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Can the Arctic be a significant contributor of critical minerals for the global energy transition?

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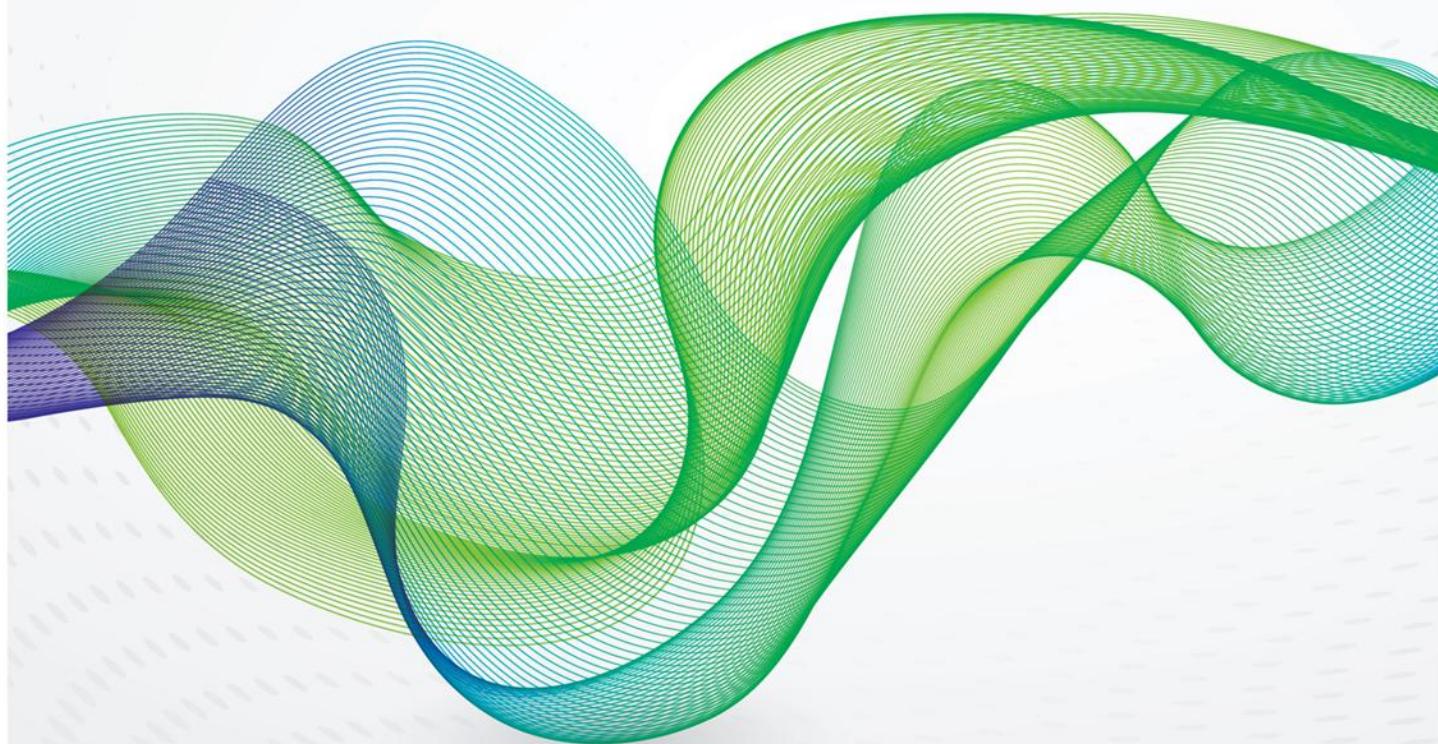
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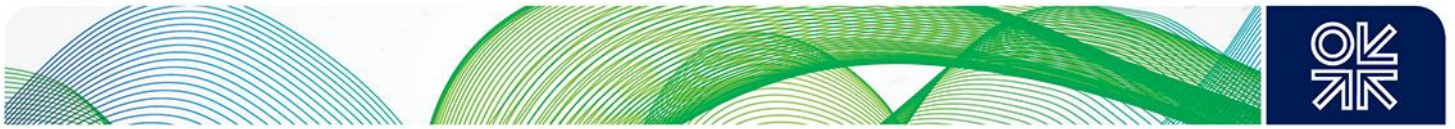
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February 2025

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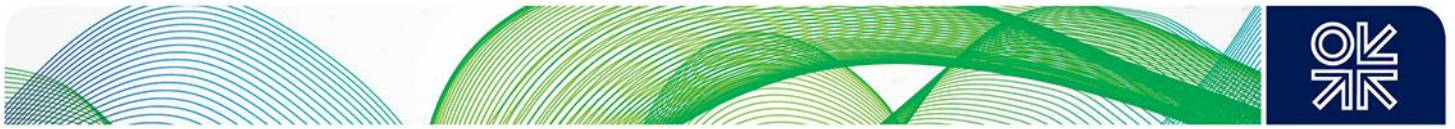


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Executive Summary

The demand for critical minerals is rising in support of the low-carbon energy transition, as well as global economic growth. Despite its hostile environment, the Arctic is a region with historic and existing mineral production. This paper assesses the potential of the Arctic to make a significant contribution to the future supply of critical minerals. It is one of the first, possibly the first, attempt to do so at a pan-Arctic scale and with a focus on critical minerals for the energy transition.

The mineral geology of the Arctic is not special. The particularities are the various physical and human geographic factors that render the costs and timelines for mineral extraction from the Arctic as significantly greater than that for many other parts of the world.

The Arctic today accounts for more than 10 per cent of global production for only three critical minerals: platinum, palladium, and nickel. Other Arctic-sourced critical minerals in smaller quantities include silver, copper, and cobalt. The Arctic also provides more than 10% of global supplies of by-products such as tellurium and selenium. The contribution of the Arctic to mineral ore production pales when compared to the Democratic Republic of Congo that provides 74% of the world's cobalt, China that provides 77% of the natural graphite and Chile that provides 48% of the lithium ore.

Most new production that is to come online between now and 2034 is likely to be from already proven mineral reserves, or from areas adjacent to existing known deposits. Given the scale of the Arctic's current mining operations and the need to boost mineral production and exports, it is possible that the major growth of production between now and 2034 will be in Russia. Exploration and feasibility studies in the Arctic regions of other countries will certainly identify new reserves and potential mining operations. However, it is likely that few of these will add significantly to the Arctic's share of the global supply of critical minerals in the next 10 years. That being said, they may start to provide additional sources of the supply of critical mineral ores for Western Europe and North America.

