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NEW SOURCES OF ALLOYING METALS FOR THE STEEL INDUSTRY IN A CHANGING GLOBAL MARKET

Abstract:
The purpose of this study is to explain the changes that have occurred in the last two decades in the market for strategic raw materials, which include metal ores used in steel metallurgy. In particular, the ores of manganese, chromium, nickel, tungsten, molybdenum and cobalt are considered. Taking up such a subject is justified because of the scarcity of up-to-date information on this subject in the current geographical literature. Such information is currently scattered in a variety of sources including economic, geological, on the technology of metals and on resource protection. Completion of the undertaken task requires gathering in one place information scattered in various sources and reviewing hundreds of information prospectuses of international mining corporations involved in this business, government documents and even reports on small and developing local companies. Their analysis will also allow, in the second part of the work, to present newly emerging and planned mining centers.

Key words: ferroalloys; mining geography; global market; resources; mines; mining corporations; ore.

Introduction

Economic growth seen in many countries around the world was often observed in conditions of uncontrolled exploitation of natural resources. Many scientific papers covering this subject has been published, what underlines the topic importance. Raw materials global market is changing so fast, that information about the most valuable sources and new policies of its exploitation are drowned within the media and scientific hum. As an economic activity, mining still suffers from a bad public perception as a result of poor past practices. Mines have often been the site of tragic events and mass mortalities, with spectacular accidents and high levels of permanent and severe pollution. However technological developments allow humanity to reduce negative impacts of mining on environment every year. On the other hand global demand for more and more raw materials was only shortly reduced by the financial crisis 2008-2009 and the CoViD-19 panic lockdowns. As Guillaume Pitron (2019, p. 28) estimates, we should extract more raw materials in the next 30 years than humanity has extracted in 70,000 years. The geopolitical importance of metal mining is growing because many countries have moved away from its extraction, leaving China in a monopoly position (Wiejaczka, Wilczyński 2021).

Research in this area is developed by international governmental and non-governmental organizations and their research teams, supported by many geographers and economists from universities around the world. Sustainability issues are the most common, but will be omitted here because they focus mainly on case studies and are disconnected from the topic. Large mining corporations are responding by advancing the idea of a sustainable mining industry and there is a lot of papers about that. There are some worthy mentions however (Bridge 2004; Calas 2017; Childs 2019; Dubiński 2013; Glassman 2011; Huber 2019; Klinger 2015; Nordhaus 2006; Phillips 2016; Tole, Koop 2011; Werner, 2021). There are some notable books on the subject as well (Anderson 2012; Combes, Mayer, Thisse 2008; Moody 2008). Geographically viable papers covering whole global mining markets are quite rare. There are some papers about mining geography, but most research are done by governmental organizations like USGS,[1] or BGS.[2]

To produce a map of bankrupting and emerging mining facilities of important alloying metals and minerals for steel industry we need to collect in one place all data from many sources, concerning the raw material mines created and closed in the last decade. The answer to the question of what policy accompanying these changes on the suppliers map will require a review of hundreds of prospectuses of all international mining corporations engaged in the business, governments, and even reports on still small and just developing local companies. In the study there are also available graphics with the closed and opened enterprises producing alloying ores of manganese, chromium, nickel, cobalt, tungsten and molybdenum.

[1] US Geological Survey, International Minerals Statistics & Information. Available online: https://www.usgs.gov/centers/nmic/international-minerals-statistics-and-information (accessed on 26 Nov. 2021).

[2] BGS World Mineral Production. Available online: https://www2.bgs.ac.uk/mineralsuk/download/world_statistics/2010s/WMP_2015_2019.pdf (accessed on 26 Nov. 2021).

Manganese is essential to iron and steel production by virtue of its sulfur-fixing or deoxidizing and very good alloying properties. Steelmaking, including its iron making component, accounts for most global manganese demand, presently in the range of 85% to 90% of the total (Lee, Han 2015; Chen et al. 2020).Manganese steel alloys, consisting of various classes, grades and types of ferromanganese and silicomanganese steel, are used to provide most of this key ingredient to steelmaking. Products for construction, machinery, and transportation are leading final products of manganese. Manganese also is in lower extent a key component of widely used aluminum alloys and, in oxide form, dry cell batteries. As ore, additional quantities of manganese are used for such nonmetallurgical purposes as plant fertilizers, animal feed additive, and colorants for various brick types (Liu 2015).

Chromium has a wide range of uses in metals, chemicals, and refractory production. It is one of the most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardenability and resistance to corrosion and oxidation (Pariser, et al. 2018). The use of chromium to produce stainless steel and nonferrous alloys are two of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, surface treatments, and refractories (Schulte 2021).

Nickel which exhibits a mixture of ferrous and nonferrous metal properties is both siderophile (i.e., associates with iron) and chalcophile (i.e., associates with sulfur). Currently most nickel ore mined comes from two types of ore deposits: laterites where the principal ore minerals are nickeliferous limonite and, or magmatic sulfide deposits where the principal ore mineral is pentlandite (Pariser, et al. 2018; Schmidt, et al.2018; Nakajima 2018).Nickel is primarily sold for first use as refined metal or ferronickel and about 65% of the nickel consumed is used to make austenitic stainless steel. Another 12% goes into superalloys or nonferrous alloys. Both families of alloys are widely used because of their corrosion resistance. The aerospace industry is a leading consumer of nickel-base superalloys. Turbine blades, discs and other critical parts of jet engines are fabricated from these superalloys. Nickel-base superalloys are also used in land-based combustion turbines, such those found at electric power generation stations. The remaining 23% of consumption is divided between alloy steels, rechargeable batteries, catalysts and other chemicals, coinage, and foundry products (McRae 2021).

Cobalt is a metal that was once primarily used in the steel industry, but now, after several technological breakthroughs, is used in a wide variety of commercial, industrial, and military applications, many of which are strategic and critical. On a global basis, currently the leading use of cobalt is in rechargeable battery electrodes. Superalloys, which are used to make parts for gas turbine engines, are another major use for cobalt still. Cobalt is also used to make airbags in automobiles; catalysts for the petroleum and chemical industries; cemented carbides and diamond tools; corrosion- and wear-resistant alloys; drying agents for paints, varnishes, and inks; dyes and pigments; ground coats for porcelain enamels; high-speed steels; magnetic recording media; magnets; and steel-belted radial tires (Schmidt, et al. 2018; Dehaine et al. 2021). Most cobalt is mined as a byproduct of copper or nickel. 80% of its consumption being used by the rechargeable battery industry. The cobalt contents of lithium-ion batteries, the leading global use for cobalt, are being reduced. Potential commercially available cobalt-free substitutes use iron and phosphorus (Shedd 2021a).

Tungsten is a metal with a wide range of uses, the largest of which is as tungsten carbide a wear-resistant material used by the metalworking, mining, and construction industries. Tungsten metal wires, electrodes, and/or contacts are used in lighting, electronic, electrical, heating, and welding applications. Tungsten is also used to make heavy metal alloys for armaments, heat sinks, and high-density applications, such as weights and counterweights; superalloys for turbine blades; tool steels; and wear-resistant alloy parts and coatings. Tungsten composites are used as a substitute for lead in bullets and shot. Tungsten chemical compounds are used in catalysts, inorganic pigments, and high-temperature lubricants (Leal-Ayala 2015; Nava, Coello-Velazquez, Menendez-Aguado 2021). World tungsten supply was dominated by production in China and exports from China. China's Government regulated its tungsten industry by limiting the number of mining and export licenses. Scrap continued to be an important source of raw material for the tungsten industry worldwide (Shedd 2021b).

Molybdenum is used principally as an alloying agent in steel, cast iron, and super-alloys to enhance hardenability, strength, toughness, wear and corrosion resistance. To achieve desired metallurgical properties, molybdenum, primarily in the form of molybdic oxide or ferromolybdenum, is frequently used in combination with or added to chromium, manganese, niobium, nickel, tungsten, or other alloy metals. The versatility of molybdenum in enhancing a variety of alloy properties has ensured it a significant role in contemporary industrial technology, which increasingly requires materials that are serviceable under high stress, expanded temperature ranges, and highly corrosive environments. Moreover, molybdenum finds significant usage as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments (Chen et al. 2020; Henckens, Driessen, Worrell 2018). 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. There is little substitution for molybdenum in its major application in steels and cast irons. In fact, because of the availability and versatility of molybdenum, industry has sought to develop new materials that benefit from its alloying properties (Polyak 2021).

Data and Methods

The main method used in this study was a systematic literature/documents review. Perfectly developed method have been improved recently by C. Sassanelli and others (Sassanelli 2019). This method was used firstly on a data coming from previously mentioned USGS and BGS mineral data sets, the financial data coming from corporations and stock market institutions, and state owned enterprises and institutions as well. The paper wants to detect, through a systematic literature review all needed data. Method proposed here allow to describe key findings to develop the next step in this research.

Following systematic literature/documents review it usually appears that there are some materials and data missing from greater view. That is why data-mining methods have been needed. It is briefly described by O. Voican (2020). To search for missing information there was multilinguistical application used. Applications and tools described by above mentioned scholar mined through data available in the World Wide Web in many languages. The Big Data involves data sets so large that traditional data analysis methods are no longer usable due to the huge amount of data. Lacking data is an extremely important aspect in data analysis, transformation, innovation and value for businesses comparison. This data-mining computing was done by various applications until valuable and verifiable pieces of missing information were collected. For those who have no access to specific applications, same data-mining can be done by using popular Internet browsers, but results might be different on personal accounts. It is advised to use default options.

Investigation procedure implemented in this research provide sufficient details to allow others to replicate and build on the published results, but with time it will be more data available. Please note that this research is conducted with data available in December 2021. Only available for free and open data were used and all associated links and references utilized are below. There are no restrictions on the availability of materials or information.

All data need to be verified. Simple two sources confirmation technique were utilized to provide verification or falsification of data. What has been not verified is described as missing data or marked as not verified in following text in next sections (Clarke 2018). Such data coming only from one source is still valuable, as an estimation. The research should also assume that data on mining production and location of mines in many countries are not public. It was shown by W.J. Wilczyński (2021, p. 318) on the example of China, where many large mining plants discernible on satellite images do not appear in the literature and the raw materials obtained there are not even known.

After verification of data it become available to show the results as a maps and other cartographic models. There are a lot of different methods to produce noteworthy synthetic pictures of the research subject. Nowadays a lot of people are trying to make maps, and especially digital maps. A wide range of computer tools and high graphic capabilities have together made maps increasingly popular and seemingly easy to prepare for any person who can use a computer. As J. Korycka-Skorupa and T. Nowacki (2019) assumed, there is a need for a new, formalized view of the method as a sequence of steps from data collection, to correct presentation, to map as a result. But here the simplest presentation forms should be utilized, as the receivers of this paper usually are not cartographers, and do not need advanced transformations of obtained data.

Results

Manganese ore mining

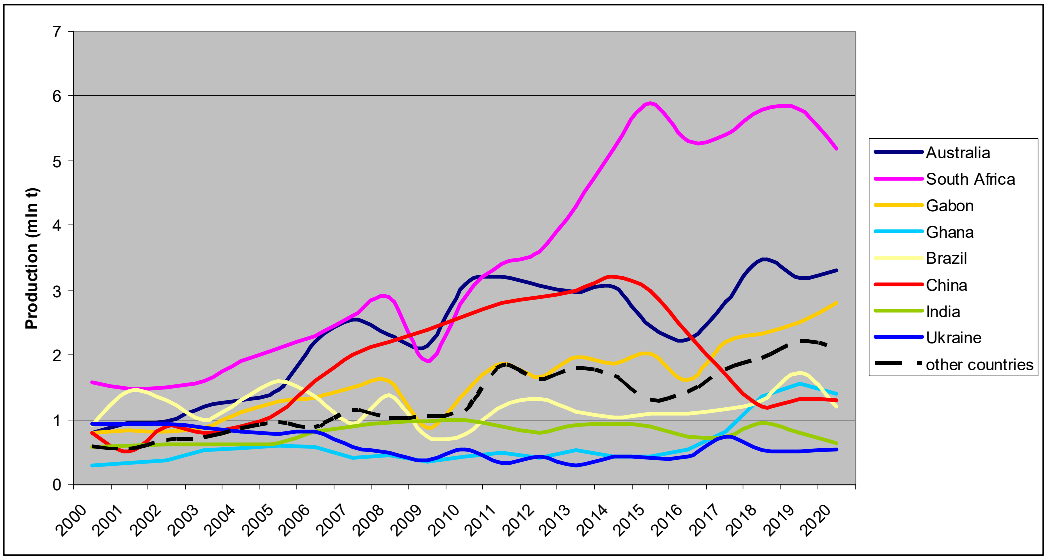
Steel production is the principal determinant of manganese demand and price. Manganese ore price increased moderately in nineties to the highest level in 2000. Competition with imports was an issue for several manganese materials that time. The annual manganese ferroalloy demand increased slightly in 2004 what caused price and production volume increase. In 2004, manganese apparent consumption was at the highest level since 1979. Furthermore a rising crude steel production in response to economic growth in North America, Europe, China and Japan coupled with supply deficits contributed to the unprecedented increase in manganese alloy spot-market prices in following years. As a result of the record ferromanganese prices, some steel companies began to place manganese surcharges on their products. Manganese alloy spot-market prices decreased in 2006 as a result of drop in steel production and stocks buildup. Manganese ore prices followed the percentage increase in the international price for metallurgical-grade ore set between Japan as main buyer that time, and all major suppliers. Manganese alloy spot-market prices in 2007 stayed at similar level as a result of problems of steel producers which coupled with higher energy costs. By the end of October 2008, weekly average spot price for high-carbon ferromanganese was double that at the start of the year. The annual average domestic manganese ore contract price followed the 314% to 413% increase in the international price for metallurgical-grade ore set between Japanese consumers and major suppliers as a result of global financial crisis. On the other hand decreasing demand was also caused by global financial problems and next year price dropped. Steel production in 2009 was 40% less than that in 2008. Trade volumes of manganese materials were also significantly less. This happened owing to high levels of manganese ore stocks in China and pricing competition between major manganese ore producers as well. The global economic recovery, as measured by the expansion of global gross domestic product, coincided with the growth in the manganese market during 2010. Ore contract price followed the increase in the average international price for metallurgical-grade ore that was set between Japanese consumers and major suppliers. Improved economic conditions led to planned expansions at manganese ore mines. As a result, worldwide manganese apparent consumption increased and average international price decreased in the following years. In 2014 the annual average manganese ore contract price followed the decrease in the average Chinese spot market price for metallurgical-grade ore. This mark a time when China has replaced Japan as a main consumer and started to impact stock price for manganese significantly. Manganese apparent consumption started to increase in 2017. This was primarily a result of increases in ferromanganese and silico-manganese production and increase in steel production. Steel production, the leading use of manganese, decreased across the globe in 2020 compared with production in 2019 owing to reduced demand attributed to the global CoViD-19 pandemic. Mining activities output followed this trend (Schnebele 2021) (for all years 2000-2020) (Tab. 1).

Table 1. Manganese ore prices and world production 2000-2020

Mn ore (46-52% metallurgical grade)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Price in $/t (stock, end year)	2,39	2,44	2,30	2,41	2,89	4,39	3,61	3,10	12,15	7,95	9,64	7,88	6,04	4,61	4,49	3,53	4,34	5,97	7,16	5,63	4,72
World production in million t	7,28	7,6	8,1	8,2	9,35	10,5	11,9	12,6	13,3	10,8	13,9	16,0	15,8	16,9	17,8	17,5	15,7	17,3	18,9	19,6	18,5

South Africa, Australia, Gabon, Ghana, Brazil, China, India and Ukraine were among top producers during 2000-2020 period (Fig. 1). Ukrainian and Indian production were reduced, giving place in a top ranking to Ghana, China and Brazil.

Figure 1. Mn ore production among top countries 2000-2020 (at least 46% metallurgical Mn content)



In 2000 there were 20 countries producing marketable manganese ore. South Africa was a top producer and dominated the world manganese market as the largest producer. Billiton's Samancor Manganese Division produced 2.16 Mt of ore from its Mamatwan open

Figure 2. Manganese ore mining distribution in 2000

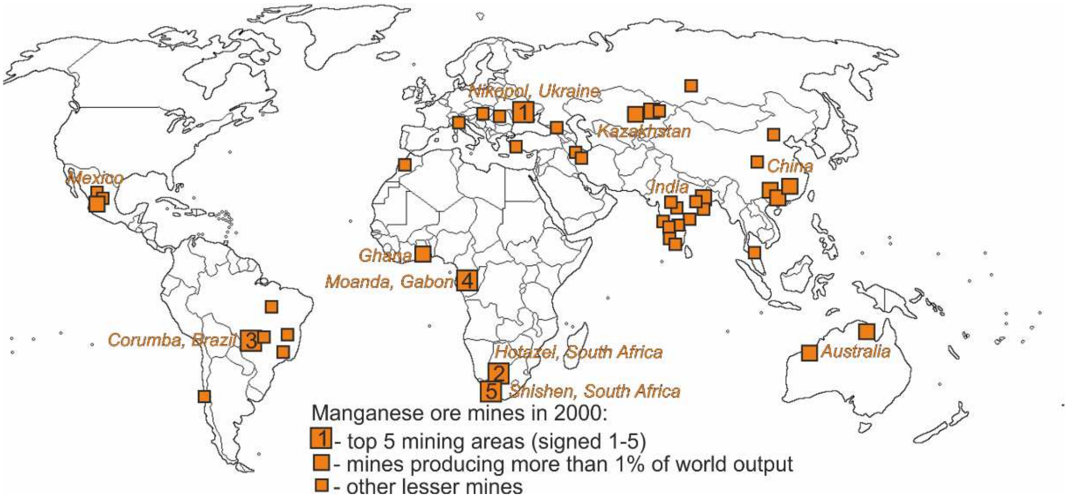
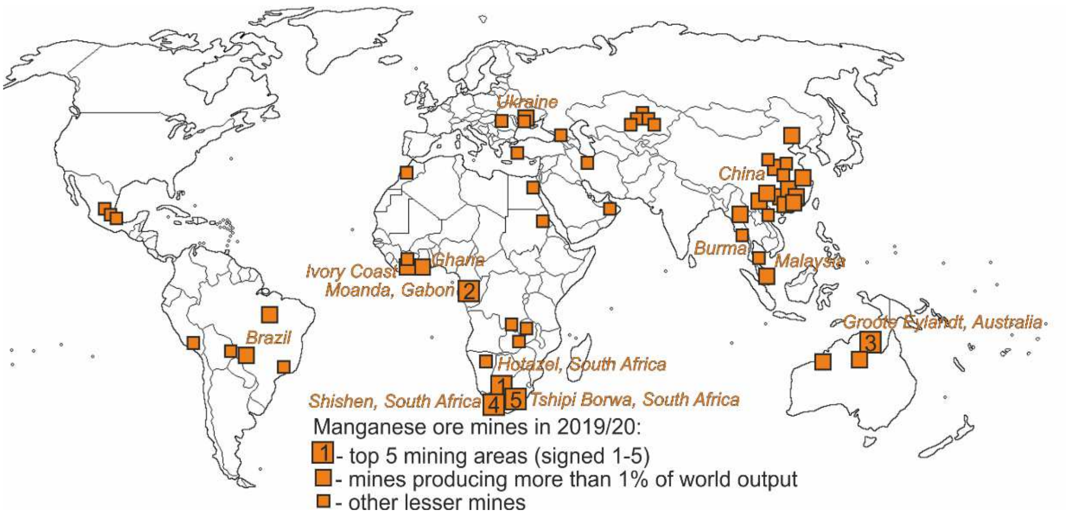


Figure 3. Manganese ore mining distribution in 2019/20



pit and Wessels underground mines near Hotazel (Fig. 2, 3). About 40% of Samancor's manganese ore production was exported to ferroalloy producers worldwide. The remainder was converted into alloys at Samancor's Manganese Division works at Meyerton, Gauteng Province. Assmang, another important producer, operated the Gloria and the Nchwaning underground manganese mines in Northern Cape Province. This corporation was investing to add a new shaft complex at the Nchwaning III Mine, which was expected to be operational by late 2003.

Assmang's ferromanganese production came from plants at Cato Ridge near Durban and Machadadorp near Middleburg (Schnebele 2021), (*2000 Yearbook*). Second producer on the list was China, but the data about the production are only from one source (*2000 Yearbook*). From other sources it can be concluded that Chinese ores were mined in southern Guangxi Zhuang and Guangdong provinces by state owned enterprises. These ores were low grade and utilized for Chinese steel production only. At third place that time there was Ukraine. The Nikopol ferroalloys plant specialized in the production of silicomanganese and high-carbon ferromanganese. The decline in steel production in Ukraine resulted in a change in the production profile of ferroalloys in future years (Koval 2021). The fourth producer was Brazil. CVRD's high-grade manganese mine Igarapé Azul in the Carajás complex accounted for 70% of metallurgical manganese production there and a raw ore came from Corumba, Mato Grosso. Construtora Polares Ltda. was a medium producer followed by small state owned producers in the States of Minas Gerais, Goiás, and Bahia. Other important producers were in descending order: Gabon, Australia, India, Kazakhstan, each producing more than 1 Mt of crude manganese ore. Further there were: Ghana, Mexico and Iran each producing more than 0,1 Mt. In a corporate review the biggest producers were in descending order: Chinese government (3,2 Mt), Nikopol Manganese Complex (2,7 Mt), Samancor (2,2 Mt), CVRD (1,8 Mt) and Comilog from Gabon (1,7 Mt).

Currently, as the latest data show (for 2019-2020), South Africa again dominated the world manganese ore production (figure 3), with 17,0 Mt of ore, and 5,2 Mt of manganese concentrate annual production (table 2). The long-term increase was attributable to increased production from the Mamatwan, the Nchwaning, and the Wessels Mines and the opening of the Kalahari, the Kudumane, and the Tshipi Borwa Mines (in Hotazel and Shishen areas). Hotazel Manganese Mines (formerly Samancor Manganese) still operated and developed the Mamatwan open pit mine and the Wessels underground mine near Hotazel in Northern Cape Province. Assmang continued to produce manganese ore at Gloria and Nchwaning Mines near Shishen/Black Rock. Assmang's mining projects was expected to increase total production to 4.6 Mt/yr; the company completed the delayed expansion in 2021. Australian Jupiter Mines and local Ntsimbitntle produced manganese ore at a grade of 37% manganese from the Tshipi Borwa Mine, as Tshipi e Ntle co-op which was adjacent to the Hotazel mines. Another mine opened last decade in Hotazel area was Kalahari Mine operated by

United Manganese of Kalahari (UMK) owned by Majestic Silver Trading (51%), and Renova of Russia (49%). Asia Minerals Ltd. (AML) of Hong Kong operated the Kudumane Mine at Fort York. The mine was producing manganese ore at the rate of about 1 Mt/yr. The company planned to increase production to 1.5 Mt/yr by expanding its mining operations at Hotazel area and subsequently to 2 Mt/yr by opening a new underground mine at Telele by 2020, but it hasn't happened yet. Guangxi N&H Metallurgy Development Co. of China started operating the Lomoteng Mine, which had a capacity of 600000 t/yr. The output of the company in recent years is all for export to China. Future investments in South Africa are expected, mainly in Hotazel area. Main future investors, at different stages of development are Arcelor Mittal of Luxembourg, Aquila Resources of Australia, and local company Lehating. Many of these projects are delayed by CoViD-19 lockdowns. On the second place in ore mining is Gabon with mine output around 7,1 Mt annually. There are two mines: the old one in Moanda operated by Comilog, where Eramet Group became main investor, and the new one close to Ndjole, operated by Chinese Citic Dameng Holdings. Gabonese economy is mainly dependent on manganese ore exports. Third place has Australia with its largest mining operation in Groote Eylandt owned by Groote Eylandt Mining – the co-op of BHP Billiton and Anglo American Corporation. Pilbara Manganese owned by Consolidated Minerals operated second largest manganese ore mine at Woodie Woodie. The youngest mine is located in Bootu Creek owned by OM Holding. Australian mine output is highly dependent on Chinese and Japanese demand. On the fourth position in the ranking currently is China, which gradually lowered its mine output due to low grade ores, and low prices on a global market. Still Daxin mine stays one of the biggest manganese mines in the world however. Further data collected are presented on fig. 4. In review of corporations, the top five currently are: Comilog (6,0 Mt), Guangxi Dameng Manganese Industry (5,8 Mt), Hotazel Manganese Mines (4,5 Mt), Groote Eylandt Mining (4,2 Mt), and United Manganese of Kalahari (4,0 Mt).

Chromium ore mining

Stainless steel, the major end use market for chromium, has shown long-term growth equivalent to about one or two new ferrochromium furnaces annually at the beginning of analyzed period. Production capacity expansion continued to be achieved through the addition of furnaces in existing plants and the policies in many companies has been shifted already to expansion through plant enhancements that improve recovery and reduce cost, such as agglomeration and preheating of furnace feed and recovery from slag. The economic slowdown that started with the Asian financial crisis in 1997 resulted in reduced demand for stainless steel in Asia and forced Asian produced stainless steel prices down. This resulted in pressure to lower the price of stainless steel produced in North America and Europe. Oversupply of stainless steel in the world market kept ferro-chromium in excess supply until late in 1999 when the price of ferrochromium rose, indicating a return to supply balance. South Africa alone accounts for majority of world production and has been the major supplier of chromium in the form of chromite ore and ferrochromium to Western countries. Rising cost of ferrochromium production and a strengthening South African rand, along with increased demand for ferro-chromium and tightness in supply of stainless steel scrap, have caused the price of ferro-chromium started to reach high levels since 2003. The high price of ferrochromium resulted in the reentry of China and India, two of the world's higher cost ferrochromium producers, in that commodity's export market. It also fueled ferrochromium production expansion in Kazakhstan and bolstered its interest in moving into stainless steel production. In 2006 or 2007, when China's stainless steel production capacity exceeded its demand, China's suppliers (Asian and European countries) had to export their production to other countries, a situation that resulted in abundant supply. The price of chromite reached historically high levels in 2007. China's role as a chromium consumer still grew along with its stainless steel production industry. The price of ferrochromium reached historically high levels in 2008, and then declined in 2009 with a weakening world economy. World financial problems relieved electrical power demand, and that the reason why in 2010, recycled chromium (contained in reported stainless steel scrap receipts) ac-counted for 44% (historical peak) of apparent consumption and cased a mine output drop. The chromium market was characterized that days as slow with escalating production cost and dismal demand while ferrochromium prices drifted downward. Several ferro-chromium plants, or interest in plants, were made available in Albania, Russia, South Africa, and Zimbabwe. Nationalism in South Africa, India, and Turkey led to control of chromite ore exports, interest in export control, and raised the specter of nationalization yet again in South Africa, where labor relations have deteriorated. Opening of many new mining and plant operations worldwide reduced the average costs since 2012 together with steady increase in marketable ore amounts on the market. As result of declining chromite ore prices early in 2016, it was thought that chromite ore stocks on the ground may have increased. However, moving that material into the market and trading ports was limited by the availability of transportation in South Africa and Zimbabwe. In Turkey, miners shifted away from chromite ore production when chromite ore prices declined early in the year. From 2017 ferrochromium prices raised, so prices have remained relatively high compared with those prior. Next year the increased labor costs, increased costs for electricity, an unreliable supply of electricity, and challenges related to deep level mining, together with the decreasing cost of chromite ore affected production in South Africa. Temporary mine closures related to the CoViD-19 pandemic since 2019 went with lower demand of steel industry. That caused drop in mines output and price. In 2020, recycled chromium (contained in reported stainless steel scrap receipts) accounted for 25% of apparent consumption (Schulte 2021) (for all period 2000-2021).

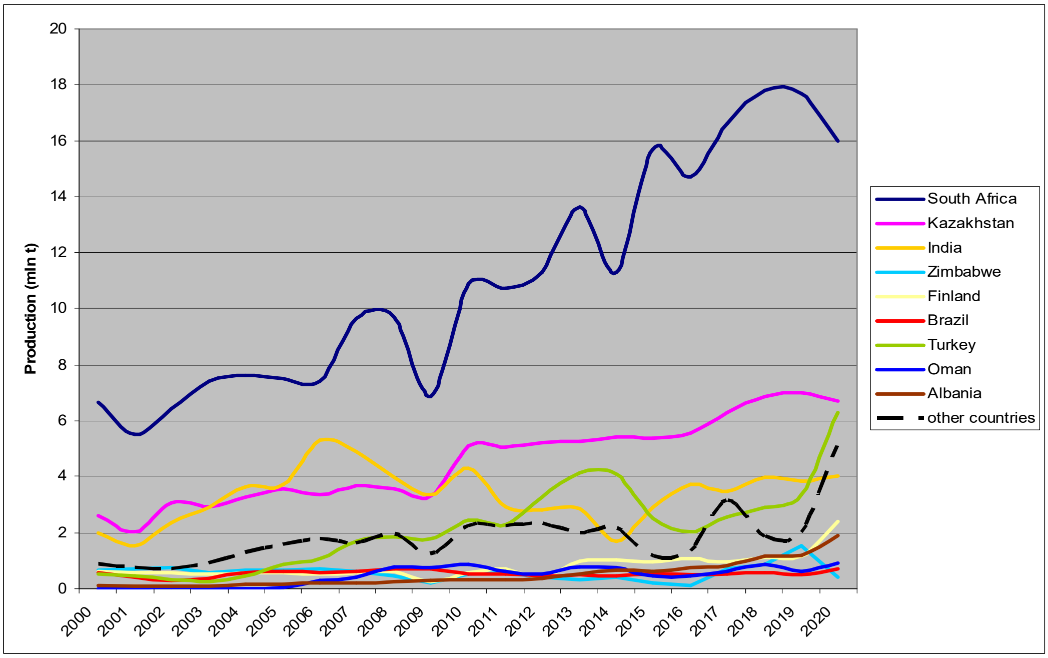
South Africa, Kazakhstan, India, Zimbabwe, Finland, Brazil, Turkey, Oman and Albania were among top producers at least once during 2000-2020 period (Fig. 4). Zimbabwean and Brazilian production were reduced, giving place in a top ranking to Turkey, Albania and Oman.

Table 2. Chromium ore prices and world production 2000-2020

Cr ore (40-50% Cr_2O_3 content shipping grade)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Price in $/t (end year)	63	50	51	53	114	140	141	156	227	226	212	355	392	310	243	217	198	259	279	248	180
World production in million t	14,4	12,1	13,5	15,5	17,5	19,3	19,6	21,5	23,8	19,3	23,7	23,3	25,6	28,8	26,4	30,4	30,2	35,7	43,1	44,8	40,4

Source: USGS, Mining Weekly (chromium materials are not openly traded. Purchase contracts are confidential between buyer and seller; however, trade journals report composite prices based on interviews with buyers and sellers, and traders declare the value of materials they import or export).

Figure 4. Chromium ore production among top countries 2000-2020 (at least 40% metallurgical Cr content)



In 2000 there were 22 countries with active chromium ore mining operations. South Africa was the global leader in chromite ore production and export. Production came from more than 20 mines located within the Bushveld Ultramafic Complex. BHP Billiton's Samancor Group, which was the world's largest integrated ferroalloys producer, produced more than 3,6 Mt of chromite ore. Samancor's operations were organized under two mining centers—Eastern Chrome Mines, which is based at Steelpoort, and Western Chrome Mines, near Rustenburg. strata AG of Switzerland was second largest company involved in chromite mining. Other companies active in South Africa were Lavino SA, Dilokong Chrome and Assmang. Second place was held by Kazakhstan, where the Kazkhrom were only producer located in Khromtau region. Third highest production belonged to India. Chrome ore exports were restricted there. Industry were represented by Ferro Alloys Corporation, Orissa Industries, Tata Iron & Steel and Mysore Minerals. Zimbabwe was at fourth place with its state-owned Zimasco and Zimalloys companies. Fifth in 2000 was Finland, where Outokumpu provided significant amounts of chromium ore, followed by Brazil, Turkey and China, which were major producers as well (fig. 5). In review of corporations, the top five were: Samancor (3,6 Mt), Kazkhrom (2,6 Mt), Xstrata, a Swiss owner of some South African mines (1,6 Mt), Orissa Industries (1,2 Mt), and Assmang (0,9 Mt).

Figure 5. Chromium ore mining distribution in 2000

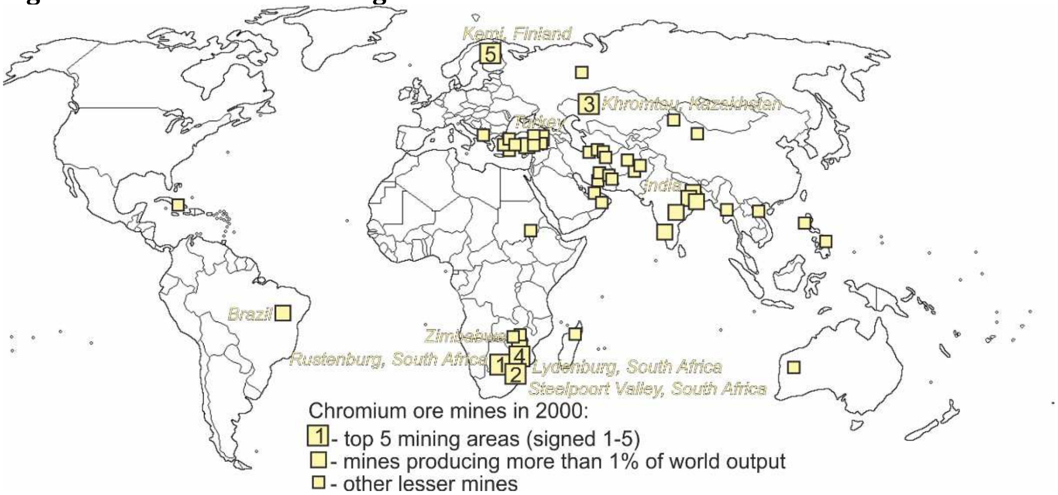
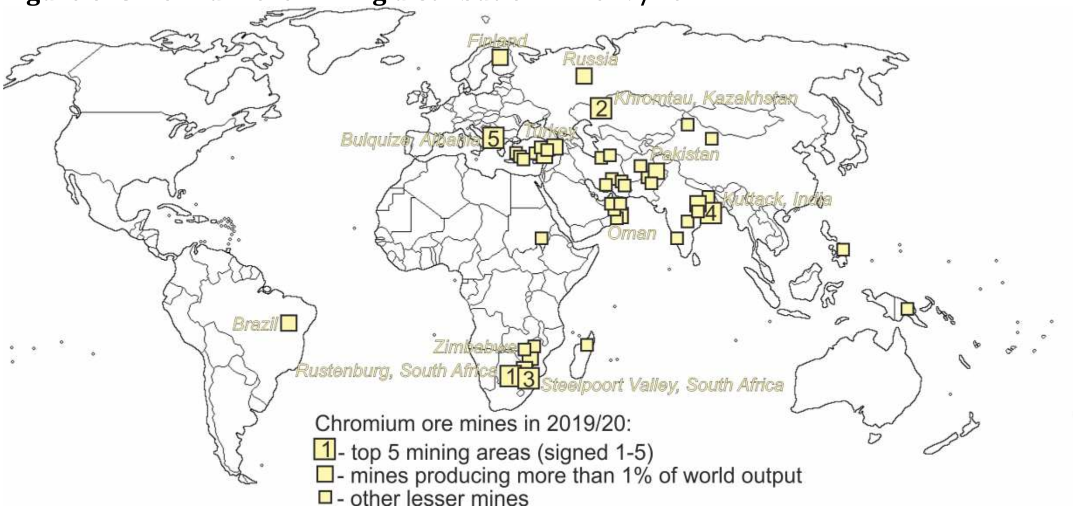


Figure 6. Chromium ore mining distribution in 2019/20



Currently, as show the latest available data, South Africa is still, and probably will be, a dominant exporter of chromium ore. Glencore, an English-Swiss mining corporation, has replaced Xstrata in a co-op with Merafe Resources. This co-op is currently a top chromite producer in South Africa, but there are many more, of which most important are: Samancor, Tharisa Minerals, Hernic Ferrochrome, Lonmin, and Assore.

