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EUROPE'S RARE EARTH DEPENDENCE ON CHINA: FUTURE PERSPECTIVES

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Europe's Rare Earth Dependence on China

Future Perspectives

By Julia Ebner[1]

Abstract

In view of the EU 2020 energy targets and the indispensability of rare earths for the ICT and clean technology sector, European demand for rare earths will likely continue to increase progressively in the years to come. Whilst Europe has made considerable efforts to decrease its dependence on China's rare earths by investing in domestic primary production and R&D of substitutes and recycling, it is today still fully dependent on external supply, mostly from China. Aiming at providing an analysis of the status quo and recent trends of Europe's dependence on China's rare earths, the briefing paper assesses developments on both the supply and demand side of the Sino-European rare earth market. After explaining China's quasi-monopoly, Europe's ICT and clean technology dependence on rare earths and the evolution of Chinese rare earth policies, it examines potential implications of the March 2014 WTO decision for China's rare earths supply equation. The paper then analyses Europe's efforts to increase and diversify its primary supply and to decrease its demand for rare earths. It makes use of interviews with European and Chinese rare earth policy and industry experts and concludes by sketching future scenarios for the Sino-European rare earths trade and Europe's supply security.

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List of Abbreviations

DOE: Department of Energy (US)

EC: European Commission

ERECON: European Rare Earths Competency Network

ICT: Information and communication technology

LED: Light-emitting diode

METI: Ministry of Economy, Trade and Industry (Japan)

MIIT: Ministry of Industry and Information Technology (Japan)

MOFCOM: Ministry of Commerce (China)

NdFeB: Neodymium magnets

NEDO: New Energy and Industrial Technology Development Organization (Japan)

NFC: Non-Ferrous Metal Industry's Foreign Engineering and Construction Co. Ltd.

R&D: Research and Development

WTO: World Trade Organization

I. Introduction

"The Middle East has oil, China has rare earths," Deng Xiaoping said in 1992, recognising the strategic importance of rare earths over two decades ago.[2] Supplying more than 85 per cent of the world's rare earths[3], China today has a quasi-monopoly on the 17 rare earth elements[4] at the bottom of the periodic table. Even though American Molycorp and Australian Lynas recently ramped up their mining and processing capacities, causing a reduction of China's share in global output from 95 per cent in 2010 to an estimated 75 per cent in 2015, China's monopoly for heavy rare earth elements remains unchallenged.[5] Europe's information and communication technology (ICT), clean technology and defense sectors are therefore to a large extent dependent on Chinese rare earths, which are indispensable for the production of such products as smartphones, computers, solar panels, lasers, and electric car batteries.

When China's Rare Earth Office was transferred to the Ministry of Industry and Information Technology (MIIT) in 2008[6], it started to impose restrictions on the export of rare earth metals[7], including export quotas and tariffs. In particular, China started to curb its rare earths exports to Europe, the US and Japan.[8] This caused great concern in Europe, as a rare earth supply shortage would not only negatively impact the EU's innovativeness and competitiveness in the high tech industry but also impede progress in the emerging alternative energy sector (e.g. energy-saving lighting, electric cars, fuel cells, photovoltaics or windmills).[9]

Although Beijing initially stated that the reduction was a measure to protect the environment and its national resources, the suspension of exports to Japan after the Senkaku/Diaoyu boat collision incident in 2010 was "widely perceived as China using its control over crucial minerals as a tool of its foreign policy."[10] In reaction to this, the US, Japan and the EU jointly filed a case against China and demanded a dispute settlement by the WTO. In March 2014, the WTO investigation reached the conclusion that China's rare earth policies constituted a violation of international trade law, saying that "China's export quotas were designed to achieve industrial policy goals"[11] rather than to mitigate environmental pollution. After China appealed these panel reports in late April the dispute settlement body adopted the appellate body reports with recommendations to bring measures into conformity on August 29, 2014.

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[2] Brennan, Eliot. (2012). Rare earths – the next oil. Asian Times. Retrieved from http://www.atimes.com/atimes/China_Business/NC16Cb01.html.

[3] Gravgaard, Anna. (2013). Greenland's Rare Earths Gold Rush. *Foreign Affairs.* The Council of Foