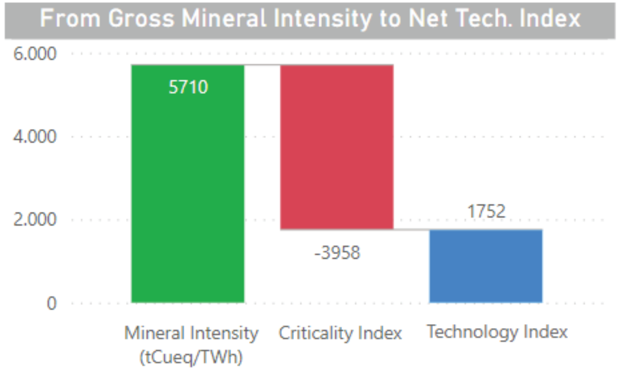
Battery storage and EVs have already displaced consumer electronics to become the largest consumer of lithium, and are set to take over from stainless steel as the largest end user of nickel by 2040.

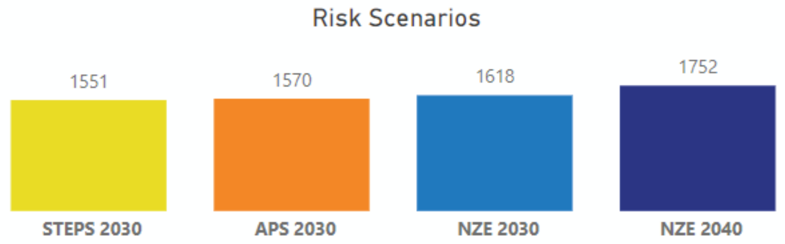
Technology Index	Ranking
1752	2

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*







Related Facts

Battery storage presents the second higest risk in terms of mineral dependency, driven by high mineral intensity (lithium, cobalt, nickel).

Results: Technology Sheets

Bioenergy

Power system flexibility will rely increasingly on bioenergy. Bioenergy main mineral needs are copper and zinc. The mineral intensity is relatively low in comparison with other technologies.

Technology Index 2

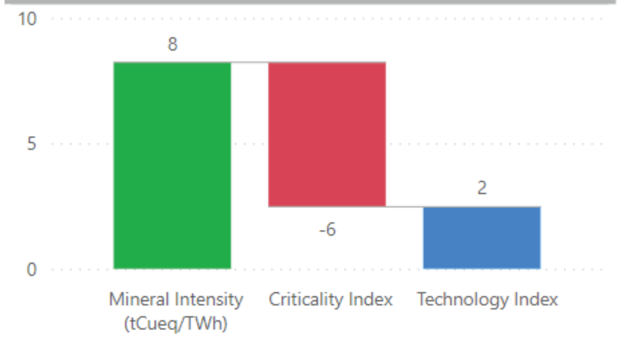
Ranking 12

Technology	Criticality Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

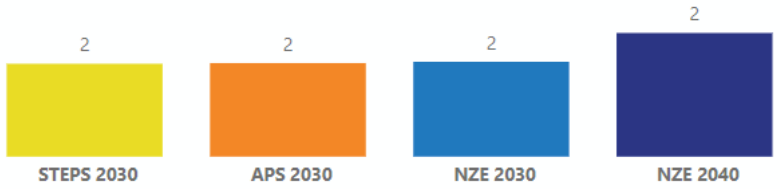
Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*

Mineral Intensity

From Gross Mineral Intensity to Net Tech. Index



Risk Scenarios



Related Facts

Bioenergy is the technology with the lowest risk value in terms of mineral dependency. Copper, titanium and zinc are the key minerals for this technology.

Results: Technology Sheets

CCS

CCS deployment has been behind expectations in the past but momentum has grown substantially in recent years, with over 500 projects in various stages of development across the CCS value chain. In this report CCS has been considered as a complement to fossil fuel generation.

Technology Index

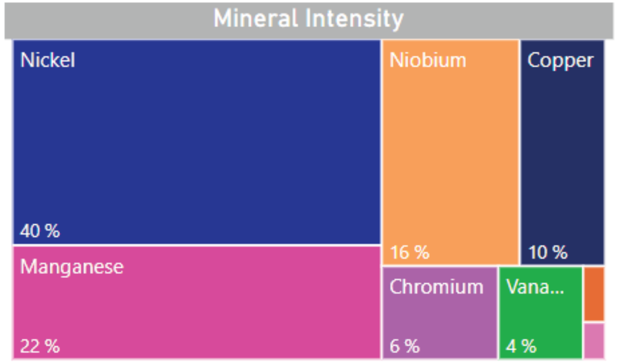
10

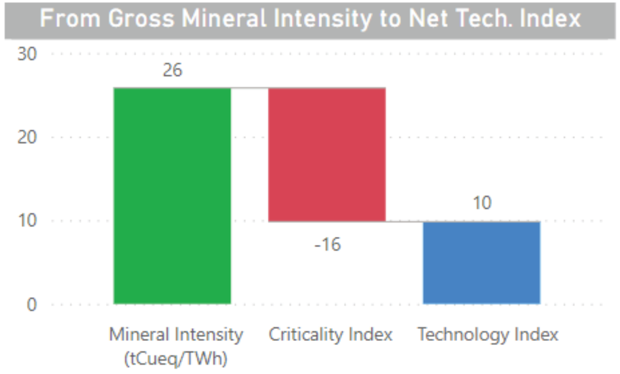
Ranking

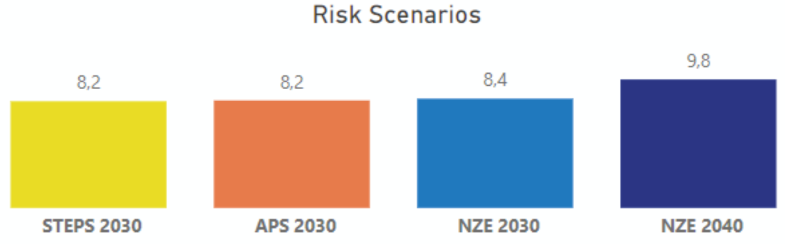
10

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)







Related Facts

CCS presents a low risk value, with nickel and manganese as key elements.

Results: Technology Sheets

CSP

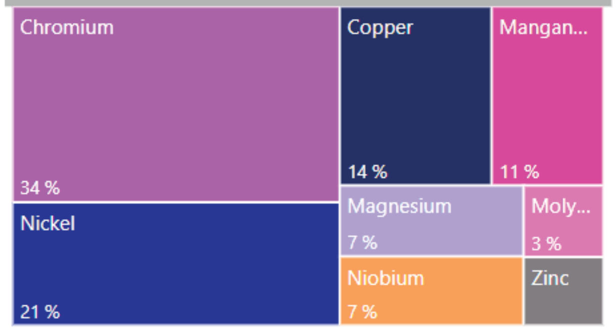
Central tower systems generally require more materials than parabolic trough systems, including eight times more manganese, four times more nickel, and twice as much silver. However, parabolic trough systems require more than twice as much copper.

Technology Index	Ranking
127	4

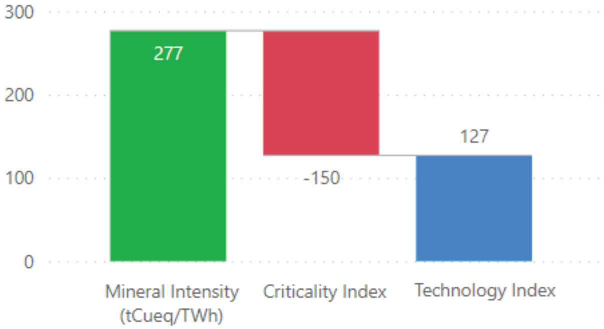
Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*

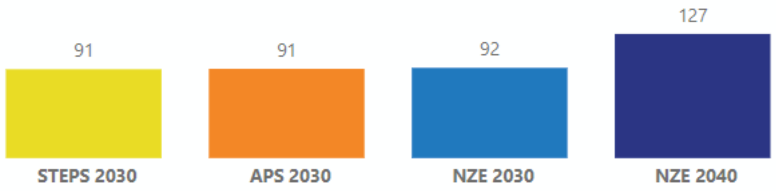
Mineral Intensity



From Gross Mineral Intensity to Net Tech. Index



Risk Scenarios



Related Facts

CSP takes the fourth place in terms mineral risk. Chromium, nickel, copper, magnesium explain the result.