Each of them produces more than 1 Mt of ore annually in Rustenburg Mining Area or Steelpoort Valley. Kazakhstan is still a second ranked producer. At Khromtau there are now two companies in operation: Eurasian Resources Group (ERG, formerly ENRC) and Turkish Yildirim Resources. Third rank remained in India, where main producing companies are Orissa Minerals and Balasore Alloys. Other lesser ones are Mysore Minerals, Tata Steel, Ferro Alloys Corp. and Indian Metals. Just behind India there is Turkey in a volume of chromium ore production. Consolidation of mining operations left two companies there: Yıldırım and Özdoğu İnşaat. Fifth rank belong to Zimbabwe, who has increased overall production of chromium ore. Suprisingly the increase was due to massive rise of small local enterprises on a Great Dyke, that took place in 2017 and following years. This wild exploitation has not been stopped fully yet, what provided cheap ore to the global market. Just behind Zimbabwe, there are Albania and Finland, both producing more than 1 Mt/year. Russia, Oman, Brazil and Pakistan account at least 1% of world production (fig. 6). In review of corporations on the global chromium ore suppliers market, the top five are: Eurasian Resources Group (6,0 Mt), Glencore-Merafe Resources (4,1 Mt), Yildirim (4,1 Mt), Samancor (3,2 Mt) and Tharisa Minerals (1,7 Mt).

Nickel ore mining

Stainless steel has traditionally accounted for two-thirds of primary nickel use worldwide, with more than one-half of the steel going into the construction, food processing, and transportation sectors. Beginning of XXI century in nickel ore mining saw new technologies of exploiting. Heap-leaching and acid-leaching were introduced to new and old mining operations, what gave an unprecedented increase in global output during the first decade. Since 1950, stainless steel production in the Western World has been growing at an average rate of 6.0% per year. Consumption of stainless steel in China has been particularly robust since 2000 and exceeded the combined output of Japan and the United States in 2007. Acquisitions and mergers have completely changed the structure of the global nickel industry since 2004. In 2006, the two leading nickel producers in Canada were taken over by even larger foreign mining companies. In 2007, the leading nickel producer in the world—a Russian company—created an entire overseas production operation by acquiring and then integrating existing facilities in Australia, Botswana, and Finland. Chinese and Australian companies have joined to explore for nickel across China. Some nickel consumers were concerned that global consumption of the metal would outstrip supply before new mining projects could be completed, what caused global price rise even before the global financial crisis to its historical peak. United States was in a severe recession and U.S. raw steel production collapsed in the fall of 2008. By yearend, capacity utilization at U.S. steelworks had dropped to 41%. Several competitors suspended or slowed work on nickel mining projects in Canada, Guatemala, Vietnam, and Zambia due to financial crisis 2008-2009. Nickel prices have been volatile in the aftermath of the global economic recession, but new mines were being developed at several locations. Additionally the global automotive industry was using more and more nickel as the popularity and familiarity of electric and hybrid vehicles increased. Companies mining lateritic ore in the Philippines continued to ramp up production in 2010 and 2011 to meet increased demand from Chinese producers of nickel pig iron, while production in Australia was not able to meet these demand. Nickel prices deteriorated further in 2011-2013 even though the global economy was slowly recovering. European debt situation worsened and the Chinese economy began to slow. Economic problems in Japan created by the March 2011 earthquake and tsunami reinforced the global slowdown. Decreased prices were largely attributed to an oversupply of nickel in the market, in particular, from the ramp up of nickel refineries in Madagascar and Canada and the resolution of production problems at new ferronickel smelters in Brazil and New Caledonia. Despite weak prices and an oversupply of nickel, companies continue to bring on new mining and processing projects in anticipation of a turnaround in the global economy. Nickel prices increased during the second half of 2016 following the historic low levels of late 2015 and early 2016. In late 2010's, production of refined nickel decreased as stainless steel producers, primarily in Asia, preferred lower cost alloys. The Philippines, the world's leading producer of nickel ore, suspended one-half of its mining operations in September 2017 for failing to meet environmental standards, helping the recovery of global nickel prices. Mine production in countries that supply direct shipping ore to nickel pig iron operations increased, while mine production supplying refineries tended to decrease. Production of nickel chemicals, however, has increased, particularly nickel sulfate used in the production of batteries. In 2020, owing primarily to reduced demand related to the global CoViD-19 lockdowns, consumption of nickel alloys was reduced globally by around 20%, and nickel ore production decreased by around 5%. Although stainless-steel production in most leading producing countries decreased, these were mostly offset by a rapid recovery in China's production of nickel-bearing stainless-steel grades and the continued ramp up of nickel and stainless-steel projects in Indonesia. Moreover in 2020 the Government of Indonesia decided to reinstate its ban on export direct-shipping nickel ore following rapid development of the country's nickel-processing capacity (table 3) (McRae 2021), (for all period 2000-2021).

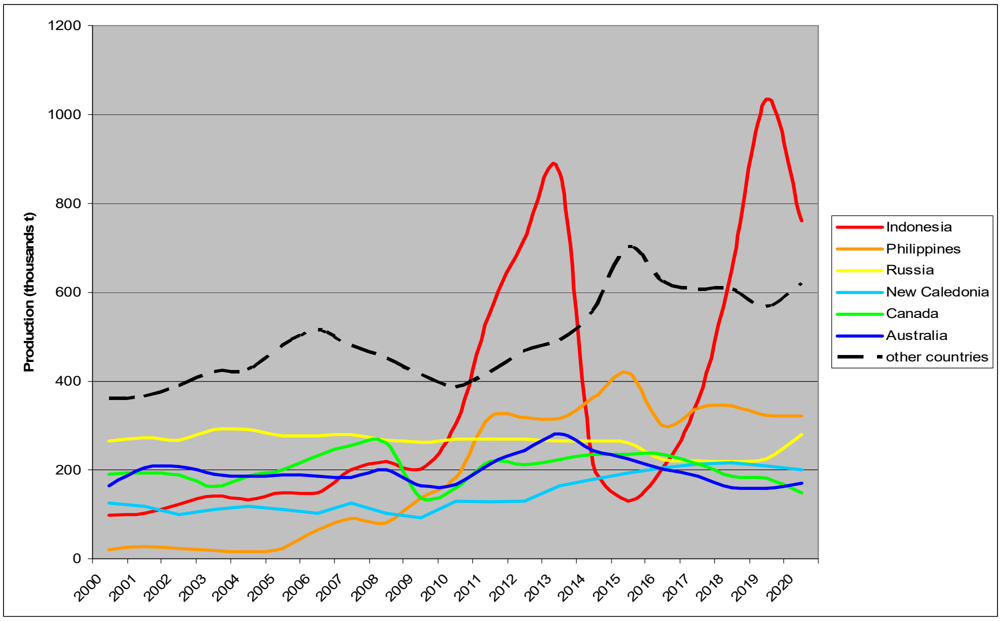
Table 3. Nickel ore prices and world production 2000-2020

Ni ore (Ni content, shipping grade)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Price in $/t (LME, end year)	8638	5945	6772	9629	13823	14738	24244	37216	21104	14649	21804	22890	17533	15018	16865	11831	9594	10403	13114	13903	14064
World production in thousand t	1227	1283	1300	1340	1358	1431	1527	1616	1581	1412	1605	2126	2361	2610	2057	2164	1993	2137	2384	2702	2500*

Source: USGS, BGS .

Indonesia, Philippines, Russia, New Caledonia, Canada and Australia were among top five producers at least once during 2000-2020 period (fig. 7). Australian and Canadian production declined to give place to extensively developing mining industry in Philippines and Indonesia.

Figure 7. Nickel ore production among top countries 2000-2020 (Ni content)



In 2000, Russia, which was the world's largest producer of nickel ore, (the RAO Norilsk Nickel, which had metal mines and production facilities in West Siberia and on the Kola Peninsula), produced about 20% of the world's output of nickel from mixed sulfide ores. The smaller amount of nickel was produced from laterite deposits in the Urals by Yuzhuralnikel and Ufaleynikel. Nickel production in Russia had fallen by almost 40% from the peak levels of the late 1980s.[3] Nickel was the most valuable metal produced in Canada, the second biggest producer, in 2000. Falconbridge Ltd. operated four nickel-copper-cobalt mines near Sudbury, Ontario, and Raglan in northern Quebec. In Sudbury mining area Inco Ltd. was also present. This corporation operated also Voisey's Bay mine in Labrador and mine in Thompson, Manitoba. At 166,000 t of nickel in 2000, Australia was the world's third largest nickel producer. Most of the country's nickel-cobalt mines are in the Kalgoorlie region, Leinster, Mt. Keith and Murrin Murrin of Western Australia (McRae 2021). The most productive corporations there were WMC Resources, Anaconda Nickel and Finnish Outokumpu (McRae 2021). New Caledonia, being then at fourth rank, continued to be economically dominated by the mining of nickeliferrous laterite-saprolite and garnierite ores by Société le Nickel (SLN) and Société Minière du Sud Pacifique (SMSP) and the production of ferronickel of various commercial grades and nickel matte. Nickel contributed about 80% to foreign exchange earnings in New Caledonia then. Indonesia was at fifth rank with three mining operations on Sulawesi and Gebe islands. It was followed by another important suppliers in descending order: Cuba, Colombia, China, Brazil, Dominican Rep., South Africa, Greece, Botswana, Philippines, with production above 1% of global (fig. 8). In review of corporations on the global nickel ore suppliers market, the top five were: Norilsk Nickel (256 kt), Inco (147 kt), Unión del Níquel from Cuba (68 kt), and Société le Nickel (64 kt) and Société Minière du Sud Pacifique (62 kt).

Currently Indonesia has remained top nickel ore producer reaching a historical peak of production in 2019 with more than 1 Mt of ore mined per year. For 2020 estimates are lower. There are three active large mines: Pomalaa owned by Aneka Tambang, Soroako of Brazilian Vale, and new project – Mekarsari mine owned by China Nickel Resources. Mine at Gebe Island had permanently ceased production. On

[3] Norilsk Nickel Annual report 2000. Available online: http://www.nornik.ru/english/press/rep.htm (accessed 12 Dec. 2021).

Figure 8. Nickel ore mining distribution in 2000

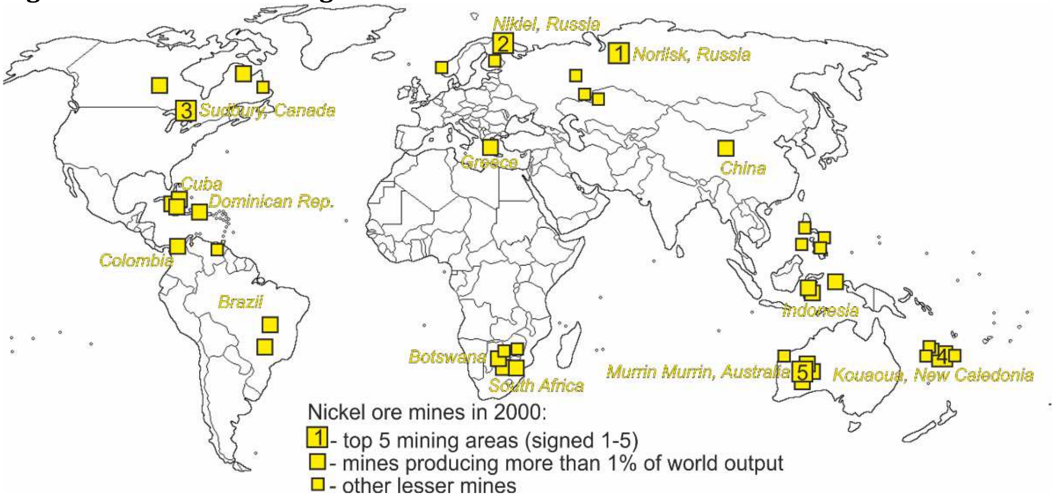
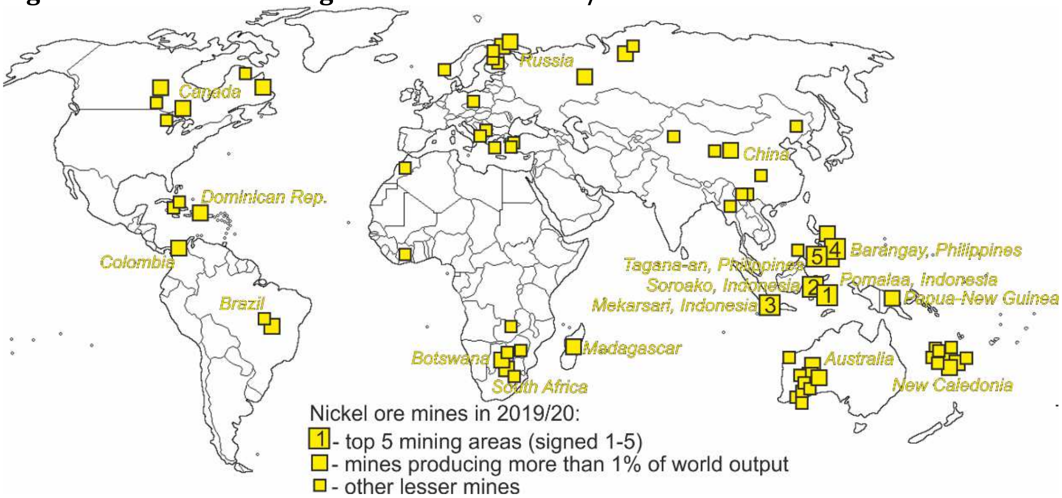


