

British Geological Survey

Risk list 2011 — Current supply risk index for chemical elements or element groups which are of economic value

| Element or element group | Symbol | Relative supply risk index | Leading producer |
|--------------------------|--------|----------------------------|------------------|
| antimony | Sb | 8.5 | China |
| platinum group elements | PGE | 8.5 | South Africa |
| mercury | Hg | 8.5 | China |
| tungsten | W | 8.5 | China |
| rare earth elements | REE | 8.0 | China |
| niobium | Nb | 8.0 | Brazil |
| strontium | Sr | 7.5 | China |
| bismuth | Bi | 7.0 | China |
| thorium | Th | 7.0 | India |
| bromine | Br | 7.0 | USA |
| carbon (graphite) | C | 7.0 | China |
| rhenium | Re | 6.5 | Chile |
| iodine | I | 6.5 | Chile |
| indium | In | 6.5 | China |
| germanium | Ge | 6.5 | China |
| beryllium | Be | 6.5 | USA |
| molybdenum | Mo | 6.5 | Mexico |
| helium | He | 6.5 | USA |
| tin | Sn | 6.0 | China |
| arsenic | As | 6.0 | China |
| silver | Ag | 6.0 | Peru |
| tantalum | Ta | 6.0 | Rwanda |
| manganese | Mn | 5.5 | China |
| magnesium | Mg | 5.5 | China |
| cobalt | Co | 5.5 | DRC |
| gold | Au | 5.5 | China |
| cadmium | Cd | 5.5 | China |
| lithium | Li | 5.5 | Australia |
| calcium | Ca | 5.5 | China |
| phosphorous | P | 5.0 | China |
| barium | Ba | 5.0 | China |
| boron | B | 4.5 | Turkey |
| zirconium | Zr | 4.5 | Australia |
| vanadium | V | 4.5 | Russia |
| lead | Pb | 4.5 | China |
| potassium | K | 4.5 | Canada |
| gallium | Ga | 4.5 | China |
| fluorine | F | 4.5 | China |
| copper | Cu | 4.5 | Chile |
| selenium | Se | 4.5 | Japan |
| carbon (coal) | C | 4.5 | China |
| zinc | Zn | 4.0 | China |
| uranium | U | 4.0 | Kazakhstan |
| nickel | Ni | 4.0 | Russia |
| chlorine | Cl | 4.0 | China |
| sodium | Na | 4.0 | China |
| carbon (diamonds) | C | 4.0 | Russia |
| sulphur | S | 3.5 | China |
| iron | Fe | 3.5 | China |
| chromium | Cr | 3.5 | Canada |
| aluminium | Al | 3.5 | Australia |
| titanium | Ti | 2.5 | Australia |

Supply risk index runs from 1 (blue — very low risk) to 10 (red — very high risk)

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Limitations and methodology are set out in accompanying notes

A new supply risk index for chemical elements or element groups which are of economic value

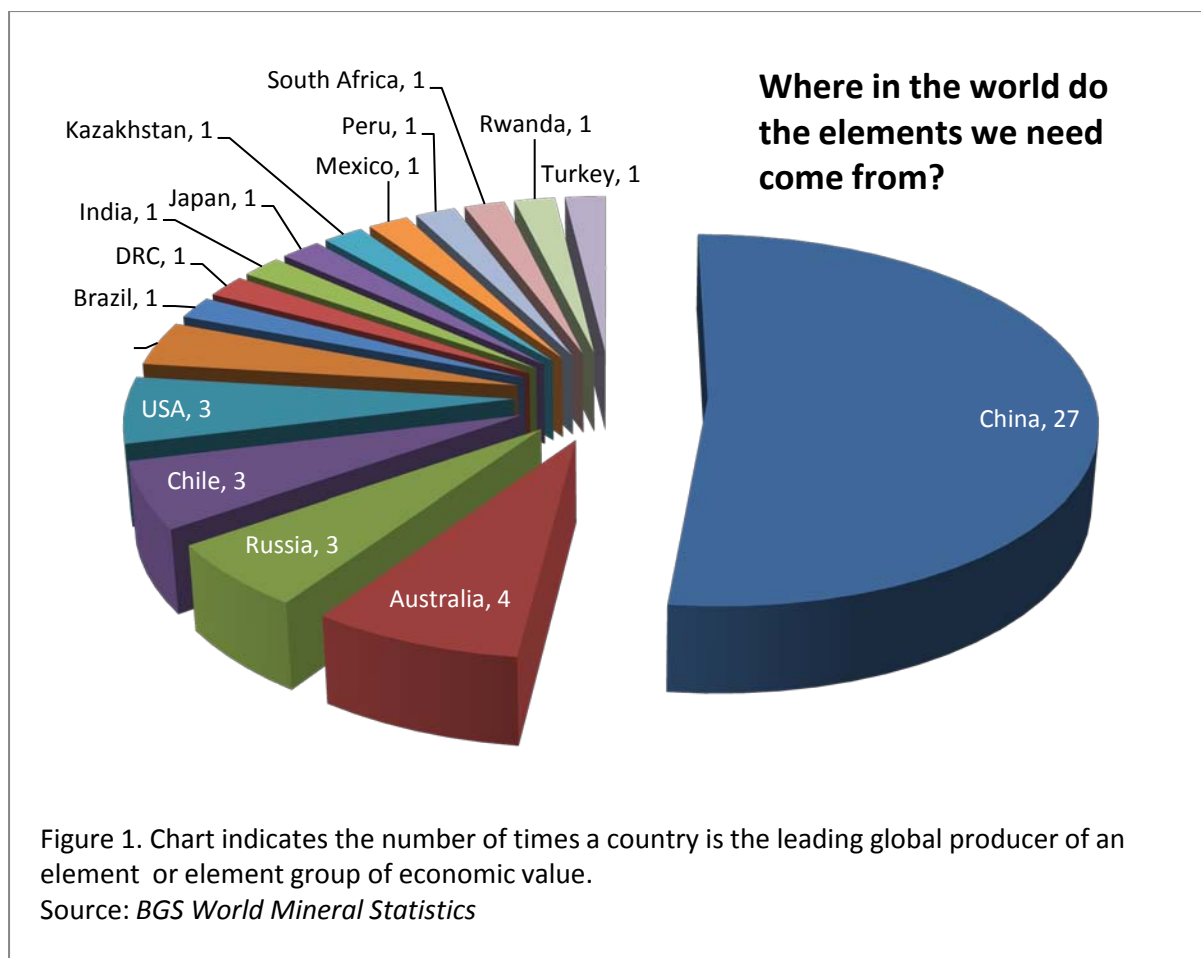
The risk list gives a quick and simple indication of the relative risk in 2011 to the supply of the 52 chemical elements or element groups which we need to maintain our economy and lifestyle. The position of an element on this list is determined by a number of factors which might impact on supply. These include the abundance of elements in the Earth's crust, the location of current production and reserves, and the political stability of those locations. Data sources used in the compilation of the list are internationally recognised and publicly available.

The risk list highlights a group of elements where global production is concentrated in a very few countries. The restricted supply base and the relatively low political stability ratings for some major producing countries combine to significantly increase risk to supply. Restriction on the availability of rare earth elements has received a good deal of attention recently and this group features close to the top of the list. However, the list highlights other economically important metals with similar high levels of risk to supply disruption including platinum group metals (active component in auto-catalysts), niobium (used in MRI scanners and touch screens) and tungsten (key hard metal used in almost all cutting tools). The list also shows the current importance of China in production of many metals and minerals. China is now the leading global producer of 27 of the 52 elements and element groups on the list (and as shown in Figure 1).

As demand for metals and minerals increases, driven by relentless growth in the emerging economies in Asia and South America, competition for resources is growing. The risk list gives an indication which elements might be subject to supply disruption, most likely from human factors such as geopolitics ('haves' seeking to influence 'have nots') or resource nationalism (state control of production), along with events such as strikes and accidents. Policy-makers, industry and consumers should be concerned about supply risk and the need to diversify supply from Earth resources, from recycling more and doing more with less, and also about the environmental implications of burgeoning consumption.

The list focuses on risks to supply and does not include any assessment of factors that influence demand, such as criticality of an element to a particular technology or how easy it is to substitute that element with another.

A more in-depth discussion of the risk list methodology and limitations can be found below.



Methodology for estimating the relative risk to supply of the chemical elements

The following methodology was used to define the relative risk to supply of the following elements:

Ag; Al; As; Au; B; Ba; Be; Bi; Br; C (coal, diamond and graphite); Ca; Cd; Cl; Co; Cr; Cu; F; Fe; Ga; Ge; He; Hg; I; In; K; Li; Mg; Mn; Mo; Na; Nb; Ni; P; Pb; PGE (Ru, Pd, Os, Ir and Pt); Re; REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu); S; Sb; Se; Sn; Sr; Ta; Th; Ti; U; V; W; Zn; and Zr.

Elements not included are those for which insufficient data exist. An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on four criteria scored between 1 and 5.

- Scarcity
- Production concentration
- Reserve base distribution
- Governance

A score of 1 indicates that a particular criterion has a low contribution to supply risk, while a score of 5 indicates a high risk. The scores for each criterion were summed to give an overall risk to supply, the larger the score the greater the potential risk to supply. Each criterion was given equal weight. The elements were ranked according to their score and a gradational colour scale applied such that increased risk is indicated by hotter colours.

Scarcity

Crustal abundances (Table 1) provide an indication of the scarcity of a given element on a global scale. For example, gold would be classified as high-risk due to its low crustal abundance of 0.0013 ppm, while iron would be classified as low-risk with a crustal abundance of about 52,157 ppm.

The scores were allocated as follows:

| | |
|--------------------|------------------|
| 1 (low) | >100 to 1000 ppm |
| 2 (medium to low) | >10 to 100 ppm |
| 3 (medium) | >1 to 10 ppm |
| 4 (medium to high) | >0.1 to 1 ppm |
| 5 (high) | <0.1 ppm |

Where data are unavailable an arbitrary score of 2 was allocated. For example, He is allocated a score of 2 since crustal abundance data is unavailable.

| Element | Abundance (ppm) | Element | Abundance (ppm) |
|---------|-----------------|---------|-----------------|
| Ag | 0.055 | Mn | 774 |
| Al | 84,149 | Mo | 0.8 |
| As | 2.5 | Na | 22,774 |
| Au | 0.0013 | Nb | 8 |
| B | 11 | Nd | 20 |
| Ba | 456 | Ni | 26.6 |
| Be | 1.9 | Os | 0.000041 |
| Bi | 0.18 | P | 567 |
| Br | 0.88 | Pb | 11 |
| Cd | 0.08 | Pd | 0.0015 |
| Ce | 43 | Pr | 4.9 |
| Co | 26.6 | Pt | 0.0015 |
| Cr | 135 | Re | 0.000188 |
| Cu | 27 | Ru | 0.00057 |
| Dy | 3.6 | S | 404 |
| Er | 2.1 | Sb | 0.2 |
| Eu | 1.1 | Se | 0.13 |
| F | 553 | Sm | 3.9 |
| Fe | 52,157 | Sn | 1.7 |
| Ga | 16 | Sr | 320 |
| Gd | 3.7 | Ta | 0.7 |
| Ge | 1.3 | Tb | 0.6 |
| Hg | 0.03 | Th | 5.6 |
| Ho | 0.77 | Ti | 4136 |
| I | 0.71 | Tm | 0.28 |
| In | 0.052 | U | 1.3 |
| Ir | 0.000037 | V | 138 |
| K | 15 025 | W | 1 |
| La | 20 | Yb | 1.9 |
| Li | 16 | Zn | 72 |
| Lu | 0.3 | Zr | 132 |
| Mg | 28 104 | | |

Table 1. Average total crustal abundance of the elements included in this study. Data from Rudnick and Gao (2003).