The period beyond the mid-2030s is when the Arctic regions could possibly start to provide a greater share of global supplies of critical minerals. The speed at which this takes place will depend on factors such as the rate of growth of demand for different critical minerals, the economic competitiveness of critical mineral supplies from Arctic regions compared with those from the rest of the world, and the scale of government and societal support. The exact locations of the mines will vary between minerals, but Russia and Canada are likely to feature strongly for several minerals on account of their geographic size. Other countries may become regionally important suppliers for specific minerals, for example Greenland and Sweden for rare earths. Sub-sea exploitation is likely to have started as well.

In summary, the Arctic is unlikely to make a significant contribution to the future global supply of critical minerals. This may be particularly important for Europe and North America.



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1. Introduction

Demand for minerals is set to rise for the foreseeable future to support the world's growing population and rising standards of living, as well as the transition to low-carbon energy. Many of these minerals are described as being 'critical' due to the risk of an interruption to supply and to the consequent impact on the economy or security of an importing country.¹ A country of particular concern today is China, which dominates the global supply of many metals refined from critical minerals.² Nevertheless, the definition of criticality changes with time due to technological advances that should reduce the need for these minerals in clean energy equipment and allow increasing levels of recycling .

Table 1: Demand growth for selected critical materials used in clean energy technologies

	Solar power	Electric vehicles/ Storage	Wind power	Projected demand growth	Target year
Germanium	x			8600%	2050
Bauxite and aluminium	x	X	x	1200%	2030
Copper	x	X	x	1000%	2025
Iron	x	x	x	1000%	2030
Lead	x	x	x	1000%	2030
Manganese		x	x	1000%	2030
Nickel	x	x		1000%	2030
Cobalt			x	1000%	2030
Lithium		x		1000%	2030

Source: Vakulchuk and Overland (2021)³

Commercial mining in the Arctic began several centuries ago in Finland and Sweden, but it was the eighteenth and nineteenth centuries that saw the development of large-scale mines for metals such as iron copper, nickel, gold, tin, lead and zinc. Many of these mines closed in the second half of the twentieth century as the internationalisation of the mining industry rendered them uneconomic. The Arctic is relatively unexplored for many critical minerals as its physical remoteness and its harsh environment present technological challenges and result in high production costs. However, the scale of future demand has triggered moves to assess the potential for increased exploitation of critical minerals in this region. Since 2023, several national governments in the region have launched strategies to assess and develop critical mineral resources in their Arctic regions.

The development of a new mine anywhere faces several interrelated constraints. First is the need for investors who have access to capital, are prepared to risk fluctuations in commodity prices, and host government regulations. Second is the time needed to move from discovery through feasibility study to first production. Even under favourable conditions, this can vary from five years or so for lithium mines to more than 10 years for copper or nickel mines.⁴ Third are the negative environmental impacts of mining. These include the use and degradation of land, pollution of air and water, damage to biodiversity, and emission of greenhouse gases. The final constraint relates to the effects on local communities, their livelihoods and health.⁵ The consequences of these and other factors vary between countries and projects. But together they result in increased costs, risks, and lead times for most projects.

These challenges become even more pressing in the Arctic. In addition to the physical harshness and remoteness of the region, depending on location they include the vulnerability of fauna and flora to human activity, sparse population, poor physical infrastructure, and the presence in some regions of indigenous peoples with traditional lifestyles. The effects of climate change are varied. On the one hand, warming temperatures are reducing the harshness of Arctic winters and opening up maritime transport routes. On the other hand, the melting of the permafrost is dramatically reducing the stability of physical infrastructure. These features will add significantly to the cost and time required to open new mines in



the Arctic compared with less challenging locations. Alongside this, the mineral geology of the Arctic is by no means special. For most minerals, it will be cheaper to extract them in other regions of the world.

The aim of this paper is to provide a preliminary assessment of the potential of the Arctic to become a significant contributor of minerals for the global energy transition. The paper focuses on two of the three categories of critical minerals identified by Overland et al (2024): the most critical minerals and moderately critical minerals (Table 2).⁶ The question of whether the Arctic can contribute a significant share of global supplies of critical minerals is addressed on three timescales: today, over the next 10 years to 2034, and beyond 2034. For the purposes of this report, we will take a proportion of 10 per cent or higher as being 'significant'.

The research involved two main tasks. The first was to identify the Arctic's share of global mineral production and reserves and, where relevant and available, refined metal production for each of the chosen minerals. This drew principally on the United States Geological Survey's (USGS) annual Mineral Commodity Summaries.⁷ The second task was to document significant mineral deposits and mines in the Arctic and to assess the scale of mine development. It was not possible to systematically assess the scale of mineral exploration, but a few specific projects are identified in the text. The initial source of information was Boyd et al.'s survey of Arctic mineral resources.⁸ This was supplemented by online searches in each country to identify recent government policies and to gauge, in general terms only, mining activity in the Arctic.

There are many definitions of the geographical extent of the Arctic. This study follows Boyd et al. (2016; Fig 1)⁹ and takes latitude 60°N as marking the southern limit of the Arctic. Finland, Greenland and Iceland lie entirely or almost entirely to the north of 60°N. Five countries straddle 60°N to a significant extent: the United States, Canada, Norway, Sweden, and Russia. As a result, it is not possible from the USGS reports to accurately allocate current reserves and production to Arctic regions in these countries. The significance of these limitations will be reiterated in the relevant chapters. However, in the case of

The overarching limitation to this study is that it is based on published information in the English language. It did not draw on commercial databases. For this reason, findings presented in this paper should be treated as being preliminary.

The paper begins with an overview of the current production and reserves of critical minerals in the Arctic. This is followed by a succession of chapters on each Arctic country. Iceland is not included as its onshore areas appear to have little potential for critical minerals.¹⁰ Rather, the potential is offshore. The potential for seabed mining is addressed in a separate chapter. The country chapters include a brief history of mining, the current production and reserves of critical minerals, a summary of government policy, and a brief assessment of current activities. The final chapter provides the conclusions.

Table 2: Ranking of critical minerals used in this report (adapted from Overland et al 2024).

Most critical minerals	Moderately critical minerals
Lithium	Silver
Cobalt	Strontium
Gallium	Phosphorous
Rare earths	Chromium
Indium	Rhodium
Platinum group metals	Aluminium
Nickel	Boron
Tellurium	Selenium
Graphite	Vanadium
Manganese	Titanium
Copper	Silicon
Germanium	

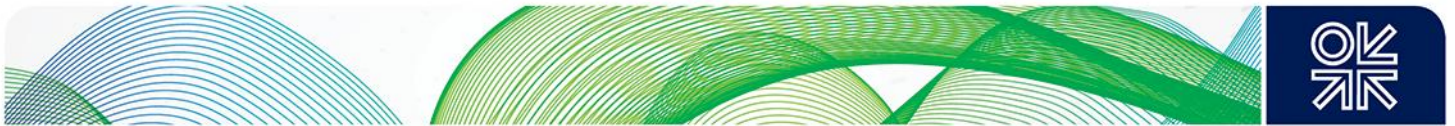


Figure 1: Map of the Arctic



Source: Map courtesy of the The Perry-Castañeda Library. Map Collection, University of Texas Libraries, The University of Texas at Austin



2. Overview of mineral production and reserves

2.1 Data sources and limitations

The principal source for data on national production and reserves is the 2024 edition of the USGS's Mineral Commodity Summaries.¹¹ Production data for mineral ores is relatively comprehensive, but data for refined metal output is limited. Whilst the USGS report may be the best global summary, the statistics it presents are compiled from many sources, and the figures for reserves are likely to be particularly uncertain due to countries following different conventions in reporting their reserves. The 2024 USGS report has been supplemented by earlier editions if a particular data point was not available in this most recent edition, and by other sources in cases where data for the United States has been withheld by the USGS.

A key limitation in applying the data to this report, as mentioned above, arises from the fact that significant areas of the United States, Canada, Norway, Sweden, and Russia straddle 60°N. In the case of the United States, the USGS's Mineral Commodity Summaries 2024 report indicates if Alaska is a significant source of a particular mineral. In which case we have initially allocated the full production and reserves figure to Alaska. For Canada, Norway, Sweden, and Russia, we have initially allocated to the Arctic the full amounts reported by the USGS. For all five countries, we have added the '<' symbol to indicate that these figures are a maximum. We have then checked for guidance in the USGS's 2024 report and Boyd et al.'s book, and scanned the internet for information on active mines for each mineral to gauge roughly what share of production occurs in the Arctic regions of these countries. Our assessment is then presented in parentheses after the respective USGS figure. To produce the adjusted reserve figures, we have assumed that most of the reserves for a particular mineral lie in a similar region to the location of current production. For both production and reserves, a question mark indicates a high degree of uncertainty.

As a result, the figures for Arctic minerals and metals production presented in this paper are undoubtedly overestimates. This is also the case for current mineral reserves. Further, any figure presented for the reserves of a specific mineral represents an estimate made at a particular time, taking into account location, technology, costs, prices, and the state of knowledge. Reserve estimates can be increased by, variously, rising minerals and metals prices, additional exploration, technological advances, and falling costs of exploitation. However, as will become clear, the apparent contribution of Arctic regions to global supplies and reserves is currently small or modest for the majority of critical minerals, even with the overestimates mentioned above.

The scale of mineral exploration across the world varies broadly in line with metals prices. Whilst we lack data for the Arctic, global exploration budgets rose by about 80 per cent in current price terms between 2016 and 2022,¹² roughly in line with the rising LME Index.¹³ Budgets fell marginally in 2023 as prices declined.



Table 3: Arctic mineral and metal data summary: Most critical minerals

	Ore production		Ore reserves		Metal production	
Metal	Arctic share of global	Key Arctic countries	Arctic share of global	Key Arctic countries	Arctic share of global	Key Arctic countries
MOST CRITICAL						
Cobalt	<4.7% (<3.8%)	Russia <3.8% ¹⁴ Canada 0.9% (0%) ¹⁵	<4.4% (<2.3%)	Russia 2.3% Canada 2.1% (?0%)		
Copper	<6.3% (<4.1%)	Russia <4.1% ¹⁶ Canada 2.2% (0%) ¹⁷	<9% (<8%)	Russia <8% Canada 1% (?0%)	<4.8% (<3.7%)	Russia 3.7% Canada 1.1% (?0%)
Gallium					<0.8%	Russia <0.8% ¹⁸
Germanium (2021 data)					<3.6%	Russia <3.6% ¹⁹ Canada (?0%) ²⁰
Graphite (natural)	<1.7% (<1.5%)	Russia 1% ²¹ Norway 0.5% Canada 0.2% (0%) ²²	<7.3% (<5.0%)	Russia 5.0% Norway (0.2%) Canada 2.0% (?0)		
Indium					4.2%	Canada 3.7% (?0%) ²³ Russia 0.5% (?0%) ²⁴
Lithium	1.9% (0%)	Canada 1.9% (0%) ²⁵	<3%	Canada 3% (?0%)		
Manganese	0%		0%			
Nickel	<11%	Russia <6% ²⁶ Canada <5% ²⁷	<8.1%	Russia <6.4% Canada <1.7%		



Palladium	<51% (<44%)	Russia <44% ²⁸ Canada <8% (0%) ²⁹				
Platinum	<16% (<13%)	Russia <13% ³⁰ Canada 3% (0%) ³¹				
Platinum Group Metals			<8.2%	Russia <7.8% Canada 0.4% (?0%)		
Rare earth metals	0.7%	Russia 0.7% ³²	<11%	Russia <9% Greenland 1.4% Canada 0.8% ³³		
Tellurium					20% (<16%) ³⁴	Russia <12% ³⁵ Canada 4% (0%) ³⁶ Sweden 4% ³⁷

Explanation:

- Figures outside brackets are those presented by the United States Geological Survey³⁸ for the group of Arctic nations and for each individual nation. In cases where this report provided no data, either earlier editions or other sources were used.
- The '<' symbol is added to the four countries that straddle 60°N (United States, Canada, Norway and Russia) to indicate that the number is a maximum for the Arctic regions.
- The figures in brackets are estimates made by us where relevant data was available.



Table 4: Arctic mineral and metal data summary: Moderately critical minerals

	Ore production		Ore reserves		Metal production	
Metal	Arctic share of global	Key Arctic countries	Arctic share of global	Key Arctic countries	Metal	Arctic share of global
MODERATELY CRITICAL						
Aluminium	<1.5%	Russia <1.5% ³⁹	<1.6%	Russia <1.6%	<8.3% (<7.0%)	Russia <5.4% Norway 1.9% (0.6) ⁴⁰ Iceland 1.0%
Boron	2.0% (0%)	Russia 2.0% (0%) ⁴¹	4% (?0%)	Russia 4% (?0%)		
Chromium	5%	Finland 5%	1.5%	Finland 1.5%		
Phosphate	<6.8%	Russia <6.4% ⁴² Finland 0.4%	<4.4%	Russia <3.2% Finland 1.4%		
Selenium					<13.6% (<10.2%)	Russia 10% ⁴³ Canada 3.3% (0%) ⁴⁴ Sweden 0.2%
Silicon metal					<4.8%	Norway <3.5% ⁴⁵ Russia <1.3% ⁴⁶
Silver	<8.4%	Russia <4.6% ⁴⁷ USA <3.8% ⁴⁸	<19%	Russia <15% USA <4%		
Strontium	0%		0%			
Titanium	11% (?0%)	Canada 6% (0%) ⁴⁹ Norway 5% (0%) ⁵⁰	13% (?0%)	Canada 8% (?0%) Norway 5% (?0%)		
Vanadium	<20% (?0%)	Russia <20% (?0%) ⁵¹	<26% (?0%)	Russia <26% (?0%)		

See Table 3 for explanation



2.2 Most critical minerals

The Arctic provides over 10 per cent of global production for only three minerals: palladium (<44 per cent), platinum (<13 per cent) and nickel (<11 per cent). In all three cases, Russia is the principal supplier, and much of this supply comes from the Russian company Nor Nickel's mines in the Arctic. Canada is the second largest Arctic supplier of nickel. The Arctic provides less than 5 per cent of global supplies of the other most critical minerals: cobalt (<3.8 per cent), copper (<4.1 per cent), natural graphite (<1.5 per cent) and rare earths (0.7 per cent). Russia is the dominant producer in each case.

A few critical metals are produced as byproducts from the processing of ores of other minerals. Russia is the leading Arctic producer of gallium (<0.8 per cent), germanium (<3.6 per cent), and tellurium (12%). Sweden also produces tellurium (4 per cent).

The data also show that the Arctic hosts only relatively small shares of global mineral reserves – less than 10 per cent in all cases. Again, Russia has the largest reserves, notably of rare earths (<9 per cent), copper (<8 per cent), platinum group metals (<7.8 per cent), and nickel (<6 per cent), and lesser shares of other minerals. The other Arctic region of interest is Greenland that is reported to host 1.4 per cent of global reserves of rare earths.

2.3 Moderately critical minerals

The Arctic makes a similarly small contribution to the global supply of moderately critical minerals, less than 10 per cent in most cases. The exception is vanadium (<20 per cent), all of which comes from Russia. Arctic Russia and Alaska contribute to silver supply (<8.4 per cent). Russia accounts for up to 6.4 per cent of phosphate supply with Finland adding a further 1.4 per cent. Finland also supplies 5 per cent of global chromium ore.

Arctic nations make a modest but useful contribution to the supply of certain refined metals. Selenium is a byproduct of copper or zinc refining. Together, Russia and Sweden supply up to 10.2 per cent of global selenium. Russia and Norway both produce silicon and aluminium metals, with Iceland also supplying the latter.

The share of current global mineral reserves in the Arctic is higher than the share of production for minerals such as vanadium (<26 per cent) or silver (<19 per cent). For the other metals, the share of reserves is similar to or less than the share of production. In most cases, the majority of the reserves in the Arctic lie in Russia. The main exception is chromium, hosted by Finland.

3. United States - Alaska

Alaska is the only U.S. state with territory to the north of 60°N and almost all of the state lies north of 60°N. The history of mining in Alaska began with the gold rushes of the late nineteenth century and with the discovery of the Kennecott copper deposit. The 1960s saw the discovery of base metal deposits, including the Red Dog lead-zinc deposit. Silver is associated with gold, copper and lead-zinc accumulations. Chromium was produced in one mine in the middle part of the twentieth century. With very few exceptions, these mines are long closed.⁵² There are few active mines in Alaska producing critical minerals. One such mine is the Red Dog mine which produces silver associated with lead and zinc.⁵³ The Pebble deposit lies just south of 60°N and hosts the world's largest undeveloped copper and gold resource, as well as molybdenum, silver, and palladium.⁵⁴ The development of this mine was blocked in January 2023 by the Environmental Protection Agency's ban on the disposal of mine waste in an environmentally sensitive area.⁵⁵ Mining contributed just 3% of Alaska's GDP in 2019.⁵⁶

As mentioned in section 2.1, applying the USGS data on mineral production and reserves to Alaska faces two challenges. First, the statistics for the United States do not distinguish the Arctic regions (Alaska) from the Lower 48 states. However, the accompanying text provides useful guidance on the location of most of the significant mines. Second, the USGS withholds production data for certain minerals due to commercial confidentiality.



Taking into account these limitations, it appears that the only critical mineral produced in the United States' Arctic region at any scale is silver. The United States accounts for 3.8 per cent of global silver supply and reserves, to which Alaska makes a contribution. The state does not host significant reserves of any other critical mineral.

A series of federal government policies have triggered a new wave of investment in the mining of critical minerals in the United States. These include Executive Order 13817 of 2017,⁵⁷ the Inflation Reduction Act of 2022,⁵⁸ and an updated list of critical minerals in 2022.⁵⁹ The State of Alaska has also been reviewing its mining policies.⁶⁰

Federal government policies have enabled exploration to pick up in Alaska, notably for lead-zinc deposits. Most of these contain associated silver, and a few host copper, notably the Arctic deposit.⁶¹ The Bornite lead-zinc deposit also contains cobalt, germanium, and gallium.⁶² Whilst geological evidence indicates that a wide range of critical minerals may be found in Alaska,⁶³ it is not yet clear whether they can be mined at scale or profitably.

4. Canada

Mining contributes about 5% of Canada's GDP.⁶⁴ A large area of Canada lies to the north of 60°N. This includes the whole of Yukon, the Northwest Territories, and Nunavut, as well as northernmost Quebec. As in Alaska, mining began with a late nineteenth century gold rush, in Yukon. Increasingly intense and systematic exploration in the twentieth century revealed a wide range of mineral deposits including gold, silver, lead-zinc, nickel, iron, copper, molybdenum, tungsten, rare earths and uranium.⁶⁵ Only a small number of these deposits are mined today. Active mines in Arctic Canada producing critical minerals include:

- Raglan and Nunavik, Quebec: nickel, copper, platinum group metals.
- Keno Hill, Yukon: silver (with lead and zinc).

As is the case with the United States, the USGS report does not distinguish the Arctic regions of Canada, neither is there text in the report to help identify the location of major mines. Whilst mining is a major industry in Canada, most of this production lies to the south of 60°N. The available data suggests that nickel is the only one of the most critical minerals produced in the Arctic at any scale, accounting for up to 5 per cent of global production and 1.7 per cent of global reserves. Canada's Arctic regions do not appear to make a significant contribution to global production or reserves of moderately critical minerals.

The federal government issued its Critical Minerals Strategy in 2022 which included a list of critical minerals.⁶⁶ The strategy highlighted the opportunities for Canada, as a mineral rich country, to benefit from the growing demand for critical minerals, and provided measures to support exploration and project development. In relation to Arctic regions, the report identified opportunities to extract several critical minerals including rare earths, copper, cobalt, nickel, and platinum group metals.

Partly in response to this and other related policies, a few mines are under development or to be developed in the Arctic. Among these mines, those focused on critical minerals are mostly for copper and silver, with one copper project including cobalt.⁶⁷ The rare earth Nechalacho deposit in the Northwest Territories is being assessed by Vital, an Australian company, in collaboration with Shenghe Resources of China.⁶⁸

Several exploration projects in the area around the active Raglan mine, in southern Nunavut and northern Quebec, are directed at nickel, copper, cobalt, and platinum group metals.⁶⁹ The Gayna River lead-zinc deposit in the Northwest Territories contains gallium and germanium as well as silver.⁷⁰

Set against the optimism for increasing wealth from mineral extraction are the real concerns for the environment and indigenous people, not least drawing on experience from previous mining eras.⁷¹



5. Greenland

Greenland's remoteness, ice cover, and harsh physical environment have constrained mineral exploration and extraction until recently. Nevertheless, the island has a long history of small-scale mining. The first mine, for cryolite, operated from 1854 to 1987.⁷² During the twentieth century, mines produced minerals such as copper, graphite, lead, and zinc at different times.⁷³ The largest of these was the Black Angel mine that produced lead, zinc, silver, and iron ore between 1972 and 1989.⁷⁴ Gold was produced for 10 years in the early twenty-first century. Today, there is no active production of critical minerals, and rare earths are the only critical minerals for which significant reserves have been proven, amounting to 1.4 per cent of the global total.

A combination of rising demand for critical minerals and melting of glaciers and the ice sheet has led to a surge of exploration in Greenland.⁷⁵ The government of Greenland has recognized that the development of a substantial mining industry would provide this self-governing administrative division of Denmark with greater financial independence. Its Mineral Strategy 2020-2024 set out five priorities:⁷⁶

- Improved sharing of geological knowledge;
- Efficient, predictable and transparent case administration;
- Simplified transition from exploration to exploitation;
- Sustainable development of the mineral resources industry; and
- Competitive tax and royalty model.

There were 147 active mineral licenses as of June 2024, of which only three related to oil.⁷⁷ Most of the mineral licenses lie in the west, southwest and far south of the island. Twenty related to rare earths. Of these, one (Tanbreez) is an exploitation license,⁷⁸ most of the rest are for exploration, prospecting or geological studies. The Kvanefjeld rare earth deposit is said to be one of the largest in the world.⁷⁹ However, mine development was suspended due to the presence of uranium, the production of which is banned in Greenland.⁸⁰ In 2023, the Ministry of Mineral Resources made a final decision to reject the application for an exploitation license⁸¹ and the project is currently under arbitration.⁸² A further 34 licenses were for copper, and many of these also included potential for other minerals such as platinum group metals, cobalt and nickel, as well as titanium, vanadium and silver.⁸³

Despite the government's enthusiasm for mineral development and the opportunity for large scale production of rare earths, the issue is highly contentious with many Greenlanders fearing environmental damage and changes to their traditional way of life.⁸⁴ Even if these concerns are allayed, the cost of mining will be much higher than in many other Arctic locations due to the geographical remoteness, poor infrastructure, and the paucity of available manpower.

6. Norway

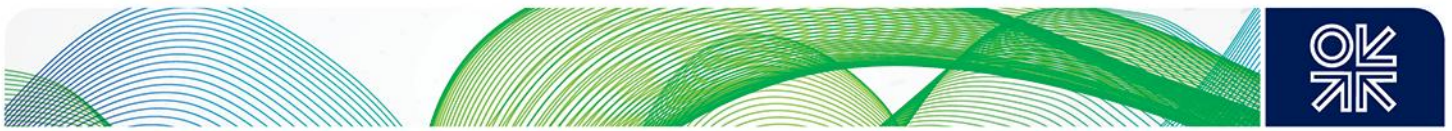
The eighteenth and nineteenth centuries saw the development of large-scale mines for minerals such as copper, cobalt, silver, nickel, and iron. Production of these minerals, along with titanium and manganese continued during the twentieth century.⁸⁵ Many of these mines have since closed, though some are planned for reopening. Mining makes a minimal contribution to Norway's GDP.⁸⁶

Most of Norway lies in the Arctic, with the exception of the far south. Active mines in Arctic Norway producing critical minerals include:

- Kvannevaun: manganese (with iron ore).
- Skaland: graphite.

Graphite is the only most critical mineral for which Arctic Norway makes a measurable contribution, but even this is very small at 0.5 per cent of global production and 0.2 per cent of reserves.

The Norwegian government published an updated mineral strategy in 2023.⁸⁷ This not only recognized the nation's opportunity to create jobs and add value to the exploitation of its mineral resources, but also stated the ambition to develop the world's most environmentally and socially sustainable mineral



industry. The report identified the opportunity to exploit deposits of critical minerals such as copper, cobalt, nickel, vanadium, and rare earths. In addition, it highlighted the possibility of extracting minerals from the seabed of the Norwegian continental shelf, a move supported by Norway's parliament.⁸⁸

The growing demand for critical minerals has resulted in increased exploration activity as well as the reopening of closed mines. Much of this activity is in the Arctic regions of Norway, including Svalbard. The far north of Norway has potential for nickel, copper, cobalt, and platinum group metals, where there are closed mines set to be reopened.⁸⁹ The central and southern regions also have potential for copper, cobalt, and nickel.⁹⁰ A potentially large discovery of rare earths lies just to the south of 60°N.⁹¹ However, it is claimed that plans to develop mines in the far north of the country threaten the livelihoods of the indigenous Sami people.⁹²

7. Sweden

Sweden's Falun copper mine started production in Viking times, more than a thousand years ago. A limited company was formed in the thirteenth century and by the seventeenth century the mine was one of the world's major sources of copper. From the seventeenth century onwards, the extraction of iron ore grew in scale to meet the demand for iron and steel. The production of other minerals such as copper, gold, silver, lead and zinc began in the second half of the twentieth century.⁹³ Many of these mines have since closed, but a few are due to reopen. Mining contributes less than 1% to Sweden's GDP.⁹⁴

A large proportion of Sweden's land area lies to the north of 60°N and nearly all mining and mineral exploration occurs in the Arctic regions.⁹⁵ Active mines in Arctic Sweden producing critical minerals include:

- Garpenberg: copper and silver (with lead and zinc).
- Lovisa Gruven: silver (with lead and zinc).
- Renstrom, Kristineberg, and Kankberg: copper, tellurium and silver (with lead and zinc).
- Björkdal: copper (with lead and zinc).
- Kiirunavaara and Leveäniemi: phosphate (with iron ore).
- Aitik: copper and silver.

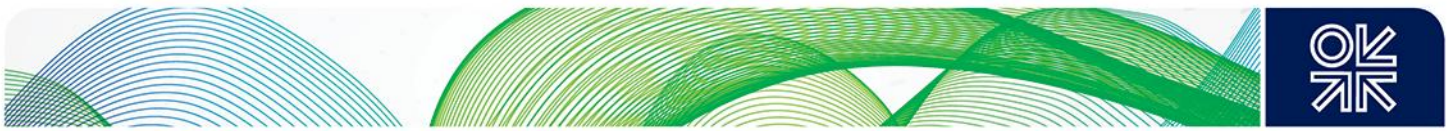
With the exception of the large Aitik operation, the scale of production from these mines is small. So Arctic Sweden does not appear to make a significant contribution to the global production or reserves of any critical mineral ore. However, it does account for 0.2 per cent of global selenium output.

Sweden's minerals strategy published in 2013 calls for the mining industry to increase its competitiveness so that it can maintain its leading position in the European Union.⁹⁶ Priorities include harmony with environmental and cultural values, innovation, and supportive regulatory framework and infrastructure. A new strategy will be published in autumn 2024.

In response to rising metal prices and government policy, exploration budgets rose almost five-fold between 2016 and 2023.⁹⁷ A combination of exploration and mine reopening has the potential to increase the country's production of copper, silver, tellurium, and phosphate, as well as to produce nickel, cobalt, and vanadium.⁹⁸ Arguably, the most significant discovery, announced in 2023, was of a potentially large deposit of rare earths (Per Geijer) adjacent to the Kiruna iron ore mine in the far north of Sweden.⁹⁹ As in Norway, it is claimed that the exploitation of this rare earth deposit will exacerbate the damage to the way of life of the indigenous Sami people that has already inflicted by the Kiruna mine.¹⁰⁰

8. Finland

The mining of iron ore in Finland dates back to the sixteenth century.¹⁰¹ The discovery of the Outokumpo deposit (copper, with cobalt, nickel, and silver) in 1910 marked the start of the nation's modern mining



industry. This was followed by discoveries of nickel, copper, titanium, vanadium, chromium, gold, phosphate and platinum group metals. Many of these mines have been closed, but some are likely to reopen. Almost all of Finland lies in the Arctic. Active mines in Arctic Finland producing critical minerals include:

- Talvivaara: copper, cobalt and nickel (with zinc).
- Sotkamo: silver (with lead and zinc).
- Kemi: chromium.
- Kevitsa: copper, nickel, cobalt and platinum group metals.
- Siilinjärvi: phosphate.

Finland is currently a significant producer of chromium ores, accounting for 5 per cent of global output and 1.5 per cent of reserves. The ore is refined to ferrochrome to make stainless steel. The country also produces 0.4 per cent of the world's phosphate and holds 1.4 per cent of the reserves.

The most recent national mineral strategy was prepared in 2010.¹⁰² The government is currently preparing a new version which was due to be completed by the end of 2024.¹⁰³ The earlier report identified several critical minerals for which there was 'good discovery potential' in Finland. These included cobalt, platinum group metals, rare earths, manganese, chromium, nickel, tellurium, and vanadium. The strategic objectives were to enhance the production of minerals in an environmentally sound manner to support global demand and domestic economic growth.

A few mines in Finland are being reopened, notably for copper, vanadium, and titanium.¹⁰⁴ Several exploration projects are directed at copper, nickel, and platinum group metals.¹⁰⁵ Anglo American is developing the large Sakatti mine in Lapland for copper, nickel and platinum group metals.¹⁰⁶ In August 2024, Sibanye Stillwater of South Africa secured debt funding for its proposed lithium mine.¹⁰⁷ Other exploration projects are focused on rare earths, vanadium, manganese, and phosphate.¹⁰⁸ As in the Arctic regions of Norway and Finland, the expansion of mining in Finnish Lapland is claimed to threaten the way of life of the Sami people.¹⁰⁹

9. Russia

The mining of silver and gold in Russia began in the eighteenth and nineteenth century respectively.¹¹⁰ By the late nineteenth century, the country was producing iron ore, copper, tin, platinum, manganese, lead, and zinc, in addition to silver and gold. Continuing exploration and mine development led to a steady increase in the country's mineral production from the 1930s onwards and formed a core component of Soviet economic strategy. Russia is now one of the world's largest producers of several critical minerals, such as platinum group metals, nickel and vanadium. Mining contributes about 12% of Russia's GDP.¹¹¹

A large share of Russia's land area lies in the Arctic. Active mines in Arctic Russia producing critical minerals include:

- Dukat, Magadan region: silver.
- Kupol, Chukotka region: silver (with gold).
- Pavlov, Novaya Zemlya: silver (with lead and zinc).
- Talnakh, Taymyr Peninsula: nickel, copper, cobalt, platinum group metals, silver, selenium, tellurium.
- Zhadanov, Kola Peninsula: copper, nickel.
- Kalyinsky, Novo-Kalyinsky and Cheremukhovskoye, North Urals region: rare earths, aluminium (bauxite).
- Vezhayu-Vorykva, Middle Timan region: rare earths, gallium, vanadium, aluminium (bauxite).
- Kovdor, Kola Peninsula: phosphate.



Russia accounts for a significant share of the global production and reserves for a variety of critical minerals. It has been difficult to assess the contribution of Arctic regions due to data limitations. In certain cases, it is evident that mines in the Russian Arctic supply a significant share of global production. Among the most critical minerals, these include palladium (<44 per cent), platinum (<13 per cent), nickel (<6 per cent), copper (<4.1 per cent), and cobalt (<3.8 per cent). It also produces small quantities of natural graphite (<1.0 per cent) and rare earths (0.7 per cent). In all cases, the Arctic hosts significant remaining reserves, notably of rare earths (<7.8 per cent). The Tomtor deposit in Yakutia has great potential to boost Russia's production of rare earths but mine development faces technological challenges.¹¹² Among the byproducts, Russia produces gallium, germanium, indium and tellurium. Only in the case of tellurium does production in the Arctic appear to be significant.

Russia is also a significant producer of some moderately critical mineral ores. A significant share of global production comes from the Arctic in the cases of aluminium (bauxite, <1.5 per cent), phosphate (<6.4 per cent), and silver (<4.6 per cent). Data on the location of vanadium mines (<20 per cent) was not found. The country hosts equivalent or greater shares of global reserves for each of these minerals.

Russia's vast mineral reserves provide the opportunity for it to play a dominant role in the supply of critical minerals.¹¹³ Western sanctions have resulted in Russian companies boosting their exports of metals such as copper, aluminium and nickel to China.¹¹⁴ Boosting the country's mining industry has become a key priority for Russia's government in order to support the economy and exports, and the Arctic appears to be a focal region for this strategy. Despite the longstanding presence of mining companies in Russia's Arctic, weak transportation infrastructure and backward technology remain important constraints.¹¹⁵

Data on new mine development and mineral exploration was not found.

10. Sub-sea mineral deposits

The growing demand for critical minerals has boosted interest in exploiting sub-sea deposits. The largest accumulations are believed to lie in the deep ocean. These deposits take three forms: cobalt-rich crusts on seamounts, massive sulphides along mid-ocean ridges, and polymetallic nodules on deep sea plains. Contained critical minerals include copper, silver, manganese, nickel, cobalt and rare earths.¹¹⁶ Mineral deposits also occur in shallower waters on continental shelves. These may be more commercially attractive than the deep-sea accumulations.¹¹⁷ The Arctic has proven potential for the production of critical minerals from massive sulphides along the mid-ocean ridges of the North Atlantic and Arctic Oceans.¹¹⁸ As mentioned in section 6 of this report, the government of Norway has approved the exploitation of such deposits on its continental shelf in the North Atlantic.

However, the whole topic of sub-sea mining has proven highly contentious due to the environmental risks. As a result, the United Nations' International Seabed Authority has yet to reach agreement on regulations to govern the mining of the seafloor. The Authority faces a deadline of 2025 to agree the regulations that would govern this mining.¹¹⁹

Conclusions

This paper provides a preliminary overview of the potential of the Arctic to make a significant contribution to the supply of critical minerals for the low-carbon energy transition. A key limitation of the study is its reliance on a selection of publicly available literature in English.

Before presenting the conclusions, it is worth reiterating that the mineral geology of the Arctic is not special. The particularities are the various physical and human geographic factors that render the costs and timelines for mineral extraction in the Arctic greater than in many other parts of the world. Of these, infrastructure is likely to prove the most important. Thus, new production is likely to come from regions with existing mines. Nevertheless, all the countries studied, with the possible exception of Russia, have published or will soon publish mineral strategies that seek to boost the exploitation of minerals, including in Arctic regions. These new strategies reflect the growing demand for critical minerals. The Nordic countries of Norway, Sweden and Finland are particularly important for the European Union.¹²⁰ Their



Arctic regions already have good mining and transportation infrastructure. Climate change will have a variety of impacts on Arctic transportation infrastructure. On the one hand, ice sheets will retreat, winters will be less harsh and sea routes will be open for longer each year. On the other hand, melting permafrost will disrupt existing installations and increase the cost of new ones.

The question of whether the Arctic can contribute a significant share of global supplies of critical minerals can be addressed at three timescales: today, over the next ten years to 2034, and beyond 2034. For the purposes of this report, we will take a proportion of 10 per cent or higher as being 'significant'.

The situation today

As presented in Section 2 of this report, the Arctic today supplies a significant share of global supplies for only three minerals: platinum (<13 per cent), palladium (<44 per cent), and possibly nickel (<11 per cent). However, the Arctic's share of global reserves of these three minerals is less than the share of global production: <7.8 per cent for platinum group metals and <8.1 per cent for nickel. The shares of silver and phosphate production in the Arctic may be as high as 8.4 per cent and 6.8 per cent respectively, but this is highly uncertain. Reserves of silver in Arctic countries amount to 19 per cent of the global total, but how much of this lies in the Arctic is not known. For all the other critical minerals, the Arctic's share of global production is less than 5 per cent. Among these, the largest shares are for copper (<4.1 per cent) and cobalt (<3.8 per cent). Reserves of these two minerals in the Arctic amount to <8 per cent and <2.3 per cent respectively. For two metals, the Arctic's share of reserves is significantly higher than the share of production: rare earths (<11 per cent) and graphite (<5 per cent). The Arctic also makes a contribution to global supplies of byproducts such as tellurium (<16 per cent), selenium (<10.2 per cent), and germanium (<3.6 per cent).