Figure 9. Nickel ore mining distribution in 2019/20



the second place are Philippines with decreasing production. Some mines are closed due to recent environmental issues and audit. Biggest operator in Philippines is Cagdianao Mining and its mine in Barangay Valencia. Third place is for Russia with five mines operated by Norilsk Nickel and Ufaleynickel. The biggest output is in Nikiel mine on Kola Peninsula. Further is New Caledonia with a recently opened new mining project – Goro owned by Brazilian Vale. Canada is next supplier, and here also Vale is the main mining company with Sudbury mining area as the most productive among all five exploitation places. Australia ranked sixth recently has reduced its nickel ore output with only 9 active mines left. BHP Billiton remained as top ore producer in Australia. Next is China with main nickel operations in Jinchuan, Gansu province. More than 1% of global ore output is supplied also by: Brazil, Cuba, South Africa, Finland, Madagascar, Papua New Guinea and Dominican Rep. (fig. 9). In review of corporations on the global nickel ore suppliers market 2020, the top five were: Aneka Tambang (496 kt), Brazilian Vale (483 kt), which operated in many countries, China Nickel Resources (260 kt), Norilsk Nickel (190 kt), and Cagdianao Mining (125 kt).

Cobalt ore mining

With the exception of production in Morocco and artisanally mined cobalt in Congo DR, most cobalt is mined as a byproduct of copper or nickel. World production of refined cobalt has steadily increased since 1993. Some of the increase has been from new operations and some has been from a net increase in production by established producers. Cobalt in recycled scrap have also contributed to supply. World demand for cobalt is strongly influenced by general economic conditions and by demand from industries that consume large quantities of cobalt, such as superalloy smelters and manufacturers of rechargeable batteries. In 2002, several factors reduced overall demand for cobalt, including continued weak economic conditions in major consuming countries such as the United States and Japan. Since 1995, the general trend in cobalt prices had been downward. However, cobalt production during the first years of analyzed period had upward trend. In most cases this was probably the result of increased production of copper or nickel, the primary metals produced at cobalt operations. Demand for cobalt to manufacture rechargeable batteries for portable electronic devices such as cellular phones increased in 2003, what caused prices to start rising, as a result of tightness in supply. High prices have begun to impact consumption, however. For example, several producers of rechargeable batteries have developed lithium-ion cells that substituted cobalt with a lower cost mix of metals. In 2004 exports of cobalt-rich ores from Congo DR to refineries mainly in China have helped to balance cobalt supply and demand, and reduce skyrocketing prices. In 2007, estimated cobalt mine production from Congo DR decreased for the first time in more than a decade as a result of restrictions on exports of unprocessed cobalt. The Chinese cobalt industry responded and was forced to develop more domestic and foreign sources of cobalt supply, to invest in other African cobalt projects, to increase the recycling of cobalt scrap, to continue to shift its consumption towards more available materials, and to consolidate into fewer larger companies. Health, safety, and environmental issues were becoming increasingly significant with respect to such metals as cobalt. The European Commission's new chemicals policy became effective June 1, 2007. This legislation affected suppliers of cobalt materials to the European market by requiring them to collect and submit risk assessment data on each material produced in or imported into the European Union. In a result prices raised again. Growing prices and demand caused progress on numerous new brownfield and greenfield projects that added to world cobalt supply. In 2008, new cobalt ore production projects begun operations in Australia, Congo DR, Finland, and Zambia. The global economic downturn that began in late 2008 resulted in reduced demand for and supply of cobalt. The crisis caused a decline in production of refined cobalt from China, closure of a Zambian refinery, miners strikes in Canada, cutback in many copper and nickel mines, and delays in new mining projects. During 2009 and into 2010, global economic conditions began to improve. The London Metal Exchange (LME) launched a cobalt contracts in February 2010, what improved international trading significantly. In following years, global cobalt production had been higher than consumption, resulting in a market surplus and downward pressure on prices. During last years Congo DR continued to be the world's leading source of mined cobalt, supplying more than one-half of world cobalt mine production. In 2016, global cobalt mine production slightly decreased, mainly owing to lower production from nickel operations. In 2017, average annual cobalt prices more than doubled, owing to strong demand from consumers, limited availability of cobalt on the spot market, and an increase in metal purchases by investors. As a result, the global cobalt supply was expected to remain limited. In 2018, average annual cobalt prices were higher than those of 2017, owing to strong demand from consumers in the re-chargeable battery and aerospace industries and to limited availability of cobalt metal despite its production increase. Cobalt mine and refinery production were decreased in 2020. Estimated annual average cobalt prices also declined. Many cobalt operations were suspended to prevent the spread of CoViD-19 causing accompanying economic crisis and reduction of global demand (table 4) (Shedd 2021a).

Figure 10. Cobalt ore production among top countries 2000-2020 (Co content)

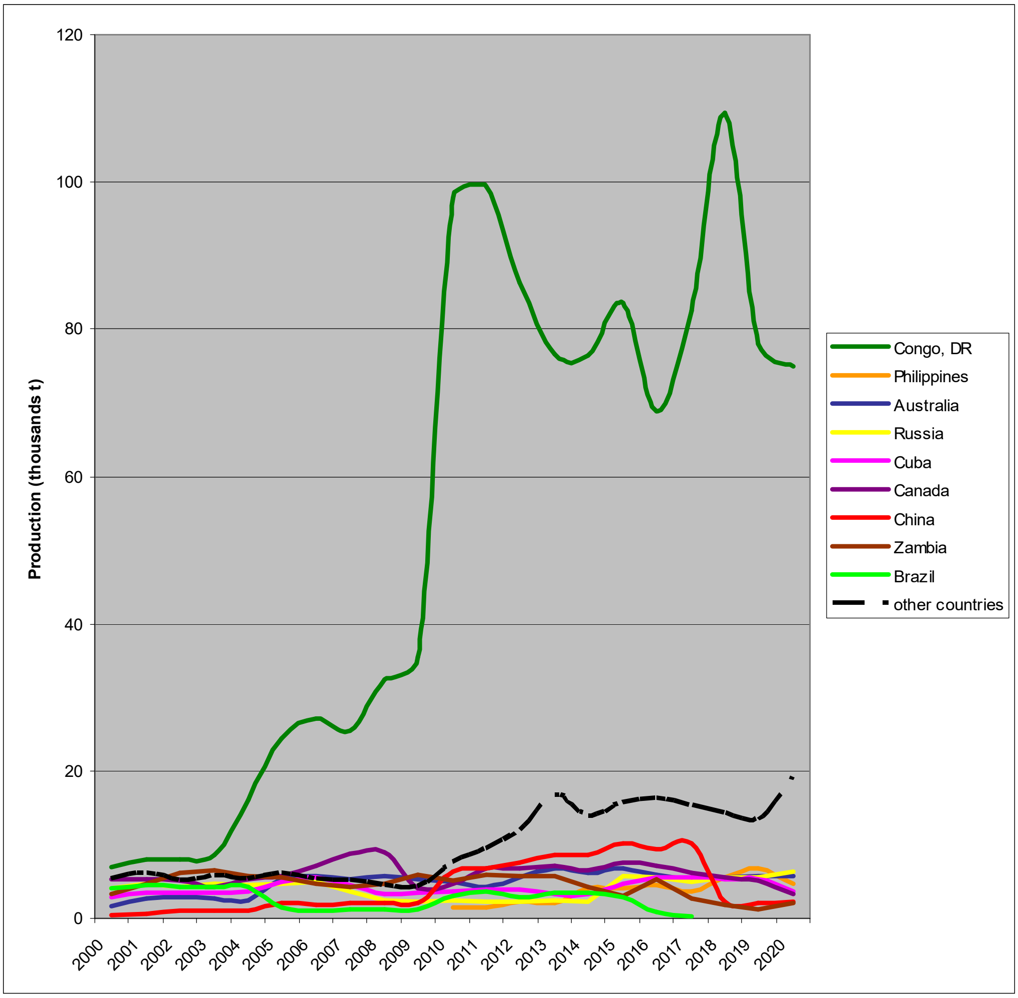


Table 4. Cobalt world prices and world production 200-2020

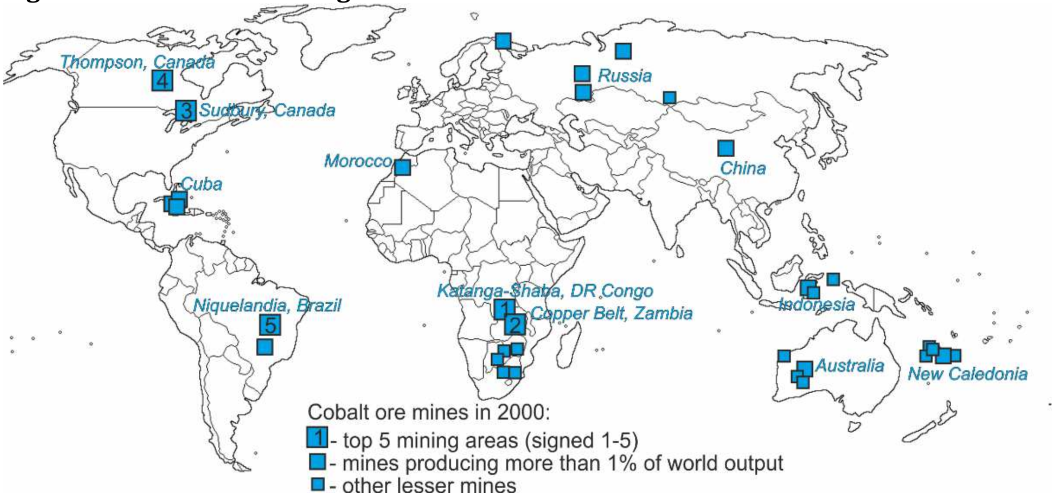
Co ore (Co content)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Price in $/kg (average, end year)	33,43	23,26	15,35	23,37	52,77	35,19	37,97	67,36	86,02	39,38	45,97	35,30	28,80	27,03	30,87	28,44	25,51	55,74	72,63	32,81	30,87
World production in thousand t	34	40	40	41	48	60	63	60	65	64	137	144	135	133	129	144	129	136	155	123	122*

Source: USGS, BGS and London Metal Exchange.[4] * - BGS estimate.

[4] London Metal Exchange. Available online: https://www.lme.com/ (accessed 31 Dec. 2021).

Congo DR, Philippines, Australia, Russia, Cuba, Canada, China, Zambia and Brazil were among top producers at least once during 2000-2020 period. Philippines started cobalt extraction in 2010, and Brazilian cobalt ore mines was shut down in 2018. Zambian and Canadian production declined to give place to extensively developing mining industry in Philippines and others (fig. 10).

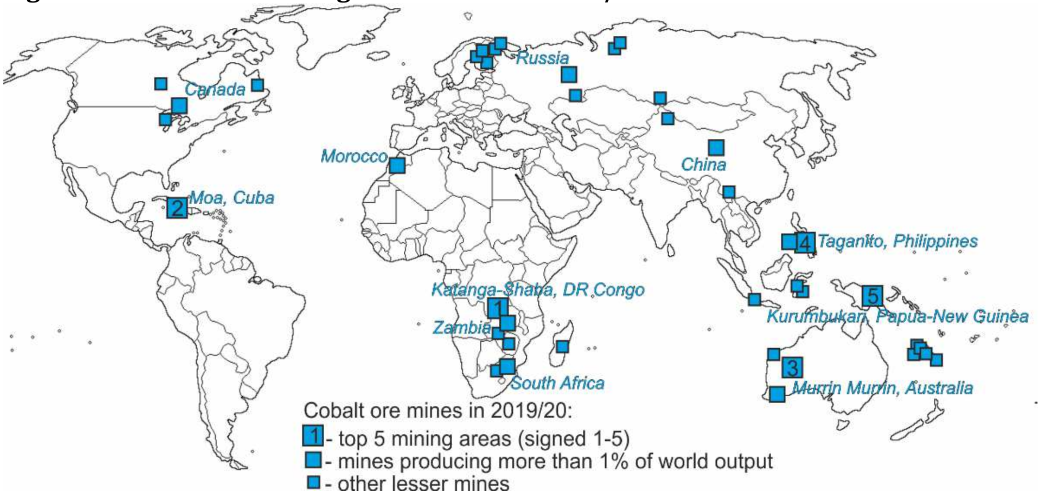
Figure 11. Cobalt ore mining distribution in 2000



During the last two decades Congo DR was a top producer of cobalt ore. Copper Belt in Katanga (Shaba) Province contained one of the greatest concentrations of high-grade copper and co-product cobalt resources in the world. Since 1993, most mining operations have come to a standstill, with total capacity utilization at less than 10% due to civil war, crises in finance, production, and transportation, thefts, corruption, flooding of open pit mines, electrical power blackouts and inability to retain professional foreign personnel (Wilczyński 2021). There were then only two fully operational mines. The bigger one located in Luiswishi was owned by American OM Group. Around 40% of Congolese cobalt production came from artisanal mining that time. The political situation stabilized in 2004 and many mines where reopened there. Canada held second rank with only two nickel-copper-cobalt mining areas: Sudbury and Thompson, both in Inco possession. The third rank was occupied by Brazil. There were active two nickel-cobalt mines. One in Niquelandia was owned by Brazilian Votarantin, and another in Fortaleza de Minas by Rio Tinto, an international corporation. Fourth place belonged to Russia. The biggest supplier of cobalt ore was Norilsk

Nickel, operating mines in Norilsk and Nikiel on Kola Peninsula. Cobalt was mined also in Ural and Altay Mountains. Fifth ranked country in production of cobalt ore was Zambia, where in 2000, the privatization of Zambia Consolidated Copper Mines (ZCCM) and the full transition of one of the world's larger copper industries from state-owned to privately owned and operated were completed. All cobalt ore operations were located in Copper Belt mining area. The most productive mine there was located in Nchanga and owned by Konkola Copper Mines – co-op of several international companies. Cuba was ranked sixth. It had nickel-cobalt-copper mines of which Moa was the biggest one, owned by Unión del Níquel. Following countries produced more than 1% of global cobalt output in descending order: New Caledonia, Australia, Morocco, Indonesia, China and South Africa. Botswana and Zimbabwe also produced some cobalt ore (fig. 11). In review of corporations on the global cobalt ore suppliers market 2000, the top five were: Inco (5,3 kt), American OM Group working in DR Congo (5,0 kt), Cuban Unión del Níquel (2,9 kt), Brazilian Votarantin (2,1 kt) and British-Australian Rio Tinto (2,0 kt).

Figure 12. Cobalt ore mining distribution in 2019/20



In 2020 DR Congo continued to be the world's leading source of mined cobalt, supplying approximately 70% of world cobalt mine production during recent years. This country was more than offset by reduced production at other operations in response to low prices and restrictions resulting from the CoViD-19 lockdowns. Currently the highest mine output of cobalt has Katanga Mining, Mutanda Mining, Tenke Fugurume, which accounts for more than half of Congolese cobalt production. Rest of shares in production belongs to numerous Congolese and foreign companies as well as artisanal miners. Second biggest supplier of cobalt is now Russia, but with production ten times less than the leader. Three companies were competing in Russia: Norilsk Nickel, Ufaleynikiel, and Yuzhnikiel. Ufaleynikiel recently became top Russian cobalt supplier as its content in Verchnyi Ufaley nickel mine ore increased significantly. Third place in cobalt ore mining is held by Australia. There are three mines of cobalt ore active. The biggest in Murrin Murrin is held by Minara Resources and Glencore joint venture. Philippines, which are fourth on a list of top cobalt ore producers, have two HPAL (high-pressure acid-leach) mines. Bigger is in Taganito (Taganito Mining), and second is in Coral Bay (Coral Bay Nickel). Cuba, the fifth producer of cobalt ore, has sole mine in Moa, owned by Moa Nickel. In Canada, cobalt operations are held by Brazilian Vale and Swiss Glencore. Sudbury region remains as main cobalt source in this sixth world's supplier. Following ranks are for Papua-New Guinea, China, Morocco, South Africa, New Caledonia, Finland, Zambia, which in descending order supplied the world with more than 1% of cobalt ore global production (fig. 12). In review of corporations on the global cobalt ore suppliers market currently the top five are: Katanga Mining (20,9 kt), Mutanda Mining (15,6 kt), Tenke Fungurume (10,2 kt) (all top three from DR Congo), Jinchuan Group of China (6,45 kt), and Shalina Resources of UAE(3,9 kt).

Tungsten ore mining

World tungsten resources are geographically widespread. China ranks first in the world in terms of tungsten resources and reserves. Beginning in 1999 and continuing into 2001, the Chinese Government took several steps to control the release of Chinese tungsten into the world market and to increase prices. These relatively high prices, in combination with the desire by western processors to diversify the sources of their tungsten raw materials, resulted in renewed interest in increasing tungsten mine production outside China. Projects to increase production from operating mines, to restart production from closed mines, and to develop new mines were under consideration and development. The most important new source of tungsten concentrates became available in early 2002, when production resumed from the Cantung Mine in Canada, giving the country a place among top five producers immediately. The price decrease in 2002 was also attributed to a severe reduction in demand for tungsten end products resulting from a slowing of the world economy. There was reported an increase in smuggling of non-licensed primary tungsten materials out of China. In 2003 Chinese Government was gradually shifting the balance of export quotas towards value added downstream tungsten materials and products. China was also becoming a larger tungsten consumer. In late 2003, the sole Canadian tungsten mine temporally suspended operations due to debt. Health, safety, and environmental issues were becoming increasingly significant to metals such as tungsten and in case of Western World this started to cause decrease of supply. In 2005, inadequate supplies of tungsten concentrates within China combined with increased demand for tungsten materials in China and elsewhere resulted in steep increases in the prices. Various companies developed operations on tungsten deposits or on reopening inactive tungsten mines in Australia, China, Peru, Russia, the United States, Vietnam and other countries. The serious downturn in the global financial markets in late 2008 delayed or cancelled many startups of additional proposed production operations. In response to global economic conditions, some Chinese tungsten mines in Hunan and Jiangxi Provinces reportedly suspended production. In 2010, global economic conditions improved and tungsten consumption increased. There was observed significant increase in tungsten scrap consumption as well. After the financial crisis Chinese Government has regulated its tungsten industry. There were introduced laws limiting the number of exploration, mining, and export licenses limiting or forbidding foreign investment. Changes had been made in taxes to gain more control over the industry, to stop illegal mining and close small inefficient mines. China wanted to improve its tungsten-processing technology and increase tungsten recovery from ores and tailings as well. These moves caused tungsten prices to rise in 2011 and 2012. Scrap continued to be an increasingly important source of raw material for the tungsten industry. As a result of a World Trade Organization (WTO) ruling that China's export restraints were inconsistent with its WTO obligations, China canceled its tungsten export quota for 2015. That caused the tungsten market oversupply. Owing to an economic slowdown in China and weak economic conditions elsewhere mine production exceeded consumption and prices started to drop. In spite of oversupply and low prices, new production entered the market. In 2015, tungsten mines in the United Kingdom and Zimbabwe began production, a large new mine in Vietnam ramped up production. As a result of dropping prices the China Tungsten Industry Association asked its members to cut their production of tungsten concentrates so tungsten prices began to trend upward in late 2015, but only for several months, due to newly opened operations increasing tungsten supply in Vietnam, United Kingdom, Mongolia, Rwanda and Spain. From 2016 through 2018, environmental and safety inspections at Chinese mines and downstream ammonium paratungstate plants resulted in intermittent periods of reduced supply. Owing to lower ore grades being mined in Vietnam and the closure of the sole tungsten mine in the United Kingdom, supply was reduced, and prices raised again. In 2020, production of tungsten concentrate outside China was expected to remain at less than 20% of world production. Impacts of the global CoViD-19 pandemic on the global economy and industrial production, particularly tungsten consuming end-use sectors such as the automotive, commercial aerospace, and oil and gas drilling industries caused decrease in tungsten consumption and production in 2020 and resulted in a market surplus taking prices downwards (table 5) (Shedd 2021b).

China is top tungsten producer for both analyzed decades (figure 13). Vietnam, Russia, Mongolia, Bolivia, Korea DPR, Rwanda, United Kingdom, Zimbabwe, Canada, Austria and Portugal were among top producers at least once during 2000-2020 period (Fig. 14). Austria and Portugal are stable suppliers, but with growing mining capacity their position on a global market was given to new or developing its production countries like Vietnam, Mongolia, Bolivia or Rwanda. Canada, Zimbabwe and United Kingdom were among tungsten producers only temporally but got almost once to top five.

Table 5. Tungsten ore prices and world production 2000-2020

W ore	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Price of shipping grade WO_3 \$/t (average)	46	65	46	47	52	134	183	177	194	151	166	199	358	358	348	302	148	245	326	270	270
World production in thousand t (metal content)	30,6	35,1	43,0	46,4	51,3	60,6	59,1	57,0	57,6	62,3	63,4	77,6	78,2	81,0	85,3	83,0	80,4	83,7	81,7	91,5	84,0*

Source: USGS, BGS, Platt's Metals Week and Metal Bulletin journals. * - USGS estimate.