Production concentration

Where the production of a given commodity is concentrated in a few countries this can increase the risk to supply. For example, about 83 per cent of the world's tungsten is currently sourced from China. The BGS' [World Mineral Production data \(2005-2009\)](#) were used to identify the top three producing countries and the percentage of world supply for which the leading country is responsible.

The percentage production for the top three countries was scored as follows:

| | |
|-----------------|-------------|
| 1 (low) | 0 to 30 % |
| 2 (medium-low) | >30 to 45 % |
| 3 (medium) | >45 to 60 % |
| 4 (medium-high) | >60 to 75 % |
| 5 (high) | >75 % |

Reserve base distribution

It is important to assess where elements might be sourced in the future. However, for many elements the global distribution of resources is poorly known, while reserves¹ are often localised. Accordingly we have used reserve base² distribution data from the USGS to provide an indication of future sources of supplies. Where the reserve base of a given commodity is concentrated in a few countries this leads to increased risk to future supplies. For example, nearly 87 per cent of the world's reserve base of niobium is found in Brazil. The USGS' Commodity Summaries (2009) reserve base data were used to identify the three countries contributing the largest share to the global reserve base and the percentage of the world reserve base held by the top country.

The percentage of the global reserve base held by the top three countries was scored as follows:

| | |
|-----------------|-------------|
| 1 (low) | 0 to 30 % |
| 2 (medium-low) | >30 to 45 % |
| 3 (medium) | >45 to 60 % |
| 4 (medium-high) | >60 to 75 % |
| 5 (high) | >75 % |

Where data are unavailable an arbitrary score of 2 was allocated. For example, Be, As, Na, S, In, Cl, Ca and Ge are allocated a score of 2 since reserve base information is unavailable. Reserve base data are also unavailable for coal; however, reserve data for 2008 are available from the Energy Information Administration (EIA).

Governance indicators

The political stability of a producing country may impact upon the supply of mineral commodities e.g. supplies may be interrupted by war, government intervention, famine or other forms of unrest. A combined overall political stability score was calculated, using World Bank (WB) governance indicators, for the leading three producing countries. The World Bank website provides percentile rank information for 213 countries on six different criteria: voice and accountability; political stability; government effectiveness; regulatory equality; rule of law; and control of corruption. Only political stability was considered as part of this study.

Countries with a political stability percentile of <33.3 per cent were scored 3, those with a percentile between >33.3 and 66.6 per cent were scored 2 and those with a percentile of >66.6 per cent were scored 1.

A combined overall political stability value was calculated by summing the individual political stability scores for the three leading global producers for each element and scored as follows:

- 1 (low) 0 to 2
- 2 (medium-low) 3 to 4
- 3 (medium) 5 to 6
- 4 (medium-high) 7 to 8
- 5 (high) 9

For example, the three leading producing countries for REE are China, Brazil and Russia. Their combined political stability factor would be calculated thus: China (WB percentile rank is 29.7 = 3), Brazil (WB percentile rank is 54.2 = 2), and Russia (WB percentile rank is 21.7 = 3), as shown in Figure 2. Combining these scores gives a combined political stability factor of 8 which equates to an overall score of 4 (medium-high risk).

