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THE NEW "RARE METAL AGE"

NEW CHALLENGES AND IMPLICATIONS OF CRITICAL RAW MATERIALS SUPPLY SECURITY IN THE 21st CENTURY

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Abstract

When Beijing threatened to restrict China's export of rare earths (widely used in numerous important civilian and military technologies) to the United States at the end of May 2019, the world was reminded of China's rare earths export disruption in the autumn of 2010 amid a maritime territorial conflict between China and Japan. In the past few years, the worldwide attention cast on the future supply security of rare earths and other critical raw materials has increased in the United States, the European Union, Japan and other countries owing to the global expansion of "green technologies" (including renewable energy sources, electric vehicles and batteries, and smart grids) and digitalisation as well as equipment and devices embedded with artificial intelligence.

In this paper, the term "critical raw materials" (CRMs) refers to raw materials critical to industries that are also import-dependent on them, and to new technologies which often have no viable substitutes and whose supply, besides being constrained by limited recycling rates and options, is also dominated by one or a few suppliers. CRMs include rare earth elements (REEs), which comprise 17 different elements (see Figure 4).

The global race for the most advanced technologies dependent on CRMs has intensified the competition for access to as well as strategic control of REEs, lithium, cobalt, copper, nickel and other CRMs. This working paper analyses the global supply and demand balance of three CRMs (REEs, lithium and cobalt, the latter two being major raw materials for batteries) in the foreseeable future and whether ASEAN countries can play a role as producers and suppliers of CRMs. It also examines potential counterstrategies for mitigating and reducing the global demand for CRMs, such as substitution, reduced use of CRMs, and recycling and re-use.

Introduction

Amid the escalating US–China trade conflict, Beijing threatened at the end of May 2019 to restrict China's exports of rare earths to the United States. The official *People's Daily* warned the US not to "underestimate China's ability to strike back", which was a serious threat, given that the United States has an "uncomfortable" dependence on rare earth elements (REEs) from China. President Xi Jinping made a politically symbolic visit to one of his country's main REE mining and processing facilities.[1] International experts had already warned previously that China might reduce its REE exports to meet its own demand for its electric vehicle (EV) industry and other hi-tech sectors.[2] While the value of the REEs market appears small, at US$9 billion in 2015, the industries relying on REEs are worth up to US$7 trillion.[3]

Rare earth minerals became known worldwide in the autumn of 2010, when China, as the world's largest producer and exporter of REEs, suspended its exports to Japan and tried to use its de facto monopoly of the global production of REEs for political ends in the midst of an escalating diplomatic conflict over maritime territories and energy resources in the East China Sea.[4]

China's threats to restrict REE exports to the United States has highlighted the US vulnerability and dependence on REE imports from China.[5] The Trump administration had also exempted REEs from the established list of tariffs it imposed on US$300 billion worth of imported Chinese goods.[6]

The Trump administration is well aware of US vulnerabilities in this domain.[7] After Beijing's threats in May 2019, the United States signed a memorandum of cooperation with Greenland for promoting investment in REE mining as part of its wider efforts to diversify its imports. Even President Donald Trump's proposal to buy Greenland, an autonomous territory belonging to Denmark, has been linked to the US need for diversifying its imports of REEs. Greenland's reserves of REEs have been

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[1] See Lucy Hornby and Archie Zhang, "China's state planner suggests using rare earths in US trade war", *Financial Times*, 29 May 2019; Lucy Hornby and Henry Sanderson, "Rare earths: Beijing threatens a new front in the trade war", *Financial Times*, 4 June 2019; Keith Johnson and Elias Groll, "China raises threat of rare-earth cut off to US", *Foreign Policy*, 21 May 2019; "China may be reaching for its rare earths gun", Stratfor.com, 30 May 2019.

[2] See also Chad Bray, "Trade war: Will China use 'nuclear option' of banning rare earth exports to US?", *South China Morning Post*, 22 May 2019; and "Will rare earth be the next front in the US–China tech war?", Stratfor.com, 20 May 2019.

[3] See John Seaman, "Rare Earths and China: A Review of Changing Criticality in the New Economy", IFRI notes, Paris 2017, 9. https://www.ifri.org/sites/default/files/atoms/files/seaman_rare_earths_china_2019.pdf

[4] See also "GIS Dossier: China dominates the rare earths supply chain", Geopolitical Intelligence Service (GIS), 7 February 2018, based on a series of articles by the author on the China–Japan conflict of 2010 and its impact on the raw material supply policies of Japan, the United States and the European Union.

[5] See Keith Johnson and Lara Seligman, "How China could shut down America's defenses", *Foreign Policy*, 11 June 2019; Matthew Kandrach, "America's Dangerous Foreign Mineral Dependence", RealClear Energy, 21 February 2018, https://www.realclearenergy.org/articles/2018/02/21/americas_dangerous_foreign_mineral_dependence_110274.html; Ernest Scheyder, "China set to control rare earth supply for years due to processing dominance", Reuters, 30 May 2019.

[6] See Henry Sanderson, "US spares rare earths in China trade war", *Financial Times*, 18 September 2018.

[7] See also F. Umbach, "Rare earth minerals return to the US security agenda", GIS, 1 August 2019.

estimated at up to 38.5 million tonnes, which are significant as worldwide reserves total around 120 million tonnes.[8]

The United States and the European Union, along with Japan,[9] have increased their attention on the supply security of REEs and other critical raw materials (CRMs)[10] since 2010[11] owing to the rapidly growing worldwide demand for them. This growing demand is inseparably linked with the global expansion of "green technologies" (including renewable energy sources), which are all heavily dependent on a stable supply of CRMs.[12] The transition to a low-carbon energy system and to non-fossil fuels in the energy sector as well as digitalisation are based on new disruptive technologies. They have fuelled a global race not just for the most advanced technologies, but also for the CRMs on which these technologies are dependent. They have intensified the competition for access to as well as strategic control of REEs, lithium, cobalt and others.[13]

Almost 60% of the worldwide demand for CRMs is associated with high-growth industries.[14] A World Bank report warned in 2017 that the clean energy shift and clean technologies "are in fact *more* material intensive in their composition than current fossil-fuel-based energy supply systems".[15] This point has been confirmed by a report of the UN Environment Programme (UNEP), which projected that to keep the increase in global temperatures to within 2°C by 2050 rather than the anticipated 6°C, low-carbon technologies would need over 600 million tonnes of additional metal resources.[16]

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[8] See Harry Dempsey, "US enticed by Greenland's rare earth resources", *Financial Times*, 20 August 2019.

[9] For Japan's REE and other CRM supply security policies, see Hiroki Hatayama and Kiyotaka Tahara, "Criticality Assessment of Metals for Japan's Resource Strategy", Materials Transactions, Vol. 56, No. 2, 2015, 229–235; and F. Umbach, "Japan's Plan to Reduce Dependence on China's Raw Materials", GIS, 15 January 2013.

[10] The overall strategic importance of CRMs can be seen in the published lists of CRMs in the United States and the European Union, which have constantly increased since 2010. The EU list of identified CRMs, for instance, has grown from 14 in 2011 to 20 in 2014 and 27 in 2017. See also F. Umbach, "Uncertain Strategies for Securing Supplies of Critical Raw Materials", GIS, 19 June 2018; European Commission, "On the List of Critical Raw Materials for the EU: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions", COM(2017) 490 final, Brussels, 13 September 2017; European Commission, "Report on Critical Raw Materials and the Circular Economy", Commission Staff Working Document, Brussels, SWD(2018) 36 final, 16 January 2018; and European Commission, "Report on Critical Raw Materials for the EU: Report of the Ad-hoc Working Group on Defining Critical Raw Materials", Brussels, May 2014.

[11] For US policies on CRM supply security, see F. Umbach, "Rare earth minerals return to the us security agenda"; Steve Dobransky, "Rare Earth Elements and US Foreign Policy: The Critical Ascension of REEs in Global Politics and US National Security", American Diplomacy – Commentary and Analysis, October 2013; US Department of Commerce, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals", Washington D.C., June 2019; US Department of Interior, "Final List of Critical Minerals 2018", Washington D.C., 2018.

[12] See also World Bank Group, "The Growing Role of Minerals and Metals for a Low Carbon Future", Washington D.C., June 2017; and John Dizard, "Clean energy world needs a thriving mining sector", *Financial Times*, 6 April 2018.

[13] See F. Umbach, "Energy Security in a Digitalized World and its Geostrategic Implications", Konrad Adenauer Stiftung–Hong Kong, September 2018; and Henry Sanderson, "Commodities: Material Revolution", *Financial Times*, 8 December 2015.

[14] See Aurélie Faure-Schuyer, Christian Edenhofer and Milan Elkerbout, "Value Chains Based on Mineral Raw Materials", CEPS-Policy Insights No. 2018/07, Brussels, February 2018, 1; and Henry Sanderson, "Electric Cars: China powers the battery supply chain", *Financial Times*, 22 May 2019.

[15] World Bank, "The Growing Role of Minerals and Metals for a Low Carbon Future", xxii.

[16] See UNEP, "Green Technology Choices: The Environmental and Resource Implications of Low-Carbon Technologies", Nairobi-Paris, 2017, 13. See also pages 49 and 56 as well as figures 13 (p.59) and 14 (p. 60) as well as table A1 Appendix (p.70).