Results: Technology Sheets

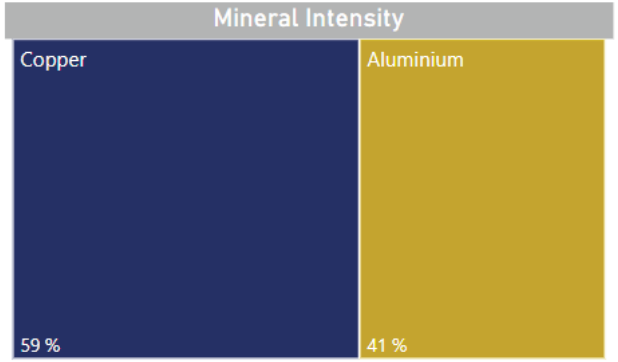
Electricity Grids

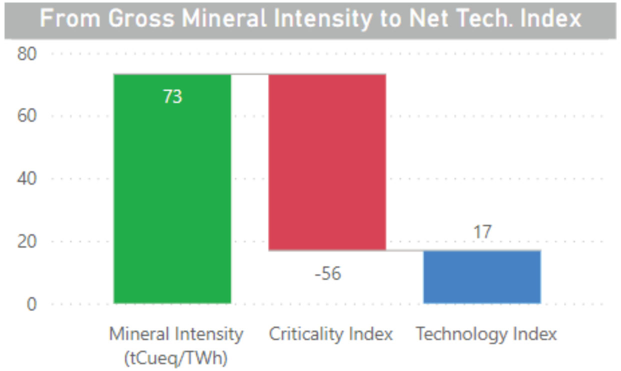
The deployment of renewable sources power generation, needs to be supported by measures to expand and modernise grids. Copper will be pivotal for grids and aluminium is the other main material in wires and cables. The choice of material is mainly driven by the typo of power line.

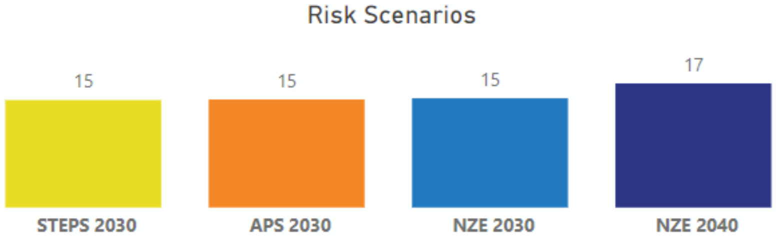
Technology Index	Ranking
17	8

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)







Related Facts

Electricity grids presents low risk. Copper and Aluminium are the main metals employed by this technology.

Results: Technology Sheets

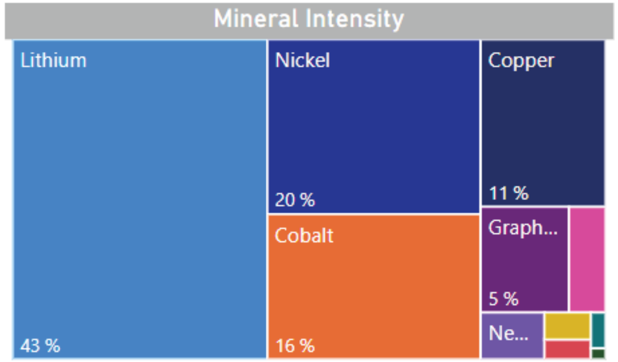
EV

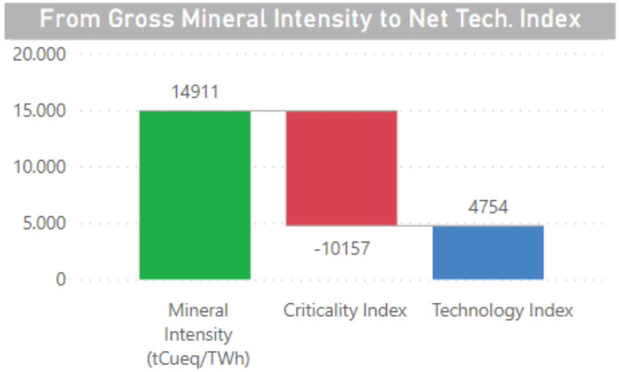
A typical electric car requires six times the mineral inputs of a conventional car. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance. In 2020, EVs accounted for 4% of global car sales. They are on track to reach 18% in 2023 with 14 million EV sales, mostly in China and the advanced economies, and are set to continue to increase rapidly in the future.

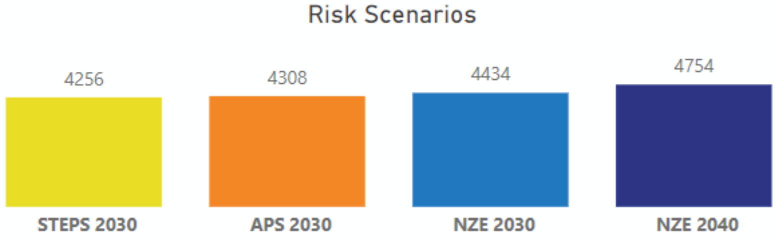
Technology Index	Ranking
4754	1

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)







Related Facts

EV is the technology with highest risk in terms of mineral dependency. Its high mineral intensity (lithium, cobalt, nickel...) makes it vulnerable to mineral supply chains.

Results: Technology Sheets

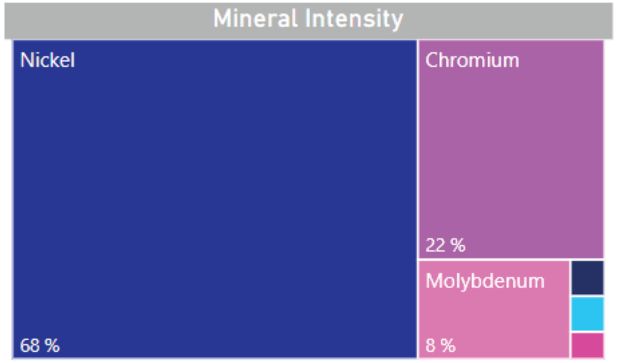
Geothermal

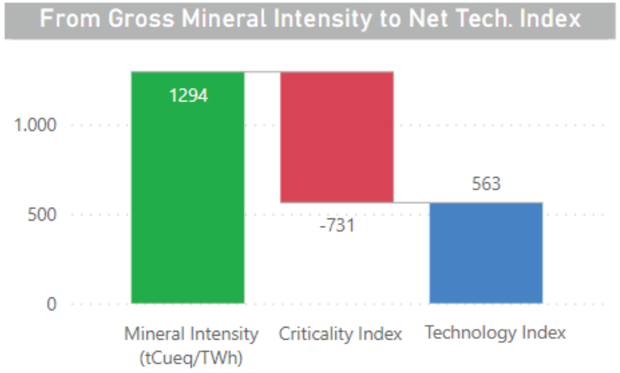
The huge rise in the share of solar PV and wind in total generation fundamentally reshapes the power system and significantly increases the demand for power system flexibility to maintain electricity security. This puts a premium on dispatchable low emissions technologies, such as geothermal. This technology will play a role as a complement to the dominant renewable electricity technologies.

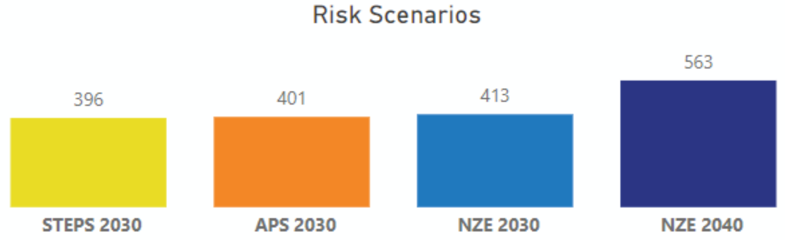
Technology Index	Ranking
563	3

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*







Related Facts

Geothermal presents the third highest risk in terms of mineral dependency. High intensity for some elements such as nickel and chromium drives this result.