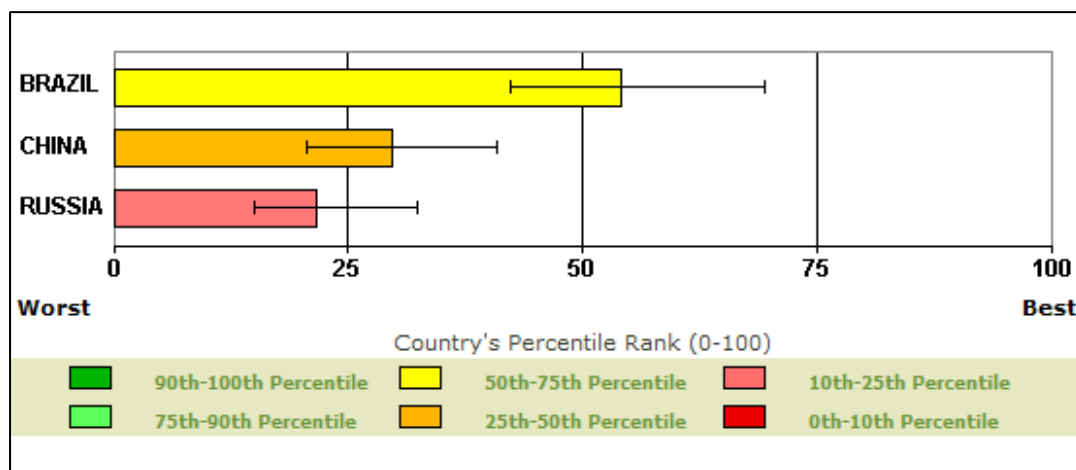


Figure 2. Political stability indicators for Brazil, China and Russia. Data from the World Bank after Kaufmann *et al.* (2010).

Supply risk

An integrated supply risk was calculated by combining the scores for each of the four criteria. This is illustrated for two elements, iron and niobium, in Table 2.

| Category | Iron Score | | Niobium Score | |
|-------------------------------|------------|------------|---------------|-----------|
| | Value | Score | Value | Score |
| Crustal abundance (ppm) | 56,300 | 1 | 8 | 3 |
| Reserve base distribution (%) | 21.4 | 1 | 86.7 | 5 |
| Production concentration (%) | 39.1 | 2 | 95.8 | 5 |
| Political Stability | 6 | 3 | 6 | 3 |
| Total | | 7 | | 16 |
| Supply Risk Index (Total/ 2) | | 3.5 | | 8 |

Table 2. The calculation of a supply risk index.

Aggregate scores were divided by 2 to produce a simple supply risk index from 1 (very low risk) to 10 (very high risk). For example, iron has an initial aggregate score of 7. This is divided by 2 to give a score of 3.5. This shows that iron has a lower relative risk to supply compared to niobium with a score of 8.

Limitations to the methodology

Previous studies of this nature have included information pertaining to the environment, supply and demand, TMR (total material requirements), climate change, and substitution and recycling. This study omits many of these factors. For instance, we have not taken into account the potential impact of supply disruptions e.g. Hg is little used therefore the impact would be less than for an interrupted supply of PGE.

IMPORTANTLY - this represents a 'snapshot' in time and does not take in to account future issues and supply-demand scenarios. The minerals market is not static, new reserves are continually added in response to drivers such as demand and advances in technology. Also recycling is likely to contribute an increasing share to the global market in the future.

Crustal abundance values do not take into account crustal dispersion, nor do they account for the tendency of an element to become economically concentrated.

Where more than one mineral source exists for a given element e.g. Ti occurring in rutile, leucoxene and ilmenite, all sources have been combined to give a total.

Where appropriate, groups of elements have been combined and dealt with a single commodity e.g. PGE and REE. For these grouped elements a worst case scenario has been taken in terms of the crustal abundance e.g. Lu at 0.3 ppm has been used to calculate the crustal abundance risk for REE rather than Ce at 43 ppm. Likewise, Ir 0.000037 ppm has been used to calculate the crustal abundance risk for PGE rather than Pd at 0.0015 ppm.

Certain commodities have been used as a proxy for a given element; this approach may mean that not all sources of an element have been included in the production and reserve base calculations (Table 3).

| Element | Proxy |
|-----------|--|
| Sodium | Halite - NaCl (+ sea salt and brine) |
| Calcium | Lime - CaO |
| Fluorine | Fluorspar - CaF ₂ |
| Carbon | Coal, diamonds, and graphite |
| Barium | Barytes - BaSO ₄ |
| Beryllium | Beryl - Be ₃ Al ₂ (SiO ₃) ₆ |
| Boron | Borate |
| Potassium | Potash - K ₂ O content |
| Titanium | Rutile and Ilmenite - TiO ₂ and FeTiO ₃ |
| Magnesium | Magnesite - MgCO ₃ |
| REE | Rare Earth Oxides (REO) |

Table 3 - Element proxies used in production and reserve base calculations.

Mineral resources³ have been omitted from this study since resources are not measured and the global distribution is poorly defined.