The growing production of raw materials in response to growing demand has already contributed to global warming, and its contribution to global emissions may rise even more in the future.[17] Mining companies have just begun to use more green energy for their raw material production and refining businesses.[18] The worldwide mining sectors are much less regulated for environmental protection and reduction of emissions compared with the global fossil-fuel sector. Furthermore, the production of batteries, which is currently heavily dependent on CRMs, including lithium, cobalt and REEs, is itself also very energy intensive. This might offset the emission savings achieved by having more EVs on the roads, so long as energy consumption in China and other battery-producing countries, as well as CRM production in mining countries, is based mostly on coal and other fossil fuels.[19]

The following examples highlight the increasing dependence on CRMs and the green technologies which use raw materials intensively:

- A mobile phone contains more than 40 different raw materials, including REEs, cobalt, gallium and platinum.[20]
- In the European Union, each citizen annually generated some 17 kg of electrical and electronic equipment waste as of 2012. This figure is predicted to rise to 24 kg by 2020.[21]
- Each hybrid electric vehicle/EV uses 1–3 kg of rare earth permanent magnets, which contain 33% rare earth oxides.[22]
- A combustion-engine-powered car contains 20 kg of copper. By comparison, a hybrid electric car requires 40 kg, a plug-in hybrid 60 kg and an electric battery vehicle about 80 kg.[23]
- Whereas 23% of wind turbines in 2018 used rare earth magnets, the figure is forecasted to increase to 72% by 2030. While the use of the REE dysprosium might be reduced, the demand for the REE neodymium will grow accordingly.[24]
- Wind and solar power require 3–15 times as much copper per unit of output as fossil-fuel generation does. A complete transition to a non-fossil-fuel age would need a dramatic increase of copper production and supply worldwide. Accordingly, copper prices could rise 57% from US$5,600 (in October 2019) to US$8,800 a tonne to meet the British government–agreed 2030

[17] See also Henry Sanderson, "Electric car growth sparks environmental concerns", *Financial Times*, 7 July 2017; and "How carbon emissions reductions will alter supply chains", Stratfor.com, 13 August 2015.
[18] For an example, see Henry Sanderson, "Miner BHP plans US$780m provision over renewables switch", *Financial Times*, 21 October 2019.
[19] See F. Umbach, "Energy Security in a Digitalized World and its Geostrategic Implications", 113 ff; and F. Umbach, "Four Implications of Electric Mobility", GIS, 2 November 2017.
[20] See European Commission, "Proposal for a European Innovation Partnership on Raw Materials: Making Raw Materials Available for Europe's Future Well-Being", COM (2012) 82 final, Brussels, 29 February 2012, 3.
[21] European Commission, "Proposal for a European Innovation Partnership on Raw Materials".
[22] See Georgia Willems, "Rare Earths Outlook 2019: EV Production to Drive Demand", *Rare Earth Investing News,* 18 December 2018, 4, 8; and "The cleantech revolution fuels market demand for rare earth metals", *Rare Earth Investing News,* 31 December 2018.
[23] See Huw McKay, "Electric cars will influence demand for metals more than oil", *Financial Times*, 31 October 2016; Joseph Keller, "The Green Energy Revolution: Driving Copper Demand into the Future", *Copper Investing News,* 15 August 2019; and John Dizard, "America's green new deal needs copper but is there enough?", *Financial Times*, 22 March 2019.
[24] See John Seaman, "Rare Earths and China", 20.

targets for decarbonisation and even to US$20,000 for complete decarbonisation by 2025, as the "Friday-for-Future" movement is demanding.[25]

A stable supply to meet the rise in global demand for CRMs (see Figure 1) may have wide-ranging geo-economic and geopolitical implications — particularly when future economic and military superpowers such as China will have the combined capability of being a future technology and R&D leader and controller of the production as well as refining capacities of CRMs, and thereby, complete control of CRM value and supply chains[26] in the new "Rare Metal Age".[27]

Figure 1. Matrix of Metals and Energy Technologies Explored in World Bank Scenario Study, 2017

	Wind	Solar photovoltaic	Concentrating solar power	Carbon capture and storage	Nuclear power	Light-emitting diodes	Electric vehicles	Energy storage	Electric motors
Aluminum	X	X	X	X		X		X	X
Chromium	X			X	X	X			
Cobalt				X	X		X	X	
Copper	X	X		X	X	X	X		X
Indium		X			X	X	X		
Iron (cast)	X		X			X		X	
Iron (magnet)	X								X
Lead	X	X			X	X			
Lithium							X	X	
Manganese	X			X			X	X	
Molybdenum	X	X		X	X	X			
Neodymium (proxy for rare earths)	X						X		
Nickel	X	X		X	X	X	X	X	
Silver		X	X		X	X	X		
Steel (Engineering)	X								
Zinc		X				X			

Source: World Bank Group, *The Growing Role of Minerals and Metals for a Low Carbon Future*, June 2017, 75, http://documents.worldbank.org/curated/en/207371500386458722/pdf/117581-WP-P159838-PUBLIC-ClimateSmartMiningJuly.pdf

But China itself is heavily reliant on increasing imports of many raw materials, such as chrome (95%), cobalt (90%), gold (79%), copper (73%), iron ore (73%) and oil (67%), although it has reduced its import dependencies by acquiring mining and production shares in these imported CRMs. In

[25] See John Dizard, "Why Is nobody buying the copper needed for a greener world?", *Financial Times*, 4 October 2019.
[26] See also F. Umbach, "Four Implications of Electric Mobility".
[27] See D.S. Abraham, "The Elements of Power: Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age (New Heaven: Yale University Press, 2015).

Beijing's view, its rising import dependence on raw materials "poses a great risk to China".[28] China's raw materials policies also play a prominent role in its Belt and Road Initiative (BRI) as well as its Made in China 2025 strategy.[29]

The World Trade Organization (WTO) ruling against China's export restrictions on REEs in 2014 was just a symbolic victory for Western countries as it did not really change the overall global supply security of REEs in the following years.[30] China redirected its efforts, no longer controlling REE exports, but instead establishing stricter control of its production after the WTO ruling.[31] In 2016, China declared its intention "to limit" its production to 140,000 tonnes by 2020, compared with 120,000 tonnes in 2018 and 105,000 tonnes in 2017. It has also reduced its export of REEs over the past few years and limited production to meet domestic demand.[32] This has led to speculation of an emerging supply shortage of REEs in the coming years.[33] China has already become the world's largest importer of REEs. Owing to China's forecasted REE demand rising to 190,000 tonnes as early as 2020, *China could even become a net importer of REEs instead of being a net exporter up to now.*[34] China's rising demand also explains why it is now interested in buying REE mines abroad and in also controlling the worldwide supply chains of other CRMs.

This working paper analyses the global supply and demand balance of CRMs (i.e., REEs as well as lithium and cobalt, these being two of the main raw materials for batteries) in the foreseeable future. It then examines potential counterstrategies for mitigating and reducing the rise in global demand for CRMs, such as substitution, re-use, decreasing demand and recycling. The working paper will also highlight some strategic implications for the ASEAN countries as they are both producers and consumers of CRMs.

The Worldwide Supply Situation for CRMs

Despite the attention cast on China's disruption of REE exports to Japan in 2010 and global efforts for diversifying production, the subsequent global decline in REE demand and prices between 2012 and 2017 weakened attention to the future challenge of supply security for REEs and other CRMs.[35] Yet, the world's demand for CRMs will grow further and could become a disruptive source for EVs and other

[28] See Zhang Hui, "China relies more heavily on mineral imports", *Global Times*, 11 July 2018.
[29] See also Martin Wolf, "How Beijing elite sees the world", *Financial Times*, 1 May 2018.
[30] See also Nabeel Mancheri, "Does the WTO ruling against China on rare earth really matter?", East Asia Forum, 30 October 2014.
[31] See Vivien Diniz, "China to tighten rare earths production after WTO ruling", *Rare Earth Investing News*, 18 August 2014.
[32] See Charlotte McLeod, "10 Top Countries for Rare Earth Metal Production", *Rare Earth Investing News*, 23 May 2019; and Georgia Williams, "Chinese rare earth exports dip to 3-year low", *Rare Earth Investing News*, 8 November 2018.
[33] See Georgia Williams, "Is a Global Rare Earths Shortage Imminent?", *Rare Earth Investing News*, 10 January 2019.
[34] See John Seaman, "Rare Earths and China", 28.
[35] See also Robert Wright, "Boom in once-scarce 'rare earth' metals ends in US miner's bust", *Financial Times,* 25 June 2015.

technology developments. According to some industry forecasts, the number of EVs will more than triple from 3.7 million in 2017 to 13 million by 2020, and even reach 125 million by 2030.[36] The production of EVs requires not just more REEs,[37] but also other CRMs such as lithium, cobalt, nickel, copper and graphite.[38]

The world's leading holders of CRM reserves and CRM producers could benefit economically and geopolitically from the switch from carbon and fossil fuels to renewables.[39] In Latin America, Chile, Brazil, Peru, Argentina and Bolivia have huge reserves of lithium, nickel, manganese, copper, iron ore, silver and zinc. Likewise, some countries in Africa could benefit from their reserves of platinum, manganese, cobalt, bauxite and chromium.

In the Asia-Pacific region, besides Australia, which is a major exporter of CRMs, some ASEAN countries have important production and refining capacities as well as CRM reserves, but they are often overlooked internationally as they appear small at first glance. While Myanmar, Thailand and Vietnam appear to be small producers of REEs in comparison to the three leading producers — China, Australia and the United States — they are increasingly important as the United States, European Union and Japan strive to diversify their REE import sources. Vietnam, for example, has the second or third largest REE reserves in the world and could potentially expand its future production as well as refining capacities. (See Figures 6, 8 and 9).

But such a positive development depends not only on attractive mining and extraction conditions but also on political stability and what are commonly known as "social licences for sustainable sourcing" requiring, among other things, higher environmental standards, human and social rights as well as conditions conducive to affordable and clean energy.[40]

[36] See "Green Energy Revolution: Driving Copper Demand into the Future", *Copper Investing News*, 13 May 2019.

[37] The REE neodymium iron boron is used to produce permanent magnets (NdFeB) for high-performance electric motors. Those magnets also use other REEs such as praseodymium (Pr) and dysprosium.

[38] See also European Commission, "Electric Vehicle Life Cycle Analysis and Raw Material Availability", Brussels, October 2017; Priscilla Barrera, "Cobalt demand set to soar as EU outlines electric car plans", *Cobalt Investing News*, 8 November 2017; and Henry Sanderson, "Electric vehicle ambitions spark race for raw materials", *Financial Times*, 24 October 2017.

[39] See also Andrew Barron, "Meet the new 'renewable superpowers': Nations that boss the materials used for wind and solar", www.energypost.eu, 26 February 2018.

[40] See also World Bank Group, "The Growing Role of Minerals and Metals for a Low Carbon Future", XIII ff. and 26 ff.

Figure 2. CRM Reserves and Production in the ASEAN Countries, 2018

ASEAN Country	**World Status as Producer**	**World Status as Holder of CRM Reserves**
Indonesia	• Largest nickel producer (560,000 tonnes or 24.35% of global production of 2.3 million tonnes). • Eighth largest producer of copper (780,000 tonnes or 3.78% of global production of 20.6 million tonnes).	• Has world's largest nickel reserves (21 million tonnes or 23.6% of global reserves of 89 million tonnes). • Has world's fifth largest copper reserves (51 million tonnes or 6.14% of global reserves of 830 million tonnes).
Myanmar	• Fourth largest producer of REEs (5,000 tonnes or ~3% of global production of 170,000 tonnes).	
Vietnam	• Second largest producer of tungsten (also known as wolfram; 7,200 tonnes or 7.58% of global production of 95,000 tonnes). • Tenth largest producer of REEs (400 tonnes or 0.24% of global production of 170,000 tonnes).	• Has world's third largest tungsten reserves (95,000 tonnes or ~2.9% of global reserves of 3.3 million tonnes). • Has world's second or third largest REEs reserves (22 million tonnes or 18.3% of global reserves of 120 million tonnes). • Has world's seventh largest graphite reserves (7.6 million tonnes or 3.23% of global reserves 235 million tonnes).
Philippines	• Fifth largest producer of cobalt (4,600 tonnes or 3.28% of global production of 140,000 tonnes). • World's second largest producer of nickel (340,000 tonnes or 14.8% of global production of 2.3 million tonnes).	• Has world's fourth largest cobalt reserves (280,000 tonnes or 4.06% of global reserves of 6.9 million tonnes). • Has world's sixth largest nickel reserves (4.8 million tonnes or 5.39% of global reserves of 89 million tonnes).
Thailand	• Eighth largest producer of REEs (1,000 tonnes or 0.59% of global production of 170,000 tonnes). • Largest supplier of natural rubber worldwide (4.6 million tonnes or ~33% of global production of 13.9 million tonnes).	

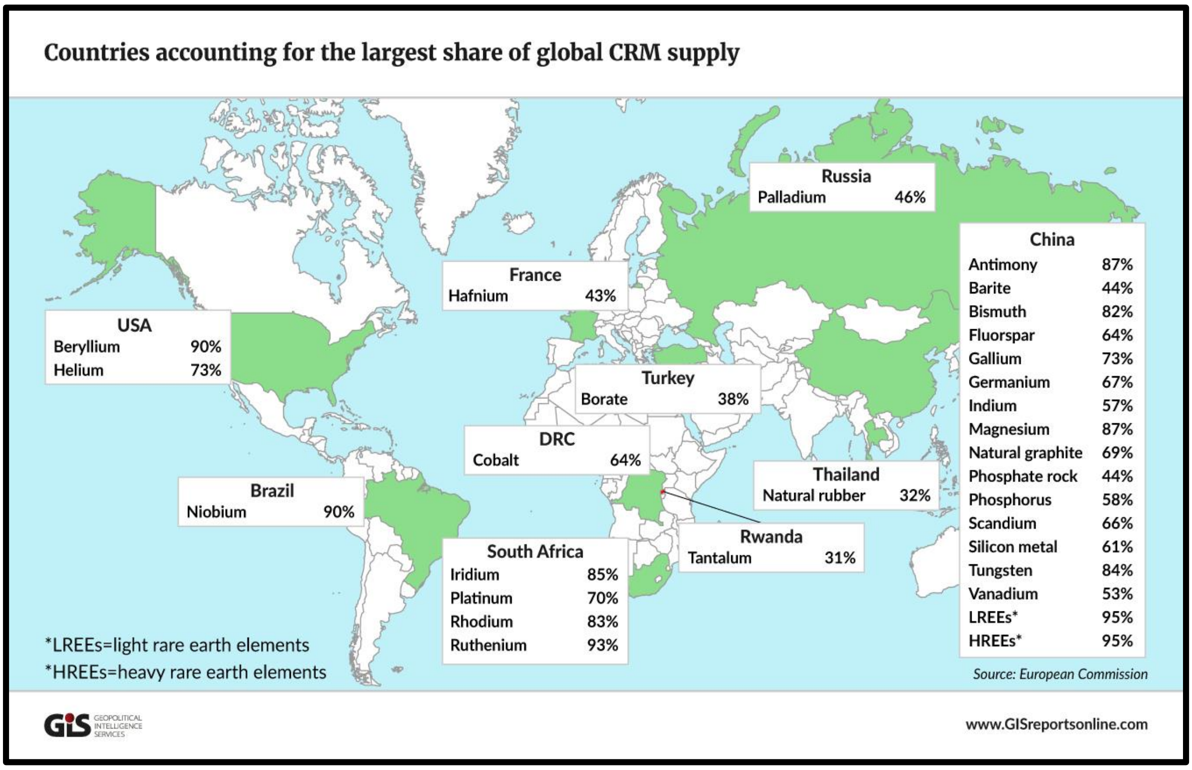
Developed by author, based on various sources.

While geological factors do not constrain the supply of CRMs in most cases,[41] geopolitical conditions, rapid market changes and restrictive environmental regulations for so-called green mining

[41] See David Humphreys and John Tilton, "No cause to panic about mineral depletion", *Financial Times*, 16 January 2018.

can lead to supply shortages, price spikes, domestic volatility and rising geopolitical dependencies as these factors decrease the number of supply countries and volumes. At present, some 50% of CRMs are located in fragile states or politically unstable regions. Compared with the supply and diversification of conventional oil and gas resources, the supply of CRMs could be geopolitically more challenging — particularly when the anticipated rise in global demand is taken into consideration. In this context, China plays a major role, both as producer of many CRMs and as the world's largest consumer of CRMs. (See Figure 3.)

Figure 3. China's Position as the World's Biggest Supplier of CRMs



Source: Geopolitical Intelligence Service (GIS)

The criticality of CRMs can change rapidly in accordance with shifts in the technological, geopolitical and economic environments as these can lead to rapid changes in the demand–supply balance of individual raw materials. Environmental risks, social factors (e.g., the NIMBY phenomenon involving public opposition and social licence for mining) and political factors can further constrain the global and regional supply security of CRMs. Western insistence on regulated "ethical and sustainable mining"[42] (as embodied in the United Nations' "Principles of Responsible Investment"), as well as on the prevention of child labour, human rights abuses and illegal artisanal, small-scale mining, has often been hampered by non-democratic conditions in many producing countries as Chinese and Western

[42] For the use of a blockchain-based platform to trace cobalt supplies from the DRC with a view to avoiding human rights abuses, see Henry Sanderson, "Ford to use blockchain in pilot to trace cobalt mined in Congo", *Financial Times*, 16 January 2019.

companies seek to get the cheapest prices possible. At the same time, Western efforts such as enhanced environmental regulations have also hindered a diversified global supply.

Assessments of combined supply risks include concentration, current as well as future production rates of individual countries and regions, political stability in producing and mining countries, current recycling volumes and an estimate of the substitutability of each raw material in each relevant field of use.[43]

The risks pertaining to the security of supply are not just confined to CRMs but also to the import of semi-manufactured and refined goods as well as finished products. Market imperfections in the form of manipulated prices, restricted supplies and attempts at cartelisation of CRM markets by powerful state-owned and private companies are threatening the stability of the future supply of many precious CRMs. And, trading houses, major producers and financial institutions are adding to the insecurity. With ever more complex global supply chains and blurred boundaries between physical and financial markets, these players have been able to exploit opaque pricing mechanisms and weakly governed market platforms to manipulate prices.[44]

Rare earths

China's halt to all REE exports to Japan in 2010 alarmed the United States and European Union regarding Beijing's long-term raw materials policies as these are closely integrated with larger Chinese industrial and technology policies to rival the United States and the European Union technologically.[45]

In spite of their unfamiliar names, the 17 REEs (see Figure 4) are quite commonly found in many countries. But they differ in regard to the volume of available reserves and their importance, the scarcest being the heavy REEs. They are scarce because their extraction and production is not economically viable. They do not exist on their own (like gold or copper do) but are found in small concentrations within rocks and often need to be mined together with radioactive materials such as thorium and radium. Separating these REEs from radioactive materials makes the extraction process difficult as well as environmentally challenging and costly.

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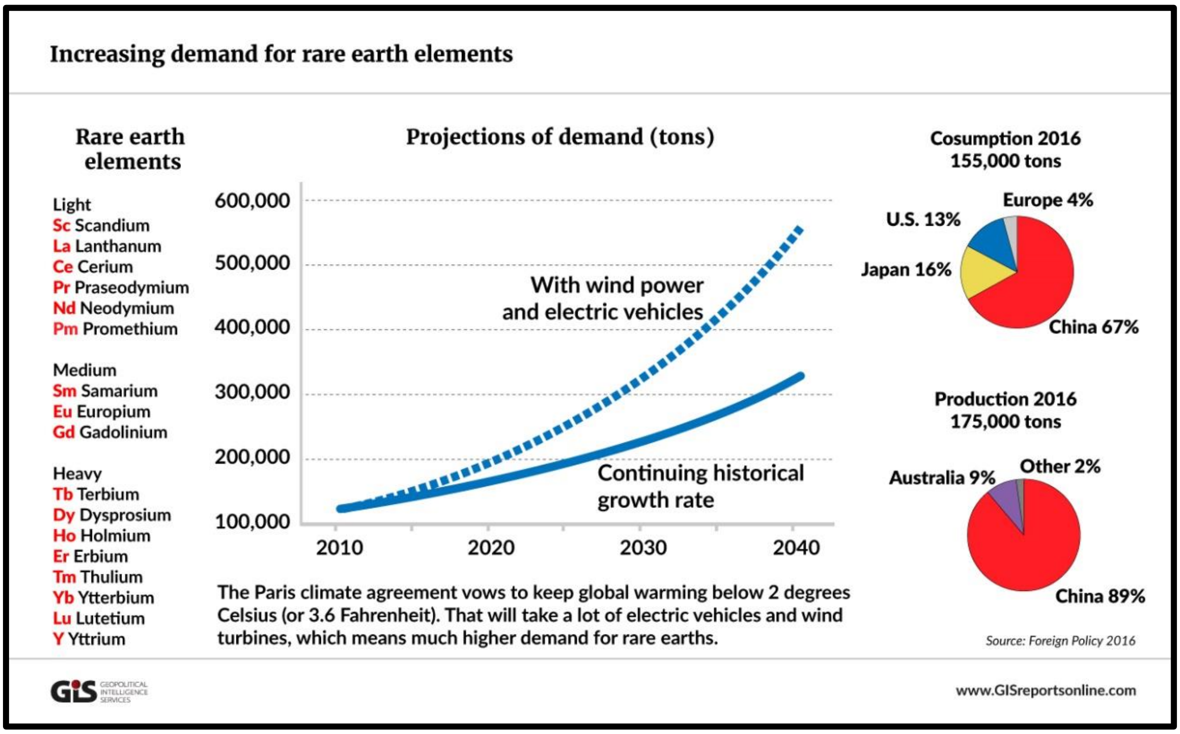
[43] See also Luis A. Tercero Espinoza, "The Role of Emerging Technologies in Rapidly Changing Demand for Mineral Raw Materials", Polinares Working Paper No. 27, March 2012.

[44] See also Jaako Kooroshy, Felix Preston and Sian Bradley, "Cartels and Competition in Minerals Markets: Challenges for Global Governance", Chatham House, London, December 2014. https://www.chathamhouse.org/sites/default/files/field/field_document/20141219CartelsCompetitionMineralsMarketsKooroshyPrestonBradleyFinal.pdf

[45] See also Lee Simmons, "Rare earth market: by monopolizing the mining of rare earth metals, China could dictate the future hi-tech", *Foreign Policy*, 12 July 2016.

Figure 4. Rare Earth Elements: 2016 Demand–Supply Balance and Demand Projections to 2040 (metric tonnes)



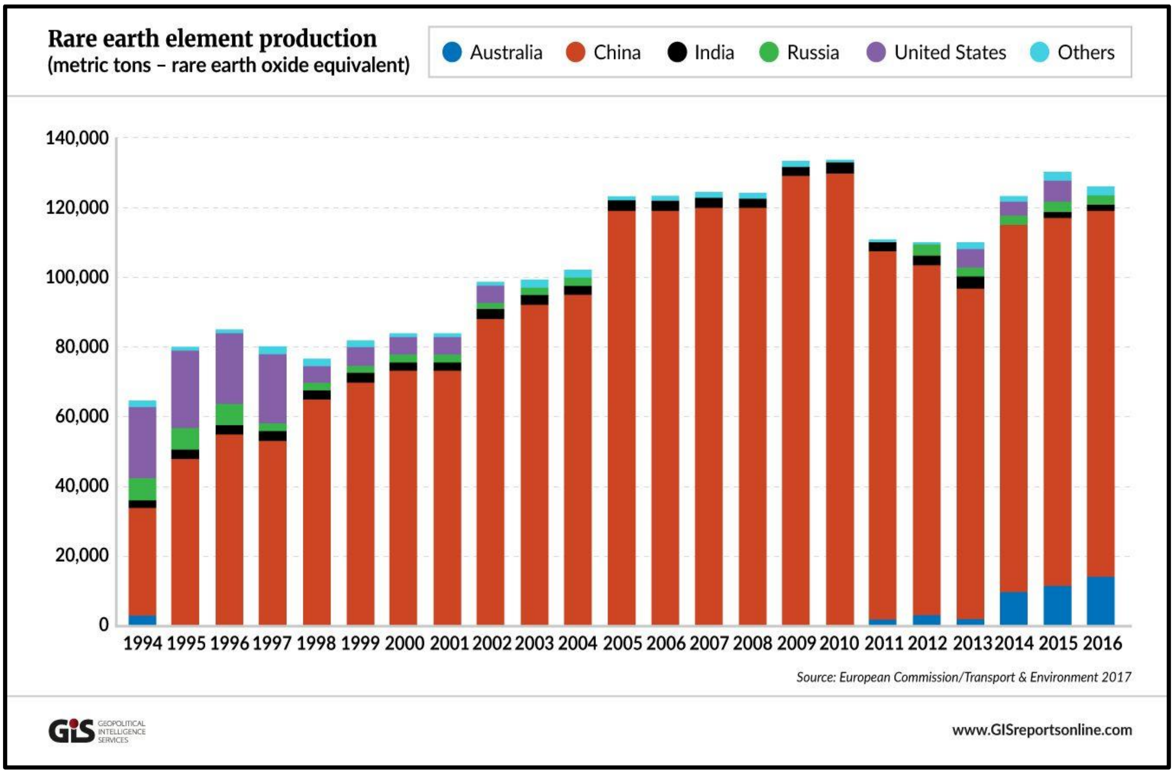
Source: Geopolitical Intelligence Service (GIS), 2018

REEs have magnetic and other unique properties and hence are used for a variety of commercial and military applications, including cell phones, computer hard drives, sensors, and precision-guided weapons and munitions. Some of these applications (e.g., windmills) rely on permanent REE magnets that have unique properties, such as the ability to withstand demagnetisation at very high temperatures.[46]

With the global production of REEs having declined and stagnated after 2010, reaching 132,000 tonnes in 2017, it jumped by almost 29% to 170,000 tonnes in 2018.[47] China's production and export monopoly of REEs have been weakened, its production proportion declining from 97% of world production in 2010 to 80–85% in 2017 and 71% in 2018 owing to the opening of the US Mountain Pass Mine and Australia's Mt. Weld mine in 2018. But China's official production data of 120,000 tonnes against the global total of 170,000 tonnes in 2018 does not include illegal mining, which, over the past 20 years, it had repeatedly declared it would bring down. China's total production through legal mining in 2018 has been estimated at up to 180,000 tonnes.[48] Even more important is the fact that, over the past few years, China has been processing more than 90% of the produced REEs to semi-finished or finished products such as permanent magnets.

[46] See also US Geological Survey (USGS), "The Rare-Earths Elements — Vital to Modern Technologies and Lifestyles", Fact Sheet 2014-3078, November 2014.
[47] See Charlotte McLeod, "Rare Earth Production", *Rare Earth Investing News*, 23 May 2019.
[48] See "How China overpowered the US to win the battle for rare earths", Bloomberg, 11 June 2019

Figure 5. REE Production (1994–2016)



Source: Geopolitical Intelligence Service (GIS), 2018

Supply diversification efforts have proved difficult to implement because of China's heavily subsidised REE production (including huge state subsidies and lax environmental laws and regulations for state companies), which have undermined the economic and commercial competitiveness of REE mines outside China.[49] The problem of lead times for opening new mines is often overlooked. Throughout much of the world, those lead times are at least 7 years on average. In Western countries, it is more than 10 years and can even take up to 20 years: 10 years from successful exploration to political and industrial consent at all levels, and another 10 years to build the infrastructure for the mine to be operational. Given the public acceptance challenge for a social licence to operate arising from environmental, social and reputational issues, it has become ever more challenging today to find investors for such long-term projects.

[49] See also Victoria Bruce, "Sellout: How Washington gave away America's technological soul, and one man's fight to bring it home" (Bloomsbury Publishing, 2017); D.S. Abraham, "The Elements of Power"; John Seaman, "Rare Earths and China"; and Cindy Hurst, "China's rare earth elements industry: what can the West learn?", Institute for Analysis of Global Security (IAGS), March 2010.

Figure 6. REE Production and Reserves in 2018 (in tonnes)

Top 10 rare earth producing countries and estimated reserves in 2018

Country	*Official production in 2018 (tons)*	*Estimated reserves (million tons)*
China	120,000	44.0
Australia	20,000	3.4
United States	15,000	1.4
Myanmar	5,000	N/A
Russia	2,600	12.0
India	1,800	6.9
Brazil	1,000	22.0
Thailand	1,000	N/A
Burundi	1,000	N/A
Vietnam	400	22.0

Source: Investing News, 2019

GIS GEOPOLITICAL INTELLIGENCE SERVICES www.GISreportsonline.com

Source: Geopolitical Intelligence Service (GIS), 2019

As noted earlier, the production and refining of REEs in Vietnam, Myanmar and Thailand may become more important for the future worldwide supply security of REEs despite their small share of global production currently. In addition to Chile and Australia (which has just identified 15 potential REE and other CRM projects), some African countries such as Burundi may hold large reserves of REEs.[50] But they all have to cope with rising worldwide attention to the social and environmental conditions of mining as well as new regulations, which might increase their production costs and hamper global competition with China's subsidised REE production.

Currently, there is also uncertainty regarding the Australian REEs company Lynas Corporation and its processing plant in Malaysia because of new challenging environmental regulations imposed by the government in Kuala Lumpur. The United States, Japan and the European Union consider the Lynas plant to be strategically important as it is currently the only processing plant for REEs outside China.[51]

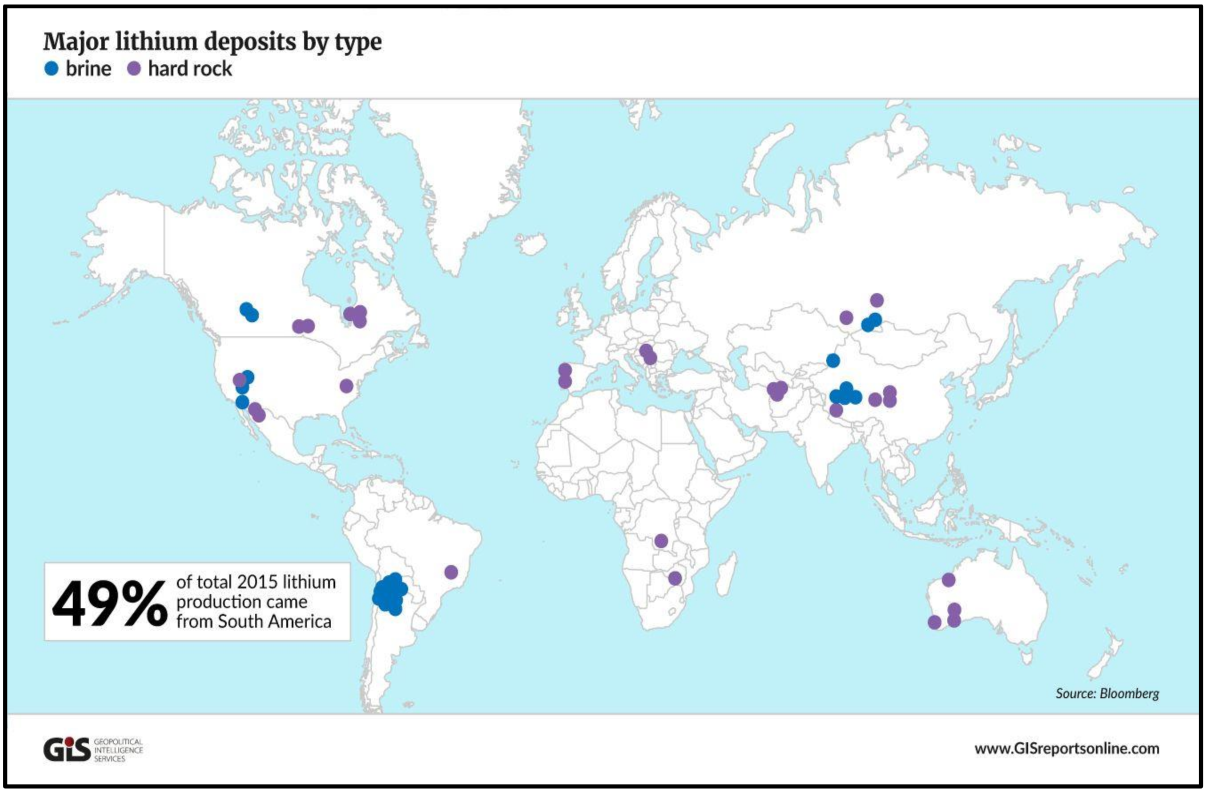
[50] See Ian Coles, "Africa holds promise of rare earth riches", *Financial Times*, 6 March 2017; Jamie Smyth, "Australia's 15 projects aim to break China rare earths dominance", *Financial Times*, 3 September 2019; and Henry Sanderson, "Hochschild Mining acquires rare earths deposit in Chile", *Financial Times*, 2 October 2019.