Results: Technology Sheets

Hydro

Hydro has a relatively low mineral intensity compared to other sources of low-carbon power. Hydropower does not use REEs, and its current use of copper, manganese and nickel are among the lowest of all low-carbon sources.

Technology Index

10

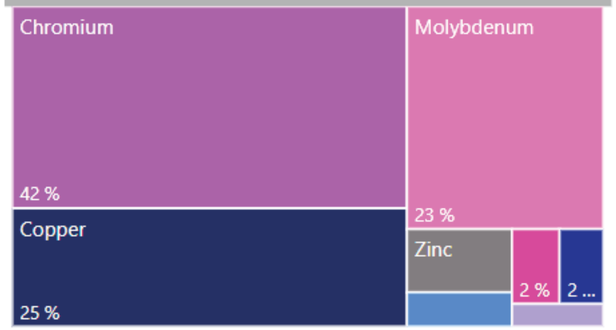
Ranking

9

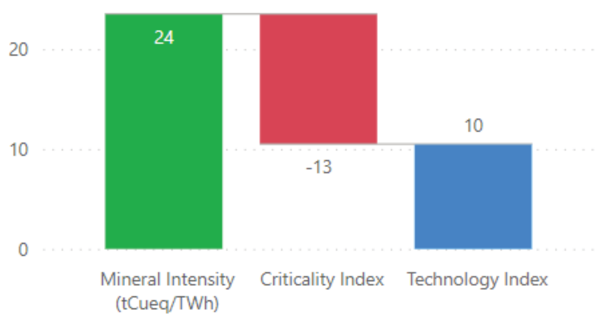
Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*

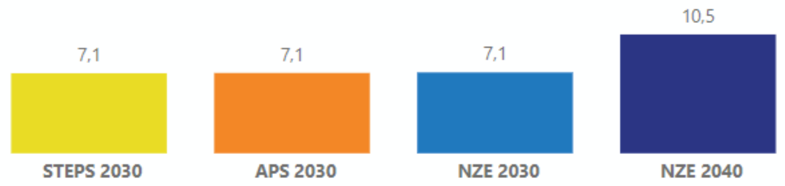
Mineral Intensity



From Gross Mineral Intensity to Net Tech. Index



Risk Scenarios



Related Facts

Hydro presents a low risk value, driven by low intensity of chromium and copper.

Results: Technology Sheets

Hydrogen

Alkaline electrolyzer are nickel and zirconium intense. Current akaline designs require nickel in quantities of around one tonne per MW, and around 100kg of zirconium. PEM electrolyser is intense in platinum, palladium and iridium and currently use around 0.3 kg of platinum and 0.7 kg of iridium per MW. Experts believe reductions of these amounts are possible in the next decade in order to minimise costs.

Technology Index

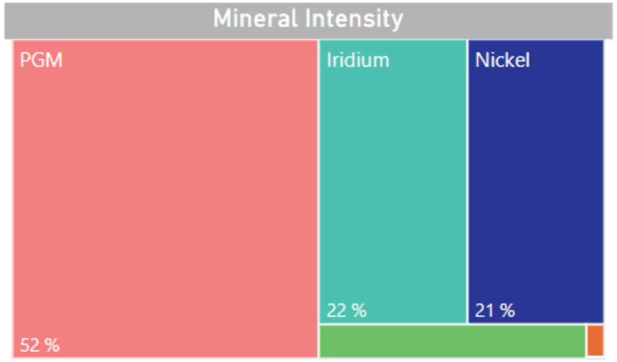
34

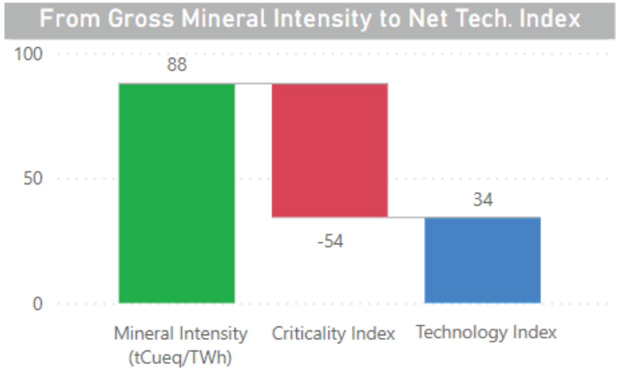
Ranking

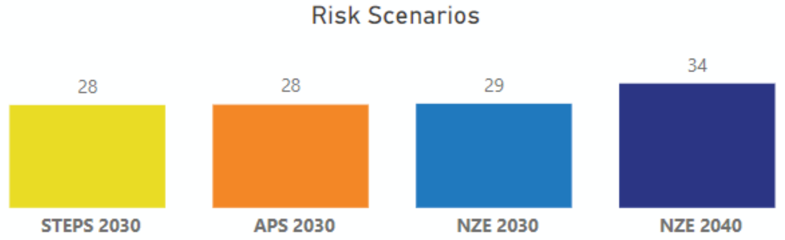
7

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)







Related Facts

Hydrogen presents a moderate risk value driven by moderate mineral intensity of platinum group metals and nickel.

Results: Technology Sheets

Nuclear

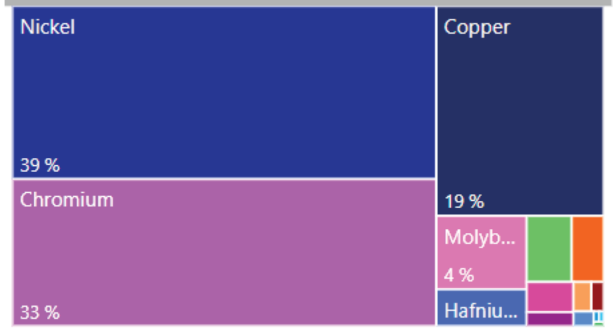
The lasting gains from the crisis accrue to low-emissions sources, mainly renewables, but also nuclear in some cases. As a short-term policy responses to the crisis, some nuclear power plants lifetime has been extended. Currently 10% of electricity generation is coming from nuclear. Among the clean technologies, nuclear is the one with less minerales requirements.

Technology Index	Ranking
9	11

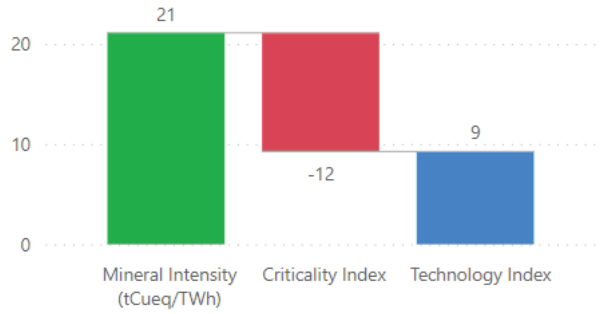
Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)

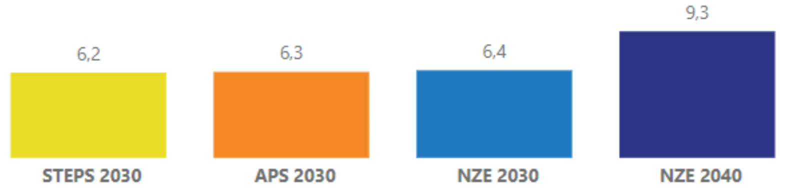
Mineral Intensity



From Gross Mineral Intensity to Net Tech. Index



Risk Scenarios



Related Facts

Nuclear presents a very low risk value. Despite employing a large number of critical minerals (15 according to the IEA), its high energy output makes it one the least exposed technologies.

Solar

In 2021, solar PV demand accounted for 11% of global silver production, over 6% of metallurgical-grade silicon and over 40% of all refined tellurium. As a huge solar PV generation increase is expected in the following years, the demand rate of critical minerals, specially both silver and silicon, will grow notably.