Elements that have little or no commercial use have been omitted from this study e.g. Po, At, and Ra. Likewise, synthetic or 'manufactured' elements have also been omitted e.g. elements of atomic number 95 to 114, and H. Elements naturally occurring in a gaseous state are also not included e.g. the Noble gases, O and N because the criteria used are unsuitable for assessing the supply risk of these elements. Production and reserve base information for some of the minor metals e.g. Sc, Y, Cs, Te, Tl, and Rb is unavailable because they are commonly produced as by-products or as co-metals. For example, Y is often associated with REE-bearing minerals; Sc is found in trace amounts in minerals such as beryl, garnet and wolframite; Cs is often a by-product of Li extraction; and Te, along with Se, is a common by-product of nickel and copper ore extraction.

Definitions

1. *Reserves* - a 'mineral reserve' is the part of the resource which has been fully geologically evaluated and is commercially and legally mineable. Reserves may be regarded as 'working inventories', which are continually revised in the light of various 'modifying factors' related to mining, metallurgy, economics, marketing, law, the environment, communities, government, etc, etc (USGS, 2010).
2. *Reserve Base* - the 'reserve base' includes the 'mineral reserve' plus those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. It has been a widely utilised concept. However, publication of reserve base estimates was discontinued in 2010 (USGS, 2010).

3. *Resources* - a 'mineral resource' regroups all identified resources. It is a natural concentration of minerals or a body of rock that is, or may become, of potential economic interest as a basis for the extraction of a mineral commodity. A resource has physical and/ or chemical properties that make it suitable for specific uses and it is present in sufficient quantity to be of intrinsic economic interest. It encompasses 'mineral reserve' and 'reserve base' plus other identified resources which could be exploited in the future if required according to the economic situation (USGS, 2010).

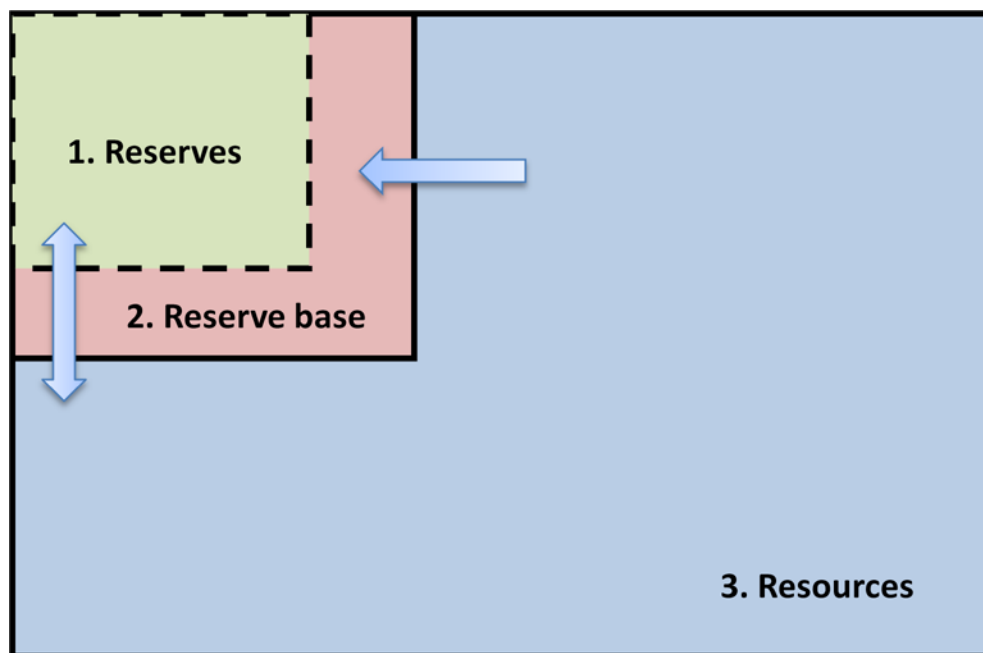


Figure 3 - Graphical representation of the relationship between reserves, the reserve base and resources.

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