[51] See Jamie Smyth, "Lynas auditors warn of material uncertainty for rare earths business", *Financial Times*, 28 February 2019; Jamie Smyth, Stefania Palma and Henry Sanderson, "Lynas seeks 'Plan B' as Malaysia rare earths plant faces threat", *Financial Times*, 15 October 2018.

Lithium

Global lithium demand has been estimated to increase fourfold by 2035. The World Bank projected in 2017 that this could double by 2050, increasing by more than 1,000%.[52] Lithium reserves are estimated at about 14 million tonnes. Lithium is mined on six continents, but largely produced in the "lithium triangle" of Chile, Argentina and Bolivia, which accounts for 49% of global production.

Figure 7. Major Lithium Deposits by Type



Source: Geopolitical Intelligence Service (GIS), 2018

Bolivia holds the world's largest lithium deposits, amounting up to 50–70% of the world's known reserves. The Salar de Uyuni region alone has 9 million tonnes of lithium, and the government has even estimated national reserves of up to 100 million tonnes, although these reserve estimates still need to be confirmed through independent investigations. But, given state control and more complex and costly production and refining processes, Bolivia has yet to become a leading producer.[53] As a landlocked country, it is also dependent on cooperation with neighbouring states for access to the sea and world markets.[54]

[52] See Henry Sanderson, "Environment a risk from clean energy switch, says World Bank", *Financial Times*, 18 July 2018.

[53] See also Ben McLellan, "Politically charged: do you know where your batteries come from?", www.energypost.eu, 11 August 2017; "Types of Lithium Brine Deposits", *Lithium Investing News*, 9 August 2017; "Expert warns Bolivia will not enter the new global energy mix with lithium", *Lithium Investing News*, 26 April 2017; and "Lithium: Powering a Global Revolution", Stratfor.com, 20 October 2017.

[54] See "Lithium: Powering a Global Revolution"; and Marcelo Azevedo et.al., "Lithium and Cobalt: A Tale of Two Commodities", McKinsey & Company, Metals & Mining, June 2018.

Figure 8. Worldwide Lithium Production and Reserves in 2018: Top 9 Countries

Country	**Production**	**Reserves**
Australia	51,000 tonnes	2.7 million tonnes
Chile	16,000 tonnes	8.0 million tonnes
China	8,000 tonnes	1.0 million tonnes
Argentina	6,200 tonnes	2.0 million tonnes
Zimbabwe	1,600 tonnes	70,000 tonnes
Portugal	800 tonnes	60,000 tonnes
Brazil	600 tonnes	54,000 tonnes
Namibia	500 tonnes	n/a
United States	n/a	35,000 tonnes

Source: *Lithium Investing News*, 2018/2019

Chile currently holds half of the world's known lithium reserves.[55] Chile's lithium is derived from continental brine and its extraction costs are lower than that involved in extracting lithium from the pegmatites (or hard-rock ore) found in Australia or from sedimentary rocks. But for lithium brine in Chile, the extraction process can be water intensive and is one of the major environmental concerns as well as potential constraints.

Australia and Argentina are expected to profit most in the coming years from the global growth in demand for lithium. While Argentina's prospects are still uncertain because of domestic policy and other constraints, Australia has already become the world's largest lithium producer and exporter. Total worldwide investments in new lithium and other mines to meet the global expansion in battery production have been calculated at US$350–750 billion by 2030.[56] For many lithium experts, security of supply is still very much underappreciated and the EV demand may cause supply challenges in the years ahead.[57]

Since 2018, China has strengthened its efforts to control the global supply chain for lithium, from ownership of overseas mines to the production of batteries and EVs. Thirty-five Chinese companies are already active in the Democratic Republic of Congo (DRC), and in June 2019, they established the Union of Mining Companies with capital from the Chinese government to enhance their

[55] In October 2019, Russia's nuclear group Rosatom and its subsidiary, Uranium One, signed a preliminary agreement to buy up to 51% of a giant Chilean lithium project in return for the mineral's supply, See Henry Sanderson and Nastassia Astrasheuskaya, "Russia's Rosatom looks to buy 51% of giant Chilean lithium mine", *Financial Times*,15 October 2019.

[56] See Didier Julienne, "Will the world suffer a lithium crisis?", *Paris Innovation Review*, 5 December 2017; Priscilla Barrera, "Can lithium demand producers keep up with electric vehicle batter demand?", *Lithium Investing News*, 9 August 2017; and "Lithium Forecast & Lithium Stocks to Buy", *Lithium Investing News*, 2017, 5 ff.

[57] See "Lithium Forecast & Lithium Stocks to Buy", 6; Jessica Shankleman, Tom Biesheuvel, Joe Ryan and Dave Merrill, "We're going to need more lithium", Bloomberg, 7 September 2017; Gregory Brew, "Could the battery boom lead to a lithium shortage?", Oilprice.com, 22 August 2017; "A Vote on the Future of Chilean Copper and Lithium", Stratfor.com, 5 December 2017; and Henry Sanderson, "Electric car demand sparks lithium supply fears", *Financial Times*, 9 June 2017.

bargaining power. Chinese companies have also increased their control of worldwide lithium-ion manufacturing capacity from 50% in 2013 to more than 60% in April 2019.[58] While the United States remains dependent on Chinese battery and permanent magnet supplies and sales, China has its own lithium reserves.[59]

Germany and the European Union have become increasingly concerned and protective of their technology know-how and their automotive sector.[60] As a response strategy, the European Union has established its so-called Battery Alliance to build up to 26 gigafactories in Europe and to promote R&D for the next generation of batteries.[61] This will intensify the battery race between China, South Korea, the European Union and the United States, and fuel a worldwide competition in the supply of lithium, cobalt and other metals used in the production of batteries.[62]

Cobalt

Cobalt is another critical raw material for the lithium-ion batteries of EVs. Each EV battery needs on average 10–11 kg of cobalt.[63] These batteries already consume 42% of the metals produced worldwide and account for 80% of the demand for refined cobalt. Like REEs, cobalt does not occur alone in the earth's crust but is a by-product of copper and nickel production.

The global demand for cobalt to meet the rise in the production of EVs is expected to increase from 46,000 tonnes in 2016 to 76,000 tonnes in 2020, and to more than 90,000 tonnes by 2030.[64] Chinese companies altogether control up to 80% of the world's refined cobalt production.[65] In 2018, China increased its refined production to 90,000 tonnes, whereas global cobalt supply grew to 140,000 tonnes.[66]

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58 See Henry Sanderson, "Electric cars: China powers the battery supply chain", *Financial Times*, 22 May 2019.

59 See also "How China Is muscling in on lithium-ion batteries", Stratfor.com, 5 July 2018; and Henry Sanderson, "China's Tianqi circles Chilean lithium producer SQM", *Financial Times*, 28 September 2016.

60 See also F. Umbach, "EU–China Relations at the Crossroads", GIS, 20 June 2019.

61 See also "Battery Technology: A Different Kind of Power Struggle", Stratfor.com, 26 October 2016; and Umair Irfan, "Researchers solve critical flaw in lithium sulfur batteries", E&E News, 21 March 2017.

62 See F. Umbach, "The Global Battery Race: Europe's Strategic Perspectives", GIS, 19 February 2019; and Gerard Reid, "The Great Battery Race", *Energy Post*, 17 March 2017.

63 See "Cobalt Market Forecast and Cobalt Stocks to Buy", *Resource Investing News* 2018, 2; and Neil Hume and Henry Sanderson, "Copper and Cobalt Markets at Risk of Supply Disruptions", *Financial Times*, 30 April 2018.

64 See European Commission, "Electric Vehicle Life Cycle Analysis and Raw Material Availability", 8; Henry Sanderson and Neil Hume, "Cobalt Stand-off Key to Future of Electric Vehicles", *Financial Times*, 17 October 2017' and "Cobalt Market Forecast and Cobalt Stocks to Buy", *Resource Investing News* 2018, 2.

65 See Henry Sanderson, "China tightens grip on global cobalt supplies", *Financial Times*, 14 March 2018; and Henry Sanderson, "China plays long game on cobalt and electric batteries", *Financial Times*, 26 May 2016.