Technology Index

43

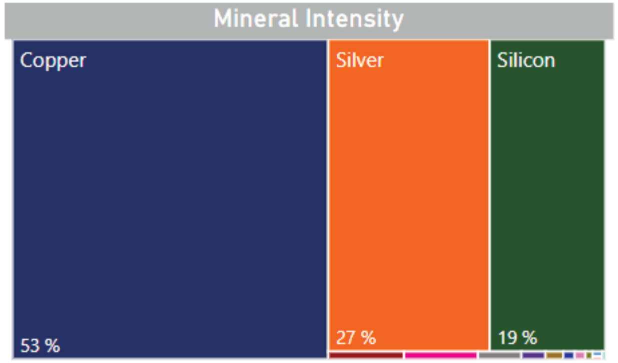
Ranking

6

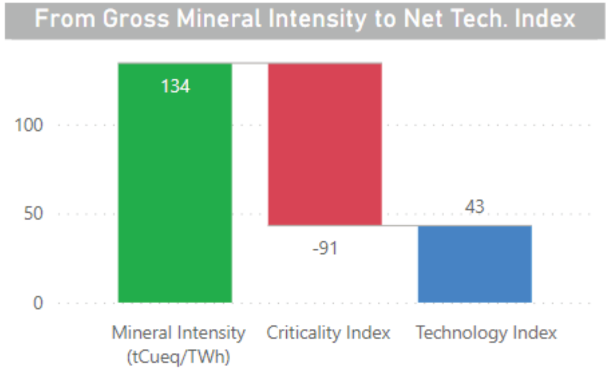
Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** (*mineral intensity, mineral risk, mineral price*)

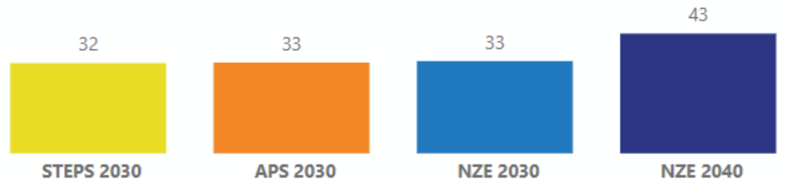
Mineral Intensity



From Gross Mineral Intensity to Net Tech. Index



Risk Scenarios



Related Facts

Solar PV presents a modrate risk. Copper, silver and silicon drive the result.

Results: Technology Sheets

Wind

An onshore wind plant requires nine times more mineral resources than a gas-fired power plant. Rare earth elements (REEs) are used to manufacture the permanent magnets for the hybrid wind turbines.

Technology Index

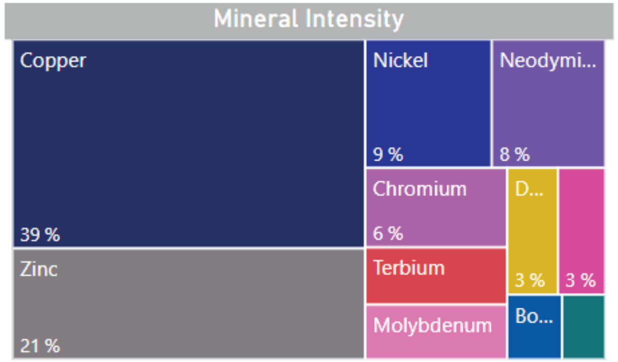
46

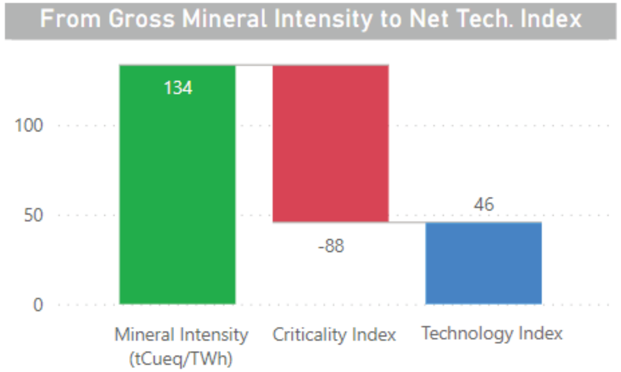
Ranking

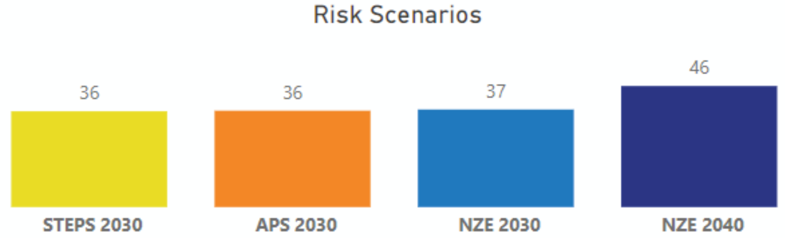
5

Technology	Technology Index
EV	4754
Battery Storage	1752
Geothermal	563
CSP	127
Wind	46
Solar	43
Hydrogen	34
Electricity Grids	17
Hydro	10
CCS	10
Nuclear	9
Bioenergy	2

Technology Index = **f** *(mineral intensity, mineral risk, mineral price)*







Related Facts

Wind is the fifth technology in the ranking. Moderate mineral intensity of copper, zinc, REE drive the result.

Results: Technology Sheets

Main trends

The last years have seen record deployment of clean energy technologies, like solar PV and electric vehicles, which is adding pressure to the critical minerals markets. But the future of the energy transition will be affected by the ability of the supply side to respond to such an unprecedented growth. The next paragraphs summarize the latest news and trends in terms of investment in the mining sector, efforts for diversification, recent policies and technology shifts.

Investment

According to the International Energy Agency, investment in critical minerals increased 20% in 2021 and 30% in 2022. Companies based in China are responsible for most of it since they doubled the capital spending in 2022.

The same source also highlights that exploration spending increased 20% in 2022 driven by Lithium, with Canada, Australia, Africa, and Brazil as main focus. Apart from Lithium, Uranium and Nickel also experienced significant growth in spending.

Despite the increase in investment spending, the world's largest Copper producers have recently warned that there is a lack of mines to provide enough Copper to keep pace with the energy transition. Mining companies struggle with falling metal prices derived from the weakness of the global economy and cost inflation, which makes executives, investors and banks cautious over financing new projects.

Diversification

One of the main hurdles for the future supply of critical minerals, and hence for the energy transition, is the diversification of the supply sources. Countries are trying to tackle this problem with a wave of new policies. These efforts try to change the current supply model where critical minerals are being extracted from resource-rich countries, processed in China, and shipped to consuming countries. Countries are choosing different approaches depending on their position on the supply chain.

Australia, a mineral producing country, has launched in 2023 its Critical Minerals Strategy, in an attempt to create diverse and resilient supply chains through strong partnerships and build sovereign capability in critical minerals processing.

Canada, also a mineral producing country, also released its Critical Minerals Strategy in 2022 to promote new projects, attract investment, support economic growth and enhance global security, among other objectives.

The US passed in 2022 the Inflation Reduction Act (IRA), a bill that aims to curb inflation, partly by investing into domestic energy production while promoting clean energy. It includes tax credits for products (i.e., electric vehicles) containing critical minerals produced and processed in the US or friend-shored countries. The White House is also pushing federal agencies to invest in mineral production and processing at home and overseas.

The EU, as a mineral consumer region, recently launched the Critical Raw

Main trends

secure, diversified, affordable and sustainable supply of critical raw materials. It sets objectives for extraction, processing and recycling by 2030. Among other measures, the Act will reduce the administrative burden of permits for raw materials and select strategic projects that will benefit from support for access to finance and shorter permitting timeframes. It will also focus on international trade in order to support global production and ensure diversification of supply.

Diversification is also happening at a company level. Automakers like Tesla are diversifying into Lithium refining in order to control the supply of the metal. The US company announced in May 2023 a $375 million investment into a refining plant in Texas aiming to internalise production of Lithium.

Mining policies and interventions

Resource-rich countries are also revising their mining legal framework, introducing new policies to promote mining activity while addressing environmental issues and social acceptance (e.g., Canada and Chile).

Some countries are trying to obtain more value from the extraction of their resources. Chile is currently introducing reforms related to Copper mining royalties and reviewing the Lithium concession system while Mexico nationalised its Lithium industry in 2022.