Figure 13. Tungsten ore production in China and in the rest of the world 2000-2020 (W content)

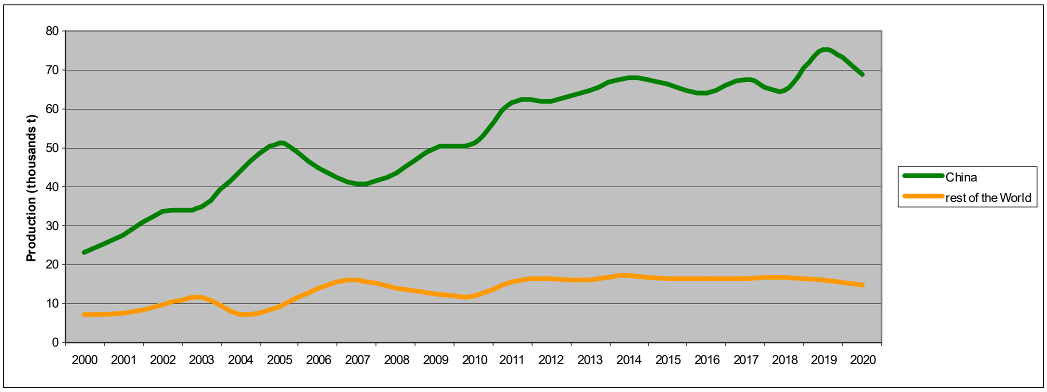
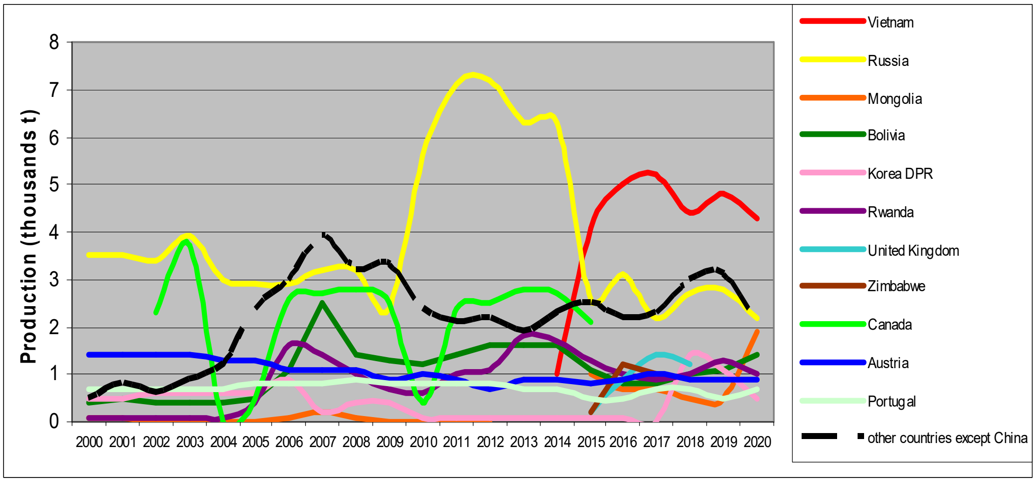
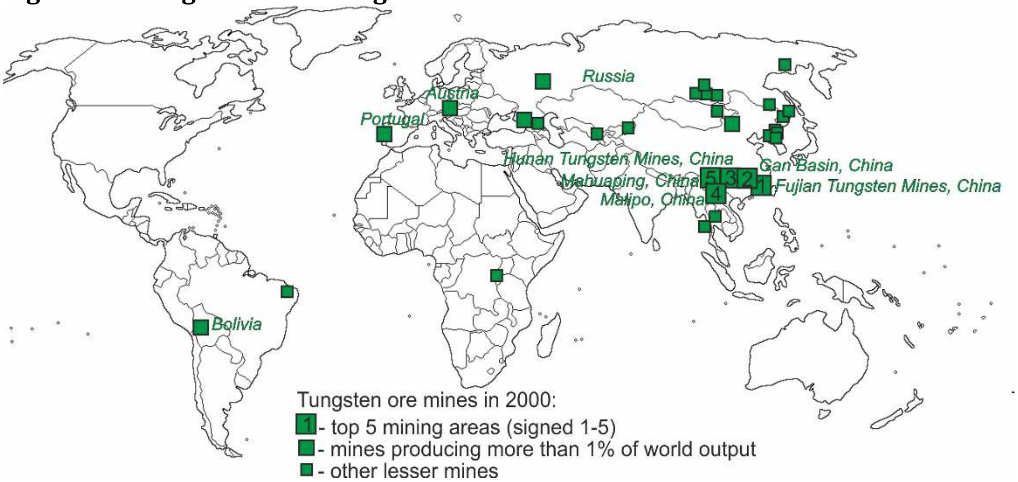


Figure 14. Tungsten ore production among top countries, except China, 2000-2020 (W content)



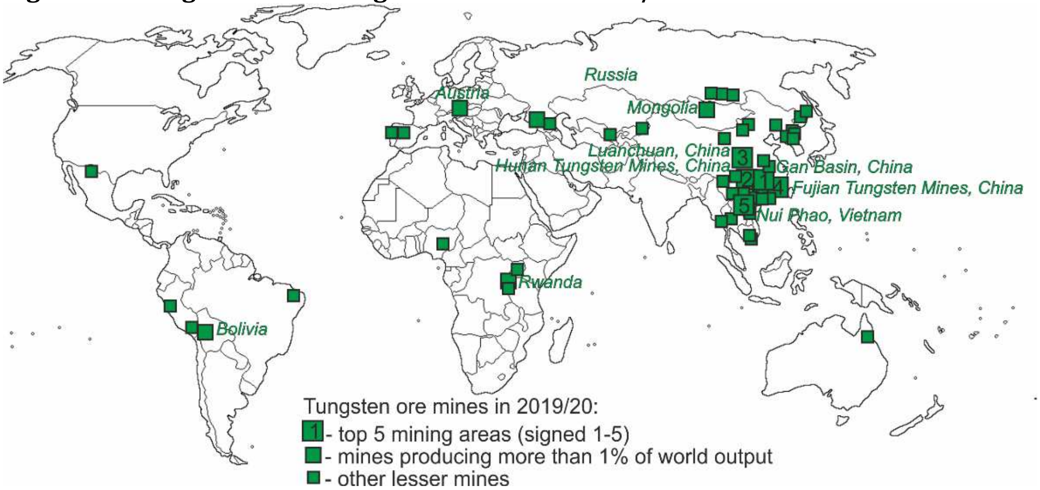
In 2000 there was 23453 tonnes of tungsten mined as ore content in China, accounting for 70% of world total. Therefore, the country had a major influence on world tungsten prices. Between 1999 and 2000, 145 illegal mines were shut down in China due to intensive policing and industrial lobbying. Only 6 major producers left, all under management of China National Nonferrous Metals Industry Corp. Russia was at second rank in 2000 with ten mines and ten decentralized corporations. Biggest Russian tungsten supply came from Tyrnyauz mine in Caucasus Mts. Austria sole mine in Mittersill was giving third rank to this country. Mine was operated by Inmet Mining, a Canadian company. The Panasqueira tungsten mine of Avocet Mining (British company) was the sole mine of tungsten ore in Portugal, ranked fourth in 2000. Important producer of tungsten ore was North Korea (KDPR) with four mines and state-owned enterprises, selling tungsten to China. Above 1% of global tungsten output was also sixth producer – Bolivia. Production there came from the small miners and co-operatives that had small deposits in so-called La Paz Tin Belt with high ore grades and local low labor costs (fig. 15). In review of corporations on the global tungsten ore suppliers market 2000, the top five were: China National Nonferrous Metals Industry Corp. (23,4 kt), Inmet Mining (1,4 kt), Avocet Mining (0,7 kt), Tyrnyauz Mine (0,7 kt) and Balkan Mine Operations (0, 5 kt).

Figure 15. Tungsten ore mining distribution in 2000



The latest available data reveals further decentralization of mining state-owned enterprises in China in 2019 and 2020. Almost half of Chinese tungsten ore production is coming from Gan Basin and the rest of Jiangxi province. Jiangxi Tungsten and Rare Earth Co. remains top Chinese company for last years. Vietnam became second ranked tungsten supplier. There are 4 mines and Nui Phao mine owned by Starck Tungsten Chemicals Manufacturing is the biggest. Third is Russia, where tungsten output dropped recently. Tyrnyauz mine remained as the leader in the industry, but several mines are now closed. Next supplier currently is Mongolia after significant Japanese investments in its sole tungsten ore mine in Erdenet. Fifth supplier is now Bolivia, where production is coming from small-scale private mining enterprises and one state-owned Corporación Minera de Bolivia (Comibol). All mines are located within La Paz Tin-Tungsten Belt. Other countries with more than 1% of global tungsten output are Rwanda and Austria (fig. 16). In review of corporations on the current global tungsten ore suppliers market, the top five were: Jiangxi Tungsten and Rare Earth Co. (30,2 kt), China Molybdenum Co. (10,1 kt), China Minmetals (7,5 kt), Amoi Tungsten (4,9 kt) and Shizhuyuan Nonferrous Metals (4,8 kt) (Shedd 2021b).

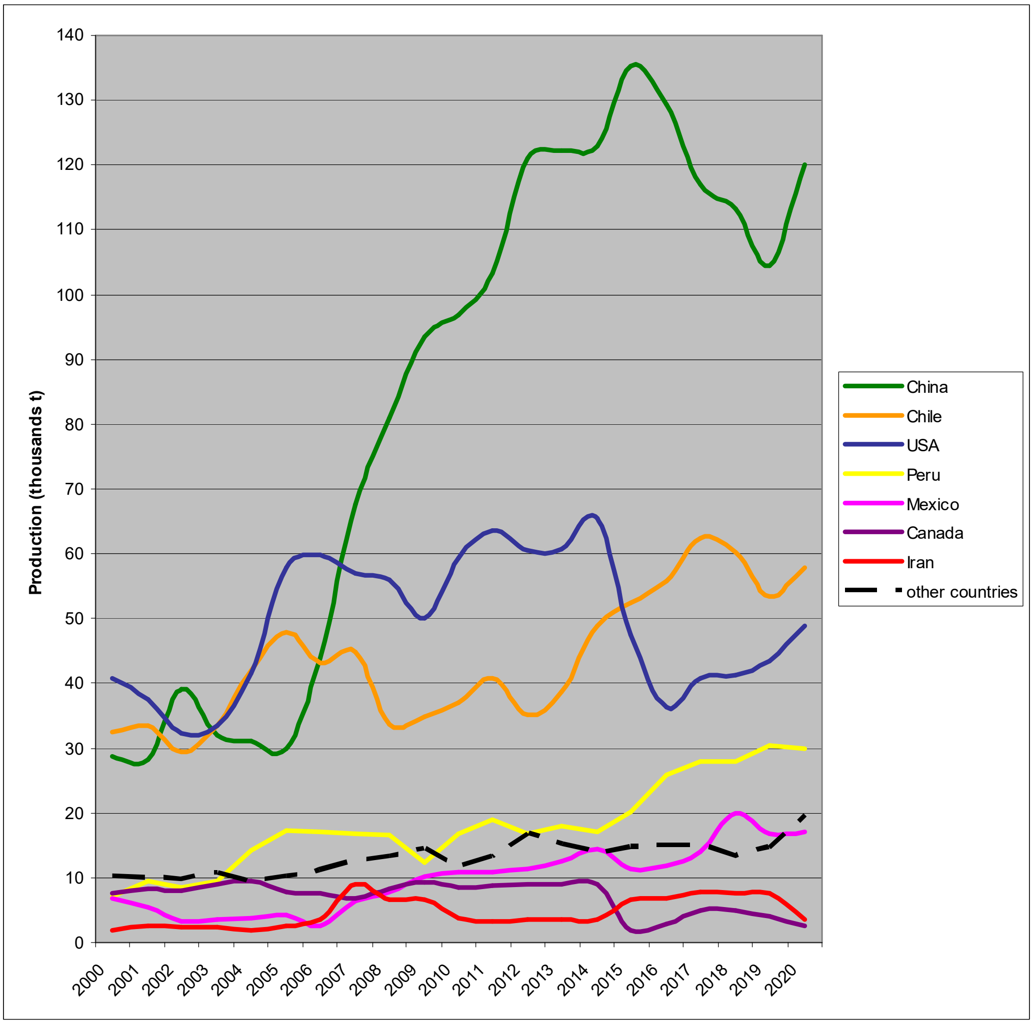
Figure 16. Tungsten ore mining distribution in 2019/20



Molybdenum ore mining

Mine output of molybdenum in 2000 and 2001 decreased to the lowest prices level since 1983. USA was the leader among suppliers that time and had largest confirmed reserves of molybdenum ores. American mines output of molybdenum in 2002 decreased and China and next year Chile became a new global biggest suppliers for 1 year each. Prices soon began to rise. China continued its high level of steel production and consumption, thus providing a stable demand increase for molybdenum. With the continuing high price of nickel-bearing stainless steel in 2003, many consumers increasingly considered use of duplex stainless steel. American mine output of molybdenum in 2005 increased due to highest prices levels of molybdenum in history and USA returned as a global leading supplier. Reduced Chinese exports and the continued roaster bottleneck in the west continued to support historically high molybdenum prices. Chinese Government funded extensive geological exploration and mining investments to increase production in this years. Growing global demand and historically highest prices caused many new

Figure 17. Molybdenum ore production among top countries 2000-2020 (Mo content)



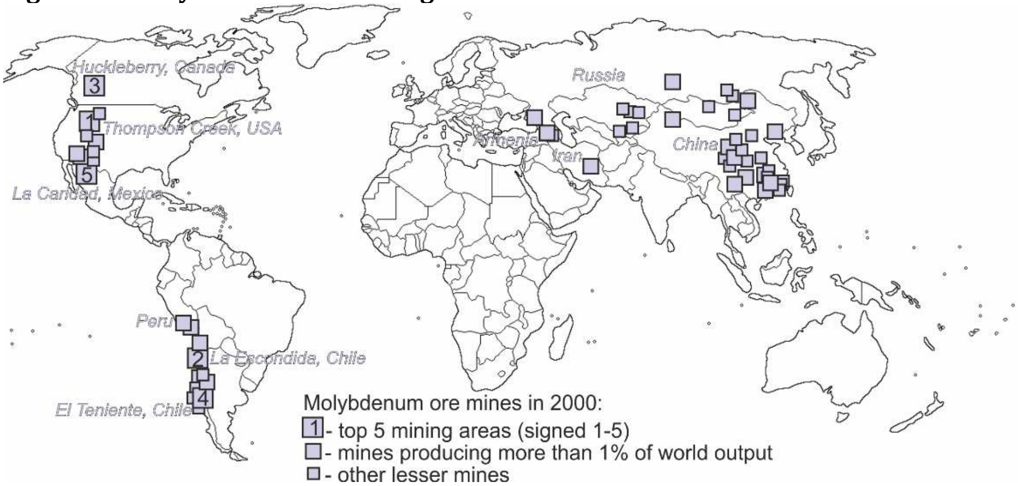
mines to start operations around the world before and after the financial crisis of 2008-9, when molybdenum prices declined. In 2008 there were many new mines opened in China, and its output almost doubled giving the leading role as a supplier on a global market. Molybdenum prices increased in 2010, because molybdenum demand remained strong as the world recovered from the crisis. Molybdenum prices slowly decreased in 2012 as an effect of increasing supply, however molybdenum demand remained strong. In November 2014, China cancelled export quotas (25,000 t) for molybdenum for 2015. This comes after a World Trade Organization panel concluded in March that China violated the organization's membership obligation by restricting exports of molybdenum. With increase of molybdenum recycling (being at that time more than 30% of global supply), this gave way to another prices reduction. This led many operations to be suspended next year, mainly in the USA. Increase in prices and decrease in global production offset the production delays caused by the global CoViD-19 lockdowns (table 6, figure 17) (Polyak 2021; Dutta 2018).

Table 6. Molybdenum ore prices and world production 2000-2020

Mo ore	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Price of shipping grade Mo content in oxide $/kg (average)	5,6	5,2	8,3	11,7	29,7	70,1	54,6	66,8	63,0	25,8	34,8	34,3	28,1	22,8	25,8	15,1	14,4	18,1	27,0	26,5	20,0
World production in thousand t (metal content)	136	135	133	134	153	178	189	221	223	231	245	263	274	280	295	290	284	290	289	275	300*

Source: USGS [32], BGS [16], CRU Group. * - USGS estimate.

Figure 18. Molybdenum ore mining distribution in 2000.



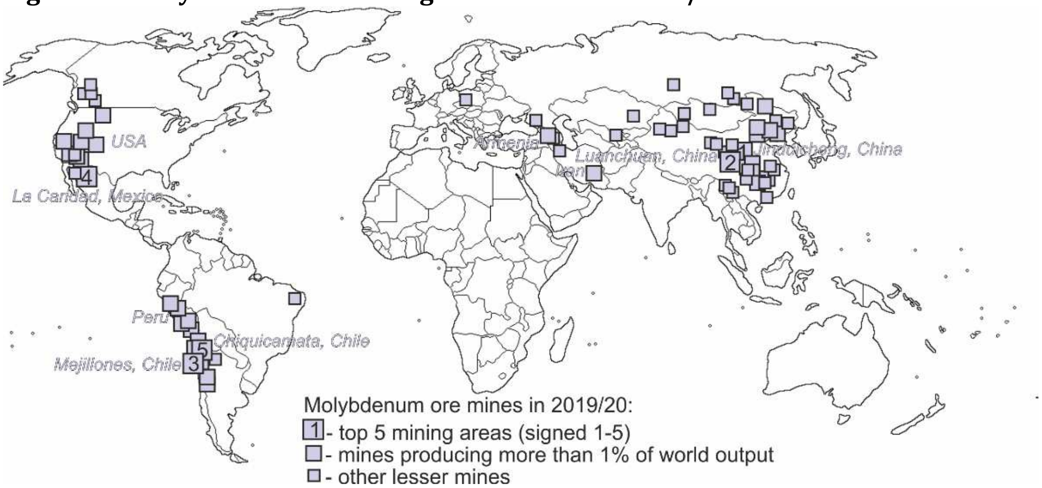
China, Chile, USA, Peru, Mexico, Canada and Iran were among top producers at least once during 2000-2020 period (Fig. 17). Iran was increasing its output but this development stopped at some stage mostly due to small ore reserves. The highest increase took place in China following intensive industrial demand and governmental investments.

Decrease of production relatively took place in the USA and Canada (Outteridge et al. 2020).

In 2000 most mined molybdenum came from USA, even when all mines worked only partially using its capacity. The molybdenum businesses were under pressure due to very low prices. The biggest mine output was generated in Thompson Creek, Idaho, by Thompson Creek Metals Company. Molybdenum was mined also in Arizona, New Mexico, Montana and Utah by various private-owned corporations of which Phelps Dodge Company had almost half of the mining locations operated. Second country with molybdenum output slightly lesser than USA was Chile. Largest molybdenum output had La Escondida mine, but there were also eight other mines competing. Most of them were owned by state-owned Corporacion Nacional del Cobre de Chile (CODELCO). China, a third most important supplier, exported about 80% of its molybdenum products mainly in the form of ferromolybdenum and molybdenum oxide. In 2000, the European Union investigated China's ferromolybdenum export practices and imposed dumping duties. In response China imposed an export limit on ferromolybdenum to the EU. Facing a dumping charge and weak demand in Japan, China's molybdenum producers had difficulty maintaining a profitable margin that time. The second issue was still very bad infrastructure in remote mountainous areas where molybdenum was mined. Only Luanchuan mine had a good transport connection. Canada was then a fourth supplier for the global market, but with much less output than the leading three countries. All production was from sole Huckleberry mine. In Peru, which was fifth producer of molybdenum in 2000, there were only two mines localized in Cuajone and Toquepala. Sixth important supplier was Mexico with its sole mine in La Caridad. Above 1% of world's molybdenum ore supply there were also Russia, Armenia, Iran and Mongolia (fig. 18). In review of corporations on the global molybdenum ore suppliers market 2000, the top five were: Thompson Creek Mining Co. (27,0 kt), Corporacion Nacional del Cobre de Chile (17,8 kt), Phelps Dodge Co. (11,6 kt), MineraEscondida (11,6 kt) and Huckleberry Mines (7,5 kt).

Recently China has dominated the market. Molybdenum mining developed mostly in Liaoning and Henan provinces, but Shaanxi remained important as well. Two state-owned corporations remained at a top, but Luoyang Luanchuan Molybdenum Industry Group changed name to China Molybdenum Co. Actually China supplies more than 40% molybdenum worldwide. Chile is now second largest supplier of molybdenum ore with 8 large mines active. The biggest output is currently in Mejillones mine opened several years ago. CODELCO is the second biggest molybdenum ore mining company in the world due to this investment. USA with closed Thompson Creek mine is now third producing country. However, new mines appeared also with very big Climax operation. Fourth position on the market has Peru, where are some new operations established recently. Two mines located in Armenia is giving fifth rank to this country. Sixth is Iran, the last country in the current ranking producing more than 1% of overall world output (fig. 19). In review of corporations on the global molybdenum ore suppliers market currently, the top five are: China Molybdenum Co. (49,5 kt), CODELCO (42,4 kt), Jinduicheng Molybdenum Industry Group (42,0 kt), Freeport-McMoran Inc. (31,8 kt) and Mexicana de Cobre (14,1 kt).

Figure 19. Molybdenum ore mining distribution in 2019/20



Discussion & Conclusions

In 20 years perspective all analyzed ferroalloy metal ores markets has grown extensively in both value and volume. Some regions expanded their mining capabilities, others maintained previously achieved levels, while others reduced production. Different states and companies policies accompanied these processes, and some global factors has had an impact as well, mainly the crisis of 2008-2009, some technological advancements and new applications for analyzed metals, and lastly the CoViD-19 lockdowns and breaking supply chains. Apart from these, the most important factors for analyzed specific markets were listed to further discussion in an above text.

In manganese ore market through 20 years prices and global output doubled. The most developments took place in South Africa, Gabon and China. Decrease is noted in Ukraine and Brazil. The manganese mining disappeared in Chile, and most European countries: Italy, Hungary, Bulgaria and Russia too. However new suppliers entered the market, mostly from Africa: DR Congo, Egypt, Ivory Coast, Namibia, Sudan and Zambia. Two Latin American countries joined manganese ore producers as well: Bolivia and Peru. Chromium ore market during last 20 years almost tripled its value and volume. Even though more countries ceased production than started it. Cuba, Burma, Australia and Vietnam don't produce chromium ore anymore, and only Papua-New Guinea has launched new chromium mine. There was significant increase of yearly output in South Africa, Kazakhstan, Turkey and Albania. Decrease can be observed in Zimbabwe and Brazil. Last 20 years has changed nickel ore mining with doubled value and volume. Many new producing countries appeared on a market map. Indonesia and Philippines responded to Chinese demand in huge increase of production. The same cannot be said about Canada and Australia, where production relatively decreased. Mining of cobalt ore has grown almost four times during two last decades, but prices with a peak around 2008-2009 dropped to the same level as 20 years ago. DR Congo reopened its cobalt mines and added the most to the increase of cobalt ore mine output. Philippines also made an investments and significantly adjusted its production volume. Canada, China and Zambia on the other hand reduced mine output. Several new suppliers appeared with Philippines being the most developing. Tungsten ore mining almost monopolized by China has noted fivefold price increase and production volume tripled. Even when China significantly developed its mines to produce more tungsten, and with increase of production in Vietnam and Mongolia, it didn't stopped prices to grow rapidly. Russia and Austria are only countries where production decreased, and there is no countries where tungsten mining ceased. China also developed molybdenum industry and mine output grew there as well, the monopoly is far from establishment, however. Prices of molybdenum, like tungsten, increased, but only four times. Production of mines doubled in volume. The most investments were in China, and Latin America (Chile, Peru, Mexico). Canada and Iran lost their position and share in the market.

Foreign investors can look for new opportunities in those countries who developed its mining recently. Closing mines means not good environment for mining development. After this analysis it can be discussed where are the most preferable conditions for mining investments. As recent history can tell, such Latin American countries as Peru, African countries as Madagascar, South Africa, Namibia, Uganda or Ivory Coast, and Asian countries like Oman, Indonesia, Mongolia and Philippines with Papua-New Guinea as well. China could be an option as well as Russia, but it is harder to invest there due to the internal policy. In Western countries, some environmental issues and labor conditions may be a disadvantage as well as high tax levels.

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Nowe źródła metali uszlachetniających stal na zmieniających się rynkach świata

Celem opracowania jest wyjaśnienie zmian jakie nastąpiły w ostatnich dwóch dekadach na rynku strategicznych surowców, do jakich należą rudy metali stosowanych w metalurgii stali. Uwzględniono w szczególności rudy manganu, chromu, niklu, wolframu, molibdenu i kobaltu. Podjęcie takiego tematu jest uzasadnione z uwagi na niedostatek aktualnych informacji na ten temat w publikacjach geograficznych. Są one obecnie rozproszone w różnorodnych źródłach, m.in. ekonomicznych, geologicznych, dotyczących technologii metali oraz ochrony zasobów. Realizacja podjętego zadania wymaga zebrania w jednym miejscu rozproszonych w różnych źródłach informacji oraz przejrzenia setek prospektów informacyjnych międzynarodowych korporacji górniczych zaangażowanych w ten biznes, dokumentów rządowych, a nawet raportów dotyczących małych i dopiero rozwijających się firm lokalnych. Ich analiza pozwoli także, w drugiej części pracy, na przedstawienie nowopowstających i projektowanych ośrodków wydobywczych.

Słowa kluczowe: metale uszlachetniające stal, geografia górnictwa; rynek światowy; zasoby; kopalnie; korporacje górnicze; rudy.