66 See Priscilla Barrera, "Top Cobalt Production by Country", *Cobalt Investing News*, 1 May 2019.

Figure 9. Worldwide Cobalt Production and Reserves in 2018: Top 10 Countries

Country	**Production**	**Reserves**
Congo	90,000 tonnes	3.5 million tonnes
Russia	5,900 tonnes	250,000 tonnes
Cuba	4,900 tonnes	500,000 tonnes
Australia	4,700 tonnes	1.2 million tonnes
Philippines	4,600 tonnes	280,000 tonnes
Canada	3,800 tonnes	250,000 tonnes
Madagascar	3,500 tonnes	150,000 tonnes
Papua New Guinea	3,200 tonnes	55,000 tonnes
China	3,100 tonnes	n/a
Morocco	2,300 tonnes	n/a

Source: *Cobalt Investing News* 2018/2019

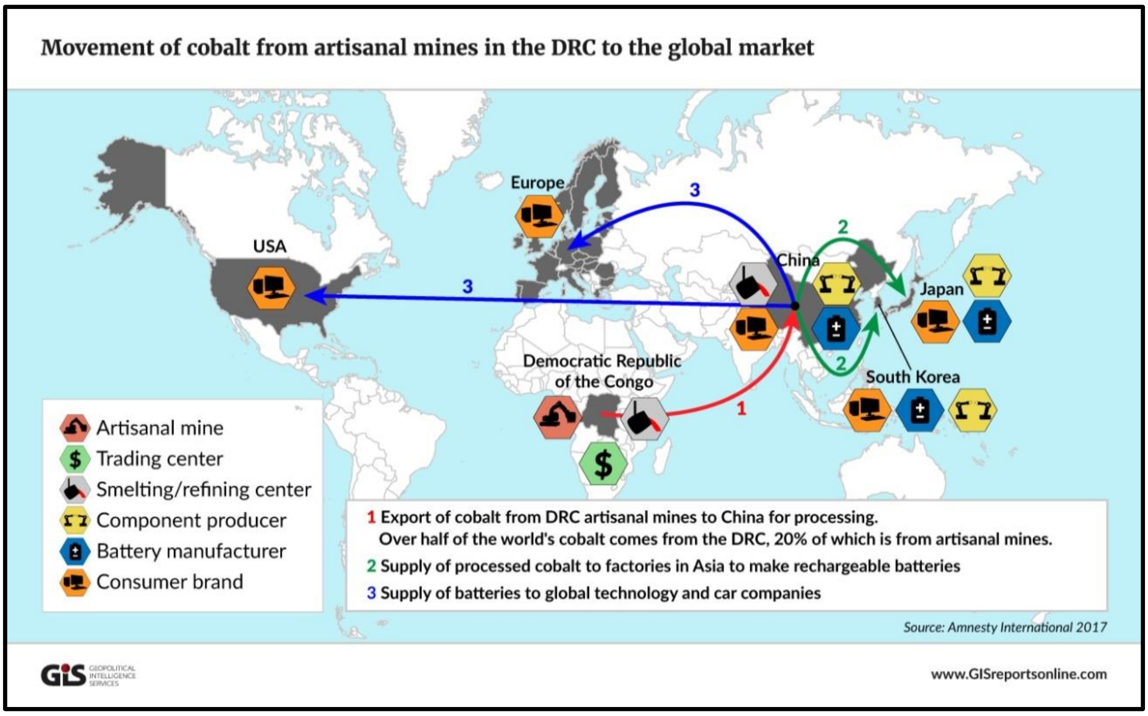
The three largest estimated reserves of cobalt, totalling about 5.2 million, are located in the DRC, Australia and Cuba. The global supply will remain tight in the short term as 69% of the worldwide cobalt supply is produced by the DRC — a country plagued by decades of violent conflicts, instability, regional fragmentation, bad governance, human rights abuses, child labour and widespread corruption, and with 73% of its population living on less than US$2 per day.[67] A new mining law in the DRC defining cobalt as a strategic raw material has raised the costs of doing business in the country, although production may increase in the medium-term perspective as new cobalt mines have been launched. New mines are expected in Uganda.[68] But, overall, new production of cobalt outside the DRC appears years away.[69]

[67] See also Teresa Nogueira Pinto, "A Fragile Alliance in the DRC", GIS, 11 December 2019; "Cobalt Market Forecast and Cobalt Stocks to Buy", 4; Priscilla Barrera, "EV makers 'not doing enough' to tackle human rights abuses in cobalt supply chains", *Cobalt Investing News*, 16 November 2017; "The Critical Need for Cobalt Supply Diversification", *Cobalt Investing News*, 20 September 2017; David Pilling, "Clean electric cars are built on pollution in Congo", *Financial Times*, 26 July 2017; and Henry Sanderson and Cloe Cornish, "Amnesty warns on use of child labor in cobalt mining", *Financial Times*, 15 November 2017.

[68] See Myles McCormick, "Umicore warns on profits as Chinese electric vehicle demand drops", *Financial Times*; 23 April 2019; Henry Sanderson, "Cobalt hits 2-year low as DRC ramps up supply", *Financial Times*, 6 February 2019; Henry Sanderson, "Cobalt supply shock a painful warning to carmakers", *Financial Times*, 9 November 2018; and "Cobalt and the Revival of Uganda's Mining Industry", *Cobalt Investing News*, 8 November 2018.

[69] See Priscilla Barrera, "EV makers join forces to 'drive sustainability' in cobalt mining", *Cobalt Investing News*, 29 November 2017.

Figure 10. Global Cobalt Trade



Source: Geopolitical Intelligence Service (GIS), 2018.

International Counterstrategies to Cope with Rising Global Demand for CRMs: Prospects and Challenges

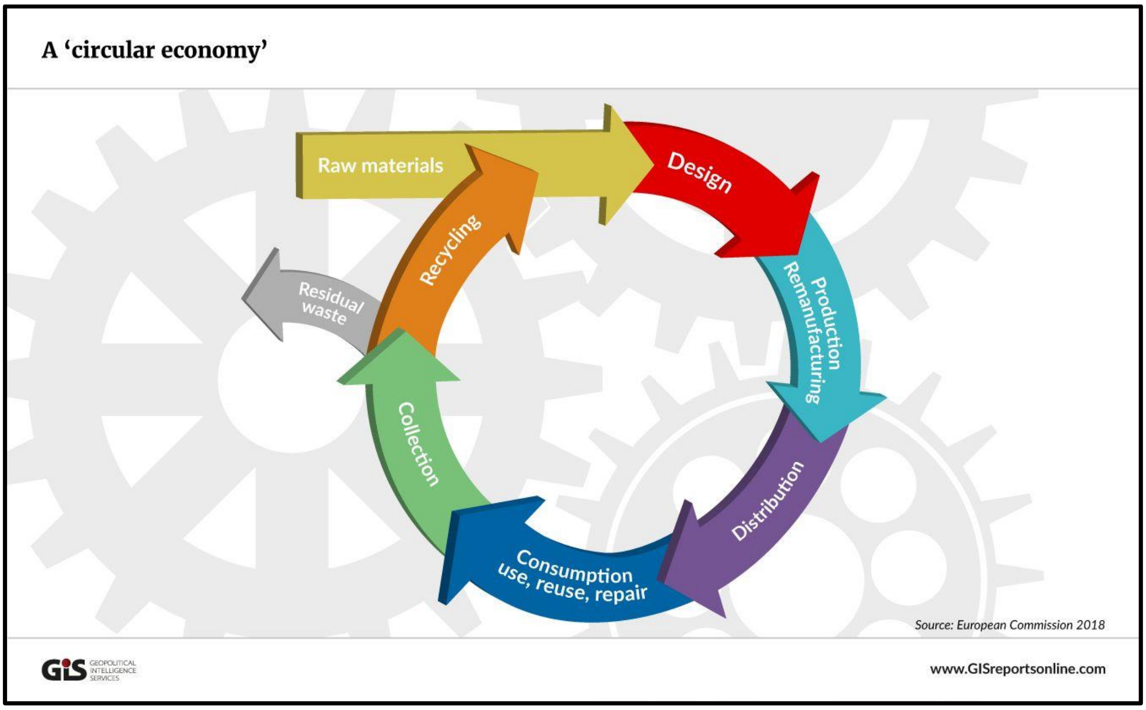
In addition to technological and geopolitical supply challenges, the future supply security of CRMs depends largely on timely investments, adequate investment conditions and alternative strategies such as:

- Diversification of imports and new supply options;
- Reducing usage;
- Substitution;
- Recycling and re-use.[70]

These options are an integral part of the development of “circular economies”, as the European Union had proposed in 2015. It is a response strategy for CRMs to be used more economically and efficiently and for their production to be more environmentally friendly in order to reduce demand and strengthen supply.

[70] On recycling, see also Luis A. Tercero Espinoza, “The Contribution of Recycling to the Supply of Metals and Minerals”, Polinares Working Paper No. 20, March 2012.

Figure 11. Elements of the EU-proposed Circular Economy (2015)



Source: Geopolitical Intelligence Service (GIS), 2018

Diversification of imports and new supply options

Since the China–Japan REEs conflict in 2010, Japan, the United States and the European Union have intensified their diversification efforts. Japan aims to diversify its REE import sources to include countries such as Kazakhstan, Vietnam and Malaysia, and to reduce imports from China as well as to control 50% of its REE demand by 2030.[71] In April 2018, Tokyo declared that it had found 16 million tonnes of rare earth oxides on the sea bottom within its Exclusive Economic Zone (EEZ). The deposits are thought to be sufficiently large to meet global demand for centuries: equivalent to 780 years' worth of yttrium supply, 620 years of europium supply, 420 years of terbium supply and 730 years of dysprosium supply. Japanese researchers have also developed a new technology for extracting REEs from mud. Whether the Japanese discovery will have any impact on global supply and prices will be dependent on whether Japan can expand production competitively.[72] Other projects being floated by some countries include mining in the jungles of the Amazon and in Afghanistan — and even extraterrestrial projects on the moon or distant asteroids.[73]

[71] See also F. Umbach, "Japan's Plan to Reduce Dependence on China's Raw Materials", GIS, 15 January 2013; and Ka-ho Yu, "Japan challenging china's rare earth hegemony?", EUCERS-Newsletter, Issue 20, January 2013.

[72] See Yui Shuzo, "Centuries' worth supply of rare earths found in Japanese waters", *The Mainichi*, 11 April 2018; Yutaro Takaya et.al., "The Tremendous Potential of Deep-Sea Mud as a Source of Rare Earth Elements", Nature-Scientific Reports, No. 8/2018, 10 April 2018.

[73] See J. M. Klinger, "Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes (Ithaca: Cornell University Press, 2017).

Overall, most of these efforts have not proven to be commercially viable as the prices of many CRMs declined between 2012 and 2017. With few exceptions, these production efforts have up to now had only marginal impact on broadening the global supply base for REEs and other CRMs. Reportedly, fewer than five out of the 400 REE start-ups that were publicly listed in 2012 had been successfully implemented up to the production stage by 2018.[74]

Reduced use of CRMs

Since 2010, Japanese companies have intensified their efforts to reduce the use of REEs and to recycle REEs. But those efforts appear to be outweighed by the magnitude of EV and battery growth. Tesla announced in May 2014 that it had achieved a significant reduction of cobalt content per battery pack while increasing nickel content and still maintaining superior thermal stability. While this technological progress has reduced Tesla's cobalt demand, most other EV makers are expected to use nickel-manganese-cobalt (NMC) batteries with higher cobalt content.[75] NMC-811 batteries with a lower cobalt share of 10% will reach a market share of 25% by 2026 and will have only marginal impact on the growth in global cobalt demand in the mid-term perspective.