According to a study by the OECD, export restrictions on raw materials have multiplied by five since 2009. A recent example is Indonesia, that banned in 2022 the export of Nickel ore, requiring Nickel to be processed domestically for export; they are considering similar moves for Bauxite, Tin and Cobalt. Some African countries are adopting similar strategies, like Namibia and Zimbabwe, that have banned the export of unprocessed mineral ore.

In November 2022 Indonesia approached Canada to propose establishing an OPEC-like organisation (cartel) for nickel producing countries (Indonesia is the main global producer of the metal and Canada the sixth). Canada rejected the offer, but Indonesia said it had to approach other nickel producers, and hence similar moves could occur for this or other minerals.

Gallium and Germanium have also been object of an export ban by China in July 2023. Both minerals are by-products of other materials such as Lead, Zinc, Copper or Bauxite, and China controls around 90% of their production. The measure comes after a US-led restriction on semiconductor sales in the context of the geopolitical competition between the two superpowers. Gallium and Germanium are mostly used for components in military and communications equipment, hence the relevance, but also in solar PV equipment.

China also produces about 65% of the world's natural Graphite, according to the US Geological Survey. In September 2023, they threatened to impose an export ban on Graphite, which is used in electric vehicle batteries.

On a global scale, deep sea mining has been a hot topic in 2023. Deep sea mining could unlock mineral resources needed for the Energy Transition, but the consequences of this activity are potentially risky, ranging from damage to ecosystems, fisheries and carbon sinks. In July representatives of 168 member states of the International Seabed Authority gathered for

Main trends

industry. Countries like France and Germany lead a fightback against plans to allow commercial mining in the deep seas, while other countries like South Korea, Russia, Norway and China pushed to lift over current restrictions. The meeting ended with no clear agreement and regulation on the topic, due in 2025, is now thought to be unrealistic.

Technology

Batteries for electric vehicles and for electricity storage are some of the main drivers for mineral demand, and most of the recent trends are associated with minerals employed by them or companies along their value chain. Lithium is the main mineral used for EV batteries.

Oil and gas companies are starting to diversify into Lithium, hoping for technology breakthroughs that will allow them to produce the mineral. New technologies for Direct Lithium Extraction (DLE) present synergies with the oil and gas activity, since Lithium present in formation water can be separated for its use in batteries. Companies like ExxonMobil, Chevron, Schlumberger, Occidental Petroleum and Equinor are investing into DLE companies to push the scale of the technology up, but some commercial hurdles need to be overcome, related to cost, time to market and ESG credentials.

Some automakers are focused on substituting current Lithium-ion technologies with solid state ones. Solid state batteries provide advantages over current Li-ion ones, such as longer range (some sources say it could be doubled) and increased safety. Toyota recently announced a manufacturing breakthrough that could make this type of batteries commercially ready as soon as 2027.

Another recent breakthrough in the battery sector was announced in November 2023 by Swedish start-up Northvolt. It claims that it has developed a Sodium-ion battery with an energy density similar to that of Lithium-ion batteries. This is an important breakthrough, since Sodium-ion batteries do not need critical minerals, and therefore is a technology that could ease the Energy Transition and minimise reliance on China.

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Appendix 1: Related GHG Emissions

The usual stages of primary elements manufacturing are mining and concentrating of the ore, smelting or separation, and refining. In each stage the material is purified, and the separation of impurities and byproducts helps increase the concentration of the element in the final product. Thanks to these processes, in their multiple forms and combinations, it is possible to obtain the primary chemical element.

The complexity of production systems is high. As elements are frequently contained in different minerals, and minerals frequently contain several elements, the manufacturing chains intersect. Therefore, elements are often obtained as co-products of the manufacturing chain of other elements. This is why the greenhouse gas emissions intensity associated with elements manufacturing is hard to estimate. For these estimates, we have the invaluable help of the life cycle analysis tools, which tell us that the emissions intensity varies greatly from one element to another. And they also show us that most of these emissions originate in the purification and refining stages, as a consequence of the intensive use of fuels.

Indeed, elements need to be refined in order to reduce the content of impurities to such levels that make them suitable for their technological uses. Smelting processes, which are frequent in the refining of metals, typically involve the use of fossil fuels, either directly as reductants or indirectly for the production of heat and electricity. Both pyrometallurgy, which consists of processing the metal concentrate at high temperatures in heating or electric arc furnaces to separate the metal from other elements present in the mineral ore, and hydrometallurgy, where the stripping takes place in a liquid solution, sometimes at high pressures, require large inputs of energy.

If forecasts of increased demand for minerals materialize, it can be expected that mined ore grades will tend to worsen as the best resources are exhausted and deposits with lower quality ores are put into exploitation. As this happens, the energy intensity of mining and beneficiation processes will increase, and so will the intensity of greenhouse gas emissions. But at the same time, it is expected that the improvement in process efficiencies will counteract this trend, at least in part, which is why a fixed emission factor per ton of element manufactured (tCO2eq/t) has been established throughout the period 2023-2050 as a reasonable hypothesis for the purpose of evaluating the weight of these emissions on total emissions.

Most of the emission factors shown in the chart below (Figure 3) have been taken from the 2014 paper entitled “Life Cycle Assessment of Metals: A Scientific Synthesis”, by Nuss, P. and Eckelman, M.J.

Appendix 1: Related GHG Emissions

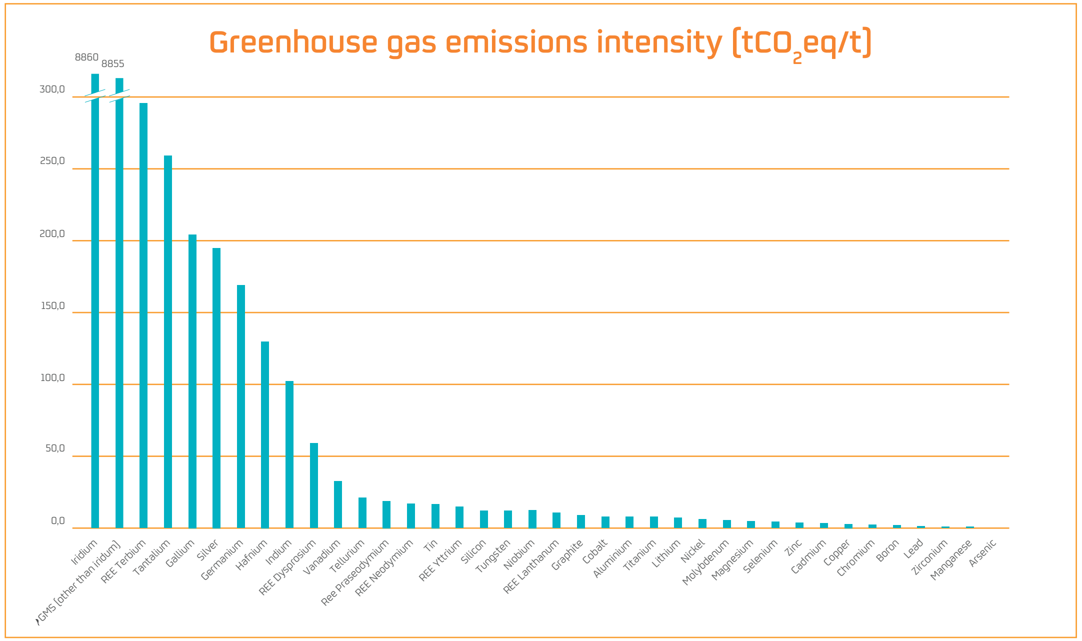

Figure 3: *GHG emission intensity for selected minerals (Nuss, P. et al., 2014)*

If we multiply these emission factors by the demand projections for each of the minerals until 2050 according to the IEA's Critical Minerals Demand Dataset (2023), for the STEPS, APS and NZE scenarios, we obtain the greenhouse gas emissions that derive from the manufacturing of elements intended to cover the needs caused by the energy transition (Table 3), under the forementioned hypothesis that the emission factors remain constant until 2050

Greenhouse gas emissions derived from the manufacturing of metals for the energy transition (ktCO2)

2022		2030	2035	2040	2045	2050
124.147	**STEPS**	191.602	**199.134**	208.976	**218.576**	209.999
	APS	228.570	**279.902**	314.047	**326.052**	320.387
	NZE	310.171	**393.803**	435.714	**405.685**	352.754

Table 3

It must be emphasized that these emissions projections are not those of the mining industry (including primary mineral production and transformation) as a whole, but only a small part of them. As an example, most sector emissions are those associated with the production of iron and steel. Iron is, by far, the most relevant metal in terms of associated greenhouse gas emissions, because of its huge demand, but it is not even considered a critical element for the energy transition, which is why it is excluded from these projections despite its relevance in terms of emissions.