Russia is the dominant Arctic producer of most of these minerals, as well as being the main producer of copper and aluminium metals and of byproducts such as germanium, selenium, and tellurium. While Canada produces several of these minerals, most of this production is not in the Arctic, with the major exception of nickel. Finland contributes to global chromium and phosphate supplies, Alaska to silver supply, Norway to graphite and silicon metal supplies, and Iceland to the global supply of aluminium.

To summarise: the Arctic makes significant contributions (>10 per cent) to the global supply of critical mineral ores in only three cases (platinum, palladium, and nickel) and to one – and possibly two – by product metals (tellurium and selenium).

The period to the mid-2030s

Exploration for rare-earth minerals has increased across the world since 2016 although we lack the data to show how this is reflected in the Arctic, with the exception of Sweden where the rise in exploration budgets has been dramatic. The reopening of previously closed mines could lead to increased production of critical minerals, and exploration could boost reserves, provided annual production does not exceed the rate of growth of reserves. This problem can be obviated in part through recycling.

In order to be economically viable in the Arctic, even with state support, mineral deposits need to be relatively large and/or high-grade. To make a significant contribution to global supplies, they would ideally form a large mineral province comprising several deposits. The copper, cobalt, nickel, and platinum group metal province in the Taymyr region of the Russian Arctic is an example. Many such geographically extensive mineral provinces are hosted within blocks of ancient geological crust known as cratons. The major cratons in the Arctic where the ancient rocks are exposed at the surface lie in Russia (northern Siberia and Taymyr), northern Canada, Greenland, Finland, Sweden, and northern Norway.¹²¹ However, many types of mineral occurrence occur in quite different geological settings. Nevertheless, the Arctic regions of Russia and Canada are much larger than those of the other Arctic countries. On these grounds alone, we should expect production of critical minerals in their Arctic regions to rise faster and be larger than in the other Arctic countries.

Most new production that comes online between now and the mid-2030s is likely to be from mineral reserves that are already proven, or from areas adjacent to existing known deposits. How rapidly production may rise in each country will depend on a variety of inter-related factors, including the extent



of state policy support, the availability of capital, the risk appetites of investors, the nature of the mineral deposits, the regulation of environmental and social issues, and the scale of existing mining operations and infrastructure in the relevant region. In many, the processing of the mineral ores will take place in sub-Arctic locations.

Given the scale of its current mining operations in the Arctic and its need to boost mineral production and exports, it is possible that the most marked growth in production between now and 2034 will be in Russia. Further, this production is likely to be for minerals in regions where mining is already taking place, such as Taymyr and Kola. But much will depend on the availability of finance, a challenge that has been exacerbated by the withdrawal of most foreign investors.

Exploration and feasibility studies in the Arctic regions of the other countries will certainly identify new reserves and potential mines. However, it is likely that few of these will add significantly to the Arctic's share of the global supply of critical minerals in the next ten years. That being said, they may start to provide additional sources of supply of critical mineral ores for western Europe and North America. To take full advantage of this, it will be necessary to build refineries to produce the required metals. These refineries need not be in the Arctic, nor even in the same country as the ore production.

The period beyond 2034

The period beyond 2034 is when the Arctic regions could possibly start to provide a greater share of global supplies of critical minerals. The speed at which this takes place will depend on factors additional to those governing the period to 2034. First is the rate of growth of demand for different critical minerals. This will be shaped by demand for final products that rely on critical minerals, the nature of the technology in these appliances that determines which minerals are in demand, and the scale of recycling of critical minerals and metals. Second is the economic competitiveness of critical mineral supplies from Arctic regions compared with those from the rest of the world. All things being equal, significant additional supplies from the Arctic are likely to come mainly from high-grade deposits where government support is strong. The exact locations of the mines will vary between minerals, but Russia and Canada are likely to feature strongly for several minerals. Other countries may become regionally important suppliers for specific minerals, for example Greenland and Sweden for rare earths. Sub-sea exploitation is likely to have started as well.

In summary, the Arctic is unlikely to make a significant contribution to the future global supply of critical minerals. Indeed, the region's share of the global production of many critical minerals is likely to decline as production grows in other areas. However, national and regional strategies could contribute to the diversification of supply sources for certain mineral importing countries. This may be particularly important for Europe and North America.



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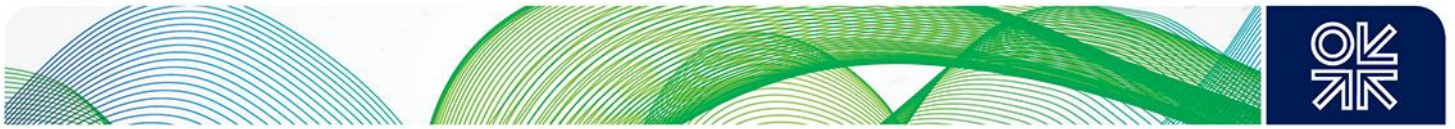
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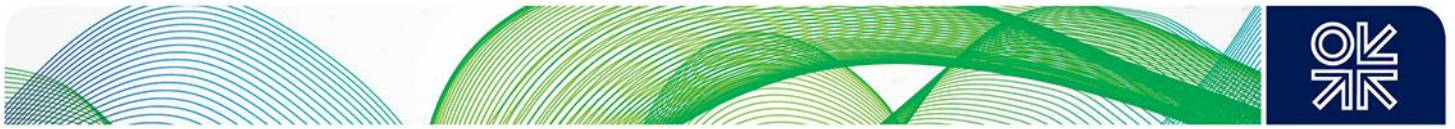
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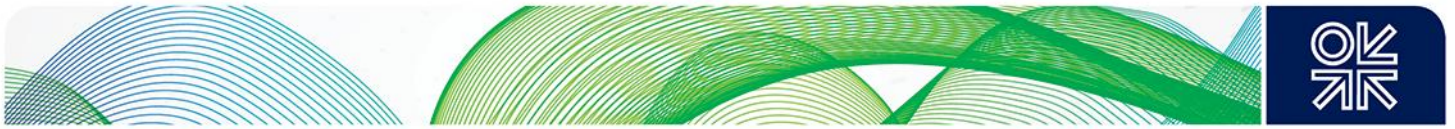
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