Other efforts to reduce CRM use involve promoting "urban mining", such as the recycling of REEs and other materials from used electronic devices. Tesla's lithium batteries, like its motors, use no REEs at all. Lighter carbon for fibre reduces the overall weight of cars and, therefore, requires fewer batteries and less REEs. Siemens has considered a technology that eliminates the use of dysprosium in its wind turbines. Another example is Toyota's newly developed heat-resistant magnet, which uses the Light REEs lanthanum and cerium instead of the costly Light REE neodymium.[76]

Substitution

While substitutes are in principle available for many applications, they are often generally less effective and efficient and/or require more energy. For some REEs (i.e., Heavy REEs), no material replacement has been found. While wind turbines can be built without REEs, REEs reduce the per megawatt cost of wind energy and improve its competitiveness through conservation of other materials such as steel and copper. Some international efforts to decrease the demand for REEs have been successful. Reduced use of REEs in certain products and the slowing down of the overall rise in demand may enhance their global supply security. But the overall rise in demand for CRMs is likely to continue. Analyses suggest that we need at least another five years of research to find an alternative to cobalt in

[74] See Ryan Swift and Chad Bray, "Mine, replace and recycle: Can the US, Europe and Japan end reliance on China for rare earths?", *South China Morning Post*, 29 June 2019, 4.
[75] See Priscilla Barrera, "Tesla to reduce cobalt use in EV batteries to 'almost nothing'", *Cobalt Investing News*, 3 May 2018.
[76] See Nicole Rashotte, "New Toyota magnet could cut electric vehicle motor costs", *Rare Earth Investing News*, 21 February 2018.

batteries. It is currently considered the most important CRM, from a strategic and cost viewpoint, for further developing lithium-ion batteries.

Recycling and re-use of CRMs

Since 2010, Japanese magnet producers have been able to reprocess industrial waste and recover as much as 30% of the rare earths used in the first production stage.[77] Owing to regulatory requirements, the life-end recycling rate of the older lead and nickel-based batteries is now 99% in Europe and North America. In the future, new EVs may only be sold in the European Union if they are re-used, recovered and recycled in line with its end-of-life vehicles directive (ELV-Directive). Some companies have already invested in used EV batteries as they can still be applied for electricity storage at power plants.

But, despite the awareness of the need for recycling CRMs and the fact that several CRMs have a high technical and economic recycling potential, no commercial recycling technologies are available yet for most CRMs. Many recycling options have not been utilised because of lack of commercial viability for businesses. Also, the true scale of recycling may be limited by the lack of data on recycling rates. Worldwide, only a few CRMs like vanadium, tungsten, cobalt and antimony have high recycling rates.[78] For instance, in the European Union, the recycling rate for the nine CRMs newly added to its revised list of CRMs in 2017 is currently low or non-existent because of failing technologies or lack of commercial viability.

Even the recycling rate for electronic waste was just 34% in the European Union in 2014, and just 17% for appliances in general in recent years. Two-thirds of them are not traced for "urban mining" and for extracting metals for re-use. But the e-waste will grow from 9 million tonnes to more than 12 million tonnes by 2020. Of the recycled e-waste in the European Union, only one-third was properly handled. Almost 5 million tonnes were mismanaged or siphoned off for illegal trading.[79] Reportedly, 34 out of 60 CRMs had recycling rates of less than 1% in 2011.[80] Although the miniaturisation of electronics is a trend that has been under way globally since the 1970s, the new technology megatrends of digitalisation as well as the new generation of electronics utilising small amounts of CRMs (e.g., mobile-phones) are making the disassembly of ever smaller components more challenging for any future recycling.

[77] See John Seaman, "Rare Earths and China", 15.
[78] See European Commission, "Report on Critical Raw Materials and the Circular Economy", Commission Staff Working Document, SWD (2018) 36 final, Brussels, 16 January 2018, 10.
[79] See Dave Keating, "Raw Power", EurActiv.com, 12 November 2018; and Catherine Stupp, "Only one-third of the EU's e-waste recycled properly", EurActiv.com, 1 September 2015.
[80] See Aurélie Faure-Schuyer, Christian Edenhofer and Milan Elkerbout, "Value Chains Based on Mineral Raw Materials", 18.

The material-efficient recycling of CRMs and complex end-of-life products (such as batteries) are dependent on various changing factors such as recycling infrastructure, market prices, possibility of disassembling products, and the amount of material becoming available after their end-of-life. Large-scale recycling is expected to become more efficient only after 2025.

Advanced recycling options for cobalt batteries are currently 10–15 years away from becoming feasible. International efforts to reduce the dependency on cobalt for batteries through recycling appear to be still outweighed by the magnitude of the projected EV and cobalt growth. The present potential for recycling cobalt and other CRMs is largely insufficient to meet the growth in demand for these materials.

Recycling of lithium batteries is still rather low as most of the batteries are used in second-life applications or sold to re-furbishers in Asia. Batteries for EVs, for instance, can still be used (or re-used) after their operational life because a storing option for electricity in power plants has made them more flexible in combination with renewable energies.[81] But, given the overall rise in battery demand and an increasing number of EV batteries being put to second-life use for energy storage and other less-demanding applications beyond 2025, recycling rates may go up from 3–5% to 58% in the second half of the coming decade.[82]

Despite those shortcomings, the ASEAN countries are increasingly interested in recycling options: they have either returned waste imported from mostly richer countries or have tightened their measures to limit waste imports. These efforts are intended to avoid being saddled with contaminated materials and the environmental impacts of non-recyclable materials (such as plastics) or the burning of hazardous wastes. China, which was the world's largest importer of waste, has also ended its decades-old policy of importing waste.[83] The Chinese no longer want to be seen as a junkyard of richer countries. At the same time, they are beginning to recognise that some wastes (CRMs in particular) are not just a liability but a resource that can be used commercially for a sustainable environment. But ASEAN's debates on recycling, the circular economy and Industry 4.0 have not touched on the issue of the supply security of CRMs, unlike in the case of the debates in the United States, the European Union and other Asian countries.[84]

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[81] EV batteries need to operate at extreme temperatures, with hundreds of partial cycles and changing discharge rates. These lithium batteries have an operation life of 8–10 years on average and then need to be replaced. But used batteries can be still re-used to perform and serve for less demanding applications such as for stationary energy storage. They can provide reserve energy capacity to maintain a utility's power reliability at lower cost (in comparison with the old, more expensive and less efficient coal power plants or combined-cycle gas plants) or store electricity for renewable-based power generation as a back-up during periods of sun and wind scarcity, which offers grid flexibility. In 2025, second-life batteries were estimated to be 30–70% less expensive than new ones in these applications. See Hauke Engel, Patrick Hertzke and Giulia Siccardo, "Second-Life EV Batteries: The Newest Value Pool in Energy Storage", McKinsey & Company, April 2019.

[82] See Hans Eric Melin, "New Report on Recycling and Second Life of Lithium-ion Batteries", Circular Energy Storage, 21 June 2018, available via https://www.linkedin.com/pulse/new-report-recycling-second-life-lithium-ion-batteries-melin/

[83] See Editorial Board, "Global recycling crisis should be a wake-up call", *Financial Times*, 23 August 2019.

[84] See also Venkatachalam Anbumozhi and Fukunari Kimura, "Industry 4.0: Empowering ASEAN for the Circular Economy", ERIA 2018.

Strategic Perspectives and Implications for ASEAN

Within ASEAN, there is no definition of CRMs or a regional concept of CRM supply security comparable to that in China, the European Union, Japan and the United States. There is no real debate about the challenges regarding new CRMs for green and other new technologies. This is partly due to the fact that producers of CRMs in ASEAN such as Indonesia, Myanmar, the Philippines, Thailand and Vietnam (See Figure 2) have different strategic interests from countries such as Singapore that are dependent on imports of consumer goods and CRMs. Singapore has clean energy ambitions and produces green hi-tech electronics for both export and domestic use.[85]

As Figure 6 illustrates, a few ASEAN countries are among the top 10 producers of REEs, with Vietnam having significant reserves, estimated at 18.3% of the world reserves of 120 million tonnes. In 2018, Vietnam exported a mere 400 tonnes of REEs, as the world's 10th largest producer, but it has a significant potential to emerge as a bigger player in the years to come. More foreign investment in Vietnam's REEs sector is anticipated. The size of the reserves in Myanmar and Thailand is not available for public scrutiny but Myanmar produced 5,000 tonnes in 2018, making it the fourth largest producer globally, while Thailand was the eighth largest producer, yielding 1,000 tonnes in the same year.

In the case of the Philippines, it has substantial reserves of cobalt. In 2018, its production of cobalt reached 4,600 tonnes or 3.28% of the global output of 140,000 tonnes. The Philippines has in fact the world's fourth largest reserves of cobalt, at 280,000 tonnes out of an estimated total of 6.9 million tonnes. (See Figure 2). News reports indicated that China and Japan were interested in investing more resources to extract the CRMs in the ASEAN region. Lynas Corporation, which, as mentioned earlier, is the world's largest non-Chinese REE firm, has invested a huge amount of money in Malaysia to build and operate the only processing and refining plant for REEs outside of China. The Malaysian facility, employing over 1,000 people, receives raw materials from Lynas' mines in Western Australia and the output from Malaysia goes mainly to China and Japan.

In view of the growing population, fast-expanding middle class, rising energy demand and GDP growth in ASEAN, the region's mineral raw material requirements will also increase. While a part of this growing CRM demand can be met by the ASEAN countries themselves,[86] the region will also become more dependent on China's CRM refining capacity and Chinese strategic control of many CRMs in other countries. In recent years, China has intensified its efforts to control the entire global supply chain of REEs and other CRMs. It now owns more mines and production and refining facilities around the globe than in the past. Chinese state-owned companies control more than 70% of worldwide

[85] See also Toh Seong Wah and Zhang Lei, "Singapore well positioned to build a sustainable, smart-energy future", *The Business Times*, 30 July 2019.
[86] See also David Humphreys, "In Search of a New China: Mineral Demand in South and Southeast Asia", *Mineral Economics* Vol. 31, May 2018, 103–112.

REE production, more than 90% of REE refining processes, around 80% of global refined cobalt production, and more than 60% of the worldwide lithium-ion manufacturing capacity.