On the other hand, global CO2 emissions derived from combustion activities, according to the IEA's World Energy Outlook 2023, are as follows (Table 4):

Appendix 1: Related GHG Emissions

Global CO2 emissions derived from combustion activities, 2010-2050 (ktCO2)						
2022		**2030**	**2035**	**2040**	**2045**	**2050**
34.042.260	**STEPS**	32.162.410	**30.141.110**	28.708.190	**27.703.350**	26.782.160
	APS	28.115.210	**21.966.330**	17.374.920	**13.756.980**	10.967.600
	NZE	21.958.070	**12.017.250**	5.820.020	**2.570.090**	654.570

Table 4

And therefore, the theoretical weight of emissions associated with the manufacture of these elements, in the different IEA scenarios, is as shown below (Table 5):

Greenhouse gas emissions derived from the manufacturing of metals for the energy transition (ktCO2)						
2022		**2030**	**2035**	**2040**	**2045**	**2050**
0,4	**STEPS**	0,6	**0,7**	0,7	**0,8**	0,8
	APS	0,8	**1,3**	1,8	**2,4**	2,9
	NZE	1,4	**3,3**	7,5	**15,8**	53,9

Table 5

That is, if we accept the hypothesis of the fixed emission factor of metal manufacturing processes, in the IEA STEPS and APS scenarios the emissions associated with their manufacturing would in any case be a small fraction of the total emissions. However, in the NZE scenario, these emissions would represent a significant fraction from the year 2040 on, greater than 15% in 2045 and 50% in 2050. The paradox would then arise that the main driver of decarbonization would be precisely an emitter with substantial weight on total emissions.

In conclusion, the manufacturing processes of critical minerals will need to be decarbonized themselves to some extent, and this circumstance can be expected to pressure their prices upwards, regardless of any other consideration related to the supply – demand balance.

Appendix 2: Methodology

The main goal of this Observatory is to regularly monitor the evolution of main trends related to critical minerals employed on clean energy technologies, from current supply to future demand, passing through technology tendencies, new regulation, etc.

In pursue of transparency and objectivity, a quantitative approach has been defined based on public data from reliable sources. In the following pages, the methodology will be explained, starting with the conceptualization, based on bibliography research, and following with the selection of data sources and definition of an index for minerals and another one for technologies.

Research on criticality index methodologies

The first step of the process was to establish a methodology, and for doing so, some literature was consulted on how to evaluate raw material supply risks (Achzet, B. et al., 2013, Glöser, S., et al., 2015, US National Science and Technology Council, 2016).

According to Achzet, B. et al., the main indicators used for the definition of criticality indexes for raw materials are:

- Country concentration
- Country risk
- Depletion time

Appendix 2: Methodology

Some of them can be obtained or estimated easily from public and reliable sources, like country concentration and country risk, and therefore applied straightforwardly.

Depletion time is a bit more complex and can, in turn, be assessed in three different ways:

- Average growth of demand projection (detail level: low)
- Depletion time of known reserves (detail level: medium)
- Supply-demand balance projections (detail level: high)

The desired option is the latter, but it would require very specialised sources of information that are not publicly available, which would clash with the transparency principle of the Observatory. The first option would only consider the CAGR of the demand projection, and therefore neglect the current production or the available resources. The second option would be a trade-off between the other alternatives, since it considers demand projections and available resources, and has been the selected one for the current study. This approach is similar to the one followed by the US National Science and Technology Council in their 2016 assessment of critical minerals.

Sources of data

It has already been mentioned that transparency and reliability of the data are paramount for the objective of the Observatory. Hence the sources of data must be public, come from reliable sources and get updated regularly at least once a year, so the indexes can be updated to detect changes.

Appendix 2: Methodology

The selected data source for demand projections is the International Energy Agency (IEA), that published the first report on Critical Minerals in 2021 and the second one in 2023. In the latest update they indicate that they plan to update it every year. These reports contain demand data for the three different scenarios that the IEA uses in its flagship report, the World Energy Outlook (WEO), published also on a yearly basis. The demand projections are split by mineral and technology, ideal for the index as we will see later. The WEO report has also been used for mineral intensity calculations.

The United States Geological Survey (USGS) publishes every month of January a report titled "Mineral Commodity Summaries", which contains information about production, reserves, resources, etc. of minerals. It is a well-known and reliable source that has been selected to obtain reserves and production data.

For Country Risk index, the World Justice Project, an independent organization, has been selected. This agency updates on a yearly basis a report called "Rule of Law Index", with information for most countries.

The methodology proposed in this section is based on the three sources described above. Other sources have been consulted to a lesser extent, and they will be mentioned through this section.

Scope

The list of minerals selected for the Study comes from IEA's and consists of 30 minerals plus 2 mineral groups (Rare Earth Elements -REE- and Platinum Group Metals -PGM-), as shown in Table 6.

Appendix 2: Methodology

Critical Mineral List		
Aluminium	Indium	Silicon
Arsenic	Lead	Silver
Boron	Lithium	Tantalum
Cadmium	Magnesium	Tellurium
Chromium	Manganese	Tin
Cobalt	Molybdenum	Titanium
Copper	Nickel	Tungsten
Gallium	Niobium	Vanadium
Germanium	PGM	Zinc
Graphite	REE	Zirconium
Hafnium	Selenium	

Table 6

For the technologies, the same approach was followed, and the 11 technologies evaluated in the first Critical Minerals report by the IEA were evaluated (Table 7).

Clean Energy Technologies		
Battery Storage	Electric Vehicles	Hydrogen
Bioenergy	Geothermal	Nuclear
Carbon Capture and Storage	Grids	Solar
Concentrated Solar Power	Hydro	Wind

Table 7

Appendix 2: Methodology

Definition of the criticality index and main assumptions

The criticality index is obtained using the following formula:

$$R_i = \alpha_1 * DT_i + \alpha_2 * CC_i$$

Where R_i is the criticality index for mineral i, DT_i is the depletion time factor for mineral i, CC_i is the country concentration factor for mineral i, and α_1 and α_2 are weighing coefficients.

DT_i factor has been defined as the ratio between cumulative demand and reserves for a given mineral (depletion time is the inverse of DT factor, but it has been defined this way because supply risk grows with demand growth and falls with reserves growth)

$$DT_i = \text{Cumulative Demand}_i \, / \, \text{Reserves}_i$$

CC_i has been defined as the product of the square root of the Herfindahl-Hirschman Index (HHI), a concentration index, of production (or reserves), and the summation of Country Risk multiplied by the production (or reserves) share of each country.

$$CC_i = \sqrt{HH_i} * \sum CR_i * \%Production_i$$

Appendix 2: Methodology

With the data from the sources mentioned above and this methodology, the index was calculated for all the minerals and scenarios available in the IEA's report. The following assumptions or simplifications were made:

• The index was calculated for 32 minerals or groups of minerals (PGM and REE were grouped), 3 scenarios (Stated Policies Scenario, STEPS; Announced Pledges Scenario, APS; Net Zero Emissions Case, NZE) and 3 years (2030, 2040 and 2050).

• CC_i for the short-term index (2030) was calculated using production data by country. CC_i for the long-term index (2040 and 2050) was calculated using reserves data by country. This approach allows us to make the indicator sensitive to the concentration of production in the short term and the concentration reserves in the long term. In this way, the hypothesis of diversification (or concentration) of future supply is implicit, so that in the long term the distribution of production between countries resembles the concentration of current reserves.

• The Rule of Law Index did not provide information for every Country; those countries without a country risk value were given the average from neighbouring or similar countries.

• The USGS does not provide reserves data for Germanium (only production); to complete the evaluation it has been assumed that it has the same index as Gallium given the similarities of both minerals in terms of production and concentration.

• The USGS does not provide reserves data for Gallium since it is a by-product of Aluminium and Zinc production. But they estimate that the content of Gallium in Bauxite and Zinc ores is 50 ppm, and this has been used as an approximation.

• The USGS does not provide reserves data for Hafnium (only production). It is a sub-product of Zirconium and the ratio of Hafnium in Zirconium ores is 1:50 (according to USGS). This proxy has been used to estimate Hafnium reserves.

Appendix 2: Methodology

- The USGS does not provide reserves data for Arsenic (only production). But they estimate that the reserves are 20 times world production, which has been used as an approximation.

- The USGS does not provide reserves data for Cadmium (only production). But Cadmium is a by-product of Zinc and Zinc ores normally contain around 0.03% of the mineral, according to the USGS. This has been used as a proxy to complete the study

- The USGS estimates that Magnesium and Silicon reserves are sufficient to supply current and future requirements. But they have been included in the study because their production is concentrated in a number of countries, which could lead to supply/demand tightness.

- The USGS does not provide reserves data for Titanium metal, only for Titanium mineral. It has been assumed that 3% of Titanium is used for Titanium metal production (USGS).

- Aluminium reserves have been estimated based on Bauxite ones, assuming that 5 mass units of Bauxite are needed to obtain 1 of Aluminium (according to Atlantic, a mining company).

- Demand projections from the IEA are only for Clean Energy. It has been assumed that the remaining production to fulfil current demand will grow at the same pace as the global economy (2,2% CAGR, according to the World Bank, an international financial institution).

Appendix 2: Methodology

- A comparison with previous year has been presented in this Report. Nevertheless, the Net Zero Emissions (NZE) case did not exist when the Agency launched the first Critical Minerals report. Therefore, the criticality index associated with SDS (Sustainable Development Scenario) from previous year has been compared with its equivalent index associated with NZE from current year.

- α_1 and α_2 were defined so that each of the terms of the equation can have values ranging between 0 and 0,5, and Ri can take values between 0 and 1.

Definition of the technology index and main assumptions

Once the criticality index was obtained for all selected minerals, the risk had to be applied to the technologies that employ them, in order to understand which ones are more vulnerable to mineral risk.

$$R_j = \sum R_i * MI_{ij}$$

Where R_j is the technology index for technology j, R_i is the risk for mineral i, and MI_{ij} is the mineral intensity of mineral i when used for technology j.

Mineral intensity for each mineral and technology was in turn obtained from several sources: IEA reports, CEPAL report (Economic Commission for Latin America and the Caribbean, a UN regional commission), Ashby M. F., 2013, and the US Department of Energy. It was then multiplied by a coefficient to express the mineral intensity in tonnes of copper equivalent per TeraWatt hour (tCueq/TWh). This is a common practise in the mining industry to compare intensities of different minerals, that means using an average mineral price for the past n years and dividing it by the average price of Copper in the same period.

Appendix 2: Methodology

The result is a value of risk for each technology (12 technologies), scenario (3 scenarios) and year (2030, 2040 and 2050). Some assumptions were made in order to complete the study:

• Mineral intensity data come from different sources since no single source consulted covers all minerals and technologies. They are present day intensities, and therefore do not account for future technology innovation. This will be reassessed in future reports in an attempt to use a single source and include technology improvements.

• The scenarios have also changed between reports: Stated Policies Scenario (STEPS) and Sustainable Development Scenario (SDS) in the first one; Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS) and Net Zero Emissions (NZE) in the second one.

• The time scope has also changed: 2030 and 2040 in the first report, and 2025-2050, with data every 5 years, in the second.

• No mineral price data are available in any of the selected sources for the conversion to Copper equivalent units. Therefore, two new sources were used: the International Monetary Fund (IMF), a financial agency of the United Nations, for the primary minerals such us Copper, Lead, Lithium etc.; and Thomson Reuters, an information company, for minor minerals such as Gallium, Tellurium and others.

METHODOLOGY (SUMMARY)

Variables explicitly included in the methodology:

Demand projections through 2050 (every 5 years, 3 scenarios).

Mineral primary production and reserves.

Country risk.

Mineral intensity.

Variables not explicitly included in the methodology:

Dynamic supply/demand balance.

Secondary supply (recycling).

Mineral/technology improvement and substitutability.

The variables that are not explicitly included in the methodology are ultimately considered, since they will be broadly updated by the providers of the included ones on an annual basis, and they will be implicitly accounting for any change.

Appendix 3: Tables

	STEPS 2030			STEPS 2040			STEPS 2050			APS 2030			APS 2040			APS 2050			NZE 2030			NZE 2040			NZE 2050		
Element	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**	**DTi**	**CCi**	**Ri**
Aluminium	0,02	18,82	**0,21**	0,06	14,34	**0,17**	0,09	14,34	**0,18**	0,02	18,82	**0,21**	0,06	14,34	**0,17**	0,11	14,34	**0,18**	0,03	18,82	**0,21**	0,07	14,34	**0,17**	0,12	14,34	**0,18**
Arsenic	0,44	31,83	**0,44**	1,13	31,83	**0,58**	2,03	31,83	**0,76**	0,44	31,83	**0,44**	1,14	31,83	**0,58**	2,07	31,83	**0,77**	0,44	31,83	**0,44**	1,15	31,83	**0,58**	2,09	31,83	**0,77**
Boron	0,02	31,72	**0,36**	0,05	50,78	**0,57**	0,09	50,78	**0,58**	0,02	31,72	**0,36**	0,05	50,78	**0,57**	0,09	50,78	**0,58**	0,02	31,72	**0,36**	0,05	50,78	**0,57**	0,09	50,78	**0,58**
Cadmium	0,20	19,45	**0,26**	0,51	19,45	**0,32**	0,89	19,45	**0,39**	0,20	19,45	**0,26**	0,51	19,45	**0,32**	0,89	19,45	**0,39**	0,21	19,45	**0,26**	0,52	19,45	**0,32**	0,90	19,45	**0,40**
Chromium	0,65	21,56	**0,37**	1,63	26,68	**0,62**	2,86	26,68	**0,87**	0,65	21,56	**0,37**	1,64	26,68	**0,62**	2,87	26,68	**0,87**	0,65	21,56	**0,37**	1,64	26,68	**0,63**	2,87	26,68	**0,87**
Cobalt	0,20	39,75	**0,48**	0,51	26,34	**0,39**	0,91	26,34	**0,48**	0,22	39,75	**0,49**	0,63	26,34	**0,42**	1,19	26,34	**0,53**	0,28	39,75	**0,50**	0,77	26,34	**0,45**	1,35	26,34	**0,56**
Copper	0,23	12,97	**0,19**	0,58	11,50	**0,24**	1,00	11,50	**0,33**	0,24	12,97	**0,19**	0,64	11,50	**0,26**	1,12	11,50	**0,35**	0,26	12,97	**0,20**	0,72	11,50	**0,27**	1,23	11,50	**0,37**
Gallium	0,00	51,71	**0,58**	0,01	51,71	**0,58**	0,04	51,71	**0,58**	0,00	51,71	**0,58**	0,02	51,71	**0,58**	0,05	51,71	**0,58**	0,00	51,71	**0,58**	0,02	51,71	**0,58**	0,06	51,71	**0,59**
Germanium	0,00	51,71	**0,58**	0,01	51,71	**0,58**	0,04	51,71	**0,58**	0,00	51,71	**0,58**	0,02	51,71	**0,58**	0,05	51,71	**0,58**	0,00	51,71	**0,58**	0,02	51,71	**0,58**	0,06	51,71	**0,59**
Graphite	0,05	36,27	**0,41**	0,13	21,95	**0,27**	0,22	21,95	**0,29**	0,06	36,27	**0,41**	0,20	21,95	**0,28**	0,34	21,95	**0,31**	0,08	36,27	**0,42**	0,28	21,95	**0,30**	0,45	21,95	**0,33**
Hafnium	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,80	15,99	**0,34**	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,80	15,99	**0,34**	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,80	15,99	**0,34**
Indium	0,76	26,31	**0,44**	1,91	26,31	**0,68**	3,36	26,31	**0,96**	0,76	26,31	**0,44**	1,94	26,31	**0,68**	3,41	26,31	**0,98**	0,78	26,31	**0,45**	2,02	26,31	**0,70**	3,51	26,31	**0,99**
Lead	0,47	20,68	**0,32**	1,18	16,33	**0,42**	2,06	16,33	**0,59**	0,47	20,68	**0,32**	1,18	16,33	**0,42**	2,06	16,33	**0,59**	0,47	20,68	**0,32**	1,18	16,33	**0,42**	2,06	16,33	**0,59**
Lithium	0,07	17,98	**0,21**	0,23	13,55	**0,20**	0,46	13,55	**0,24**	0,08	17,98	**0,22**	0,38	13,55	**0,23**	0,82	13,55	**0,31**	0,13	17,98	**0,23**	0,54	13,55	**0,26**	1,04	13,55	**0,36**
Magnesium	0,03	48,22	**0,54**	0,08	48,22	**0,55**	0,14	48,22	**0,56**	0,03	48,22	**0,54**	0,08	48,22	**0,55**	0,15	48,22	**0,57**	0,03	48,22	**0,54**	0,08	48,22	**0,55**	0,15	48,22	**0,57**
Manganese	0,10	20,75	**0,25**	0,26	20,98	**0,29**	0,47	20,98	**0,33**	0,10	20,75	**0,25**	0,27	20,98	**0,29**	0,47	20,98	**0,33**	0,11	20,75	**0,25**	0,27	20,98	**0,29**	0,48	20,98	**0,33**
Molybdenum	0,19	22,57	**0,29**	0,48	19,29	**0,31**	0,83	19,29	**0,38**	0,20	22,57	**0,29**	0,50	19,29	**0,31**	0,87	19,29	**0,39**	0,21	22,57	**0,29**	0,54	19,29	**0,32**	0,91	19,29	**0,40**
Nickel	0,33	20,12	**0,29**	0,88	13,33	**0,32**	1,55	13,33	**0,46**	0,36	20,12	**0,29**	1,04	13,33	**0,36**	1,89	13,33	**0,53**	0,42	20,12	**0,31**	1,21	13,33	**0,39**	2,09	13,33	**0,57**
Niobium	0,04	43,33	**0,49**	0,10	42,06	**0,49**	0,17	42,06	**0,50**	0,04	43,33	**0,49**	0,10	42,06	**0,49**	0,17	42,06	**0,50**	0,04	43,33	**0,49**	0,10	42,06	**0,49**	0,17	42,06	**0,50**
PGM	0,05	27,56	**0,32**	0,13	38,63	**0,45**	0,22	38,63	**0,47**	0,05	27,56	**0,32**	0,13	38,63	**0,46**	0,24	38,63	**0,48**	0,05	27,56	**0,32**	0,15	38,63	**0,46**	0,27	38,63	**0,48**
REE	0,02	34,57	**0,39**	0,05	21,62	**0,25**	0,09	21,62	**0,26**	0,02	34,57	**0,39**	0,06	21,62	**0,25**	0,10	21,62	**0,26**	0,02	34,57	**0,39**	0,06	21,62	**0,25**	0,10	21,62	**0,26**
Selenium	0,35	19,04	**0,28**	0,88	14,21	**0,33**	1,53	14,21	**0,46**	0,35	19,04	**0,28**	0,88	14,21	**0,33**	1,53	14,21	**0,46**	0,36	19,04	**0,28**	0,90	14,21	**0,34**	1,55	14,21	**0,47**
Silicon	0,03	32,58	**0,37**	0,09	32,58	**0,38**	0,15	32,58	**0,39**	0,03	32,58	**0,37**	0,09	32,58	**0,38**	0,16	32,58	**0,39**	0,04	32,58	**0,37**	0,10	32,58	**0,38**	0,16	32,58	**0,39**
Silver	0,41	14,99	**0,25**	1,02	13,26	**0,35**	1,73	13,26	**0,49**	0,43	14,99	**0,25**	1,06	13,26	**0,36**	1,78	13,26	**0,50**	0,46	14,99	**0,26**	1,14	13,26	**0,37**	1,86	13,26	**0,52**
Tantalum	0,06	24,08	**0,28**	0,15	27,91	**0,34**	0,25	27,91	**0,36**	0,06	24,08	**0,28**	0,15	27,91	**0,34**	0,26	27,91	**0,36**	0,06	24,08	**0,28**	0,15	27,91	**0,34**	0,26	27,91	**0,36**
Tellurium	0,16	25,28	**0,31**	0,37	4,16	**0,12**	0,60	4,16	**0,17**	0,18	25,28	**0,32**	0,44	4,16	**0,13**	0,72	4,16	**0,19**	0,28	25,28	**0,34**	0,72	4,16	**0,19**	1,03	4,16	**0,25**
Tin	0,60	22,68	**0,37**	1,50	16,73	**0,49**	2,63	16,73	**0,71**	0,60	22,68	**0,37**	1,50	16,73	**0,49**	2,63	16,73	**0,71**	0,60	22,68	**0,37**	1,51	16,73	**0,49**	2,64	16,73	**0,71**
Titanium	0,11	29,93	**0,36**	0,29	29,93	**0,39**	0,50	29,93	**0,43**	0,11	29,93	**0,36**	0,29	29,93	**0,39**	0,51	29,93	**0,43**	0,12	29,93	**0,36**	0,30	29,93	**0,39**	0,51	29,93	**0,43**
Tungsten	0,20	43,45	**0,52**	0,49	19,93	**0,32**	0,86	19,93	**0,39**	0,20	43,45	**0,52**	0,49	19,93	**0,32**	0,86	19,93	**0,39**	0,20	43,45	**0,52**	0,49	19,93	**0,32**	0,86	19,93	**0,39**
Vanadium	0,03	38,90	**0,44**	0,12	21,71	**0,27**	0,28	21,71	**0,30**	0,04	38,90	**0,44**	0,15	21,71	**0,27**	0,37	21,71	**0,32**	0,04	38,90	**0,44**	0,20	21,71	**0,28**	0,54	21,71	**0,35**
Zinc	0,54	15,35	**0,28**	1,36	13,10	**0,42**	2,38	13,10	**0,62**	0,55	15,35	**0,28**	1,39	13,10	**0,42**	2,43	13,10	**0,63**	0,57	15,35	**0,28**	1,45	13,10	**0,43**	2,49	13,10	**0,64**
Zirconium	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,80	15,99	**0,34**	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,80	15,99	**0,34**	0,18	15,35	**0,21**	0,46	15,99	**0,27**	0,81	15,99	**0,34**

Table 8: *Criticality Index for STEPS, APS and NZE scenarios and 2030, 2040 and 2050*

Appendix 3: Tables

	Mineral Intensity	Technology Index								
Technology	**t Cueq/TWh**	**STEPS 2030**	**STEPS 2040**	**STEPS 2050**	**APS 2030**	**APS 2040**	**APS 2050**	**NZE 2030**	**NZE 2040**	**NZE 2050**
EV	14911	4256	3975	5025	4308	4349	5877	4434	4754	6409
Battery Storage	5710	1551	1448	1823	1570	1594	2159	1618	1752	2372
Geothermal	1294	396	501	697	401	532	760	413	563	796
CSP	277	91	121	160	91	124	165	92	127	169
Wind	134	36	43	57	36	44	59	37	46	61
Solar	134	32	40	52	33	41	54	33	43	56
Hydrogen	88	28	33	36	28	33	38	29	34	39
Electricity Grids	73	15	16	19	15	16	21	15	17	22
Hydro	26	7	10	14	7	10	14	7	10	14
CCS	24	8	9	11	8	9	12	8	10	13
Nuclear	21	6	9	12	6	9	13	6	9	13
Bioenergy	8	2	2	3	2	2	3	2	2	3

Table 9: *Technology Index for STEPS, APS and NZE scenarios and 2030, 2040 and 2050*

Observatory of critical minerals

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