With new disruptive technologies being developed at an ever-increasing rate, both in the civilian and the defence sectors, the availability and stable supply of CRMs as the foundation of these technology revolutions have become a major concern of companies and governments worldwide. Access to and a stable supply of these CRMs as well as access to their supply chains are pre-conditions for any new technology to enter the market. These concerns have increased with the intensification of the US–China trade rivalry.

Unlike traditional commodities, the production of CRMs for green technologies is often of low volume. It often takes place in politically troubled countries where transparency is lacking. The lack of transparency and unregulated raw material markets lead to overreaction and rapid changes in demand and supply as well as volatility in prices. In the next decade, the expansion of EVs and lithium-ion batteries for electricity storage will have the most significant impact on the world of CRMs as it will tremendously increase the global demand for metals used in batteries such as lithium, cobalt, copper and REEs.

Currently, 50% of CRMs are located in fragile states or politically unstable regions. Security and supply risks are not just confined to CRMs but also to the import of semi-manufactured and refined goods as well as finished products.

The advent of new technologies also means the need for new raw materials and new suppliers. For raw material exporters, including the ASEAN countries, this offers the potential for enhanced economic development and welfare, apart from expanded trade with the industrialised hi-tech countries that are increasingly dependent on CRM imports. But the rise of such exporters has brought social imbalances, widespread corruption and new geo-economic as well as geopolitical competition. The more the world becomes dependent on CRMs for green technologies, including digitalisation and equipment and devices embedded with artificial intelligence, the more the world's future CRM mining sector will need to meet internationally agreed social and environmental standards as well as regulation comparable to those that apply to the global fossil fuel markets.

The future supply security of CRMs depends largely on timely investments, which are themselves dependent on adequate investment conditions, and alternative strategies such as the re-use of CRMs, reduction in use, substitution and recycling. Using these strategies may reduce the need for imported and locally produced CRMs in the mid- to longer-term perspectives. They are part of the circular economy, which will use CRMs more economically and efficiently and will be more environmentally friendly by reducing mining and import demands to strengthen supply security. But, owing to the specific functions and characteristics of each CRM, they are often difficult to recycle and/or substitute, and, in some cases irreplaceable for emerging technologies for the time being.

Overall, efforts at recycling, reducing use, re-using and substituting have up to now had only a marginal impact on the global demand and supply of REEs and other CRMs. But the intensity and efficiency of such efforts as well as life-cycle analyses will become ever more important factors in the future when examining the demand and supply of CRMs as well as the mining and manufacturing industries. There is a need for more policy attention to these issues in ASEAN even as its member states grapple with the politics of environmental protection and climate change.

ASEAN cooperation and mechanisms: An insider's view

According to former Secretary-General of ASEAN Ong Keng Yong, who is currently following ASEAN affairs at the S Rajaratnam School of International Studies (RSIS), Nanyang Technological University, Singapore, the supply of CRMs is closely linked to a range of issues in ASEAN such as accelerating development of the circular economy, addressing the transboundary movement of waste/plastics, combatting marine debris/litter, and reducing single-use plastics.

In this regard, Ong Keng Yong stated that ASEAN could do more in developing upstream measures, such as comprehensive waste management and circular economy systems and policies that could potentially help address the various downstream challenges. This includes (i) giving greater priority to these issues at the deliberations of the relevant working groups in ASEAN's environment and economic sectors as well as ensuring coordination between the two sectors; (ii) exploring how domestic e-waste recycling markets could be developed and enhanced; and (iii) exploring the scope for economies of scale through cross-border CRM trade and the recovery of CRMs through recycling e-waste.

As Ong Keng Yong put it, ASEAN does not have a policy position on the concept of circular economy at present. However, ASEAN, with support from the European Union, has begun discussing the circular economy, including efforts to develop comprehensive waste management strategies as well as addressing marine litter/plastics. The European Union supported a gap analysis study on the circular economy for plastics through its Enhanced Regional EU-ASEAN Dialogue Instrument (E-READI). Based on inputs by the ASEAN countries on their current policies and strategies, the study identified gaps and opportunities to address plastics and develop a circular economy. A workshop was conducted in June 2019 as part of the study and a report was made available subsequently.[87]

According to Ong Keng Yong, in 2019, ASEAN decided on two streams of work relating to the circular economy, waste management and marine debris. First, the Bangkok Declaration on Combating

[87] See Lewis Akenji et.al., "Circular Economy and Plastics: A Gap-Analysis in ASEAN Member States", Policy Report (Brussels: European Commission Directorate General for Environment and Directorate General for International Cooperation and Development, Jakarta: ASEAN, 2019), available via https://www.iges.or.jp/en/publication_documents/pub/policyreport/en/10382/FINAL_CE+and+Plastics+-+A+gap+analysis+in+ASEAN+Member+States_1004.pdf

Marine Debris in ASEAN Region and the ASEAN Framework of Action on Marine Debris were adopted by the ASEAN leaders at the 34th ASEAN Summit in June 2019. The declaration highlights the development of a circular economy as one approach for addressing marine litter. To put the declaration into action, ASEAN countries are currently developing the ASEAN Regional Action Plan on Marine Debris through a series of workshops led by Thailand and facilitated by the World Bank.

Second, ASEAN Foreign Ministers adopted the Statement on Illegal Transboundary Movement of Hazardous Waste in August 2019. Among other things, the statement called for greater exchange of information, capacity building efforts and cooperation through international frameworks to address transboundary waste issues. An existing ASEAN Working Group on Chemicals and Waste (AWGCW) is tasked to act on the elements in the statement in the coming years, particularly developing guidelines for the transboundary movement of plastic waste as well as enhancing implementation of the relevant Basel, Rotterdam and Stockholm Conventions.

Thailand has proposed to develop a Roadmap for E-Waste Management under the ASEAN dialogue partnership with South Korea. This project is being pursued under the ASEAN Economic Community pillar. On the environment front, discussions on e-waste have been ad hoc, with no recent developments since the matter was discussed in 2017 under the AWGCW.

Ong Keng Yong said that within ASEAN, there is also an ASEAN Minerals Cooperation Action Plan (AMCAP), which serves as a blueprint for ASEAN cooperation on minerals and is aimed at enhancing “ASEAN mineral sector dynamism”. AMCAP was initiated in 2005 and is currently in its third implementation plan (2016–2025). The vision of AMCAP III is to create a vibrant and competitive ASEAN mineral sector and it outlines four strategic areas, namely (i) facilitating and enhancing trade and investment in minerals; (ii) promoting environmentally and socially sustainable mineral development; (iii) strengthening institutional and human capabilities in the ASEAN minerals sector; and (iv) maintaining an efficient and up-to-date ASEAN Minerals Database.

In addition, ASEAN has set up the ASEAN Ministerial Meeting on Minerals (AMMin) as a platform for ASEAN ministers to discuss issues and developments of common interest, as well as to set policy directions for cooperation in the ASEAN minerals sector. The ASEAN Senior Officers Meeting on Minerals (ASOMM) is the main working-level forum to discuss matters relating to ASEAN cooperation in minerals. It is held at least once annually. The ASOMM also works with related-industry partners such as the Coordinating Committee for Geoscience Programmes (CCOP), the ASEAN Federation of Mining Associations (AFMA) and the InterGovernmental Forum (IGF) on Mining, Minerals, Metals and Sustainable Development.

In Ong Keng Yong’s assessment, the key concern is how the ASEAN countries, individually and as a regional grouping, strategically manage the intensifying political, economic and technological competition between China and the United States. Geographically, China is a close neighbour of

ASEAN and shares land and maritime boundaries with a number of ASEAN countries. Economically, China is today the number one trading partner of all the 10 ASEAN member states. Politically and militarily, however, the United States is entrenched in Southeast Asia through its post–Second World War alliance with Japan and South Korea. Washington has also maintained that it is part of the region and has devised a refreshed Indo-Pacific strategy to stay engaged in the Pacific and Indian Oceans. While ASEAN has vowed not to take sides between the United States and China, it may be required to consider greater regional cooperation to deal with the implications of CRM supply security in the new Rare Metal Age.

About the Author

Dr Frank Umbach has been appointed as Adjunct Senior Fellow in RSIS with effect from 22 September 2017. Dr Umbach graduated from the University of Bonn with a M.A. degree in Political Science and a PhD ("Dr. phil"). He is presently the Research Director of the European Centre for Energy and Resource Security (EUCERS) at King's College in London as well as a Senior Associate at the Centre for European Security Strategies (CESS GmbH), Munich and a Visiting Professor at the College of Europe in Natolin (Warsaw) in Poland, teaching on "EU External Energy Governance". Furthermore, he is also a consultant for the Gerson Lehrman Group (GLG) and Wikistrat.com. Since 2014, he is an independent "Subject Matter Expert (SME)" on international energy security of NATO's annual "Strategic Forecasting Analysis (SFA)". He's an internationally recognised expert on global energy security, geopolitics, critical (energy) infrastructure protection/CEIP, and (maritime) security policies in Asia Pacific as well as Russia/Central Asia.

Previously, he was also a (Non-Resident) Senior Fellow of the Atlantic Council of the United States (ACUS) in Washington D.C. between 2010 and 2015. From 2003 to 2007, he was a Co-Chair of the European Committee of the Council for Security Co-operation in Asia-Pacific (CSCAP-Europe). From 1996 to 2007, he was the head of the programmes "Security Policies in Asia-Pacific" and "International Energy Security" at the German Council on Foreign Relations (DGAP) in Bonn and Berlin; a research fellow at the Federal Institute for East European and International Studies (BIOst) from 1991 to 1994 and a visiting research fellow at the Japan Institute for International Affairs (JIIA) in Tokyo from 1995 to 1996.

Dr Umbach has done consultancy work and testimonies for the German Ministries of Foreign Affairs and Defence Policies; European Commission and European Parliament, US-State and Energy Departments, US-China Economic and Security Review Commission (US-Congress), the Lithuanian Government, the House of Lords (British Parliament), the Polish Foreign and Economic Ministries, Hungarian Foreign Ministry, South Korean Foreign Ministry, NATO, OSCE, World Energy Council (WEC), Federation of the German Industries (BDI), energy and consultancy companies (incl. APCO and Roland Berger) and has advised international investors (via GLG). He is also the author of more than 500 publications in more than 30 countries worldwide, including being a contract author of the Geopolitical Intelligence Service (GIS) in Liechtenstein since 2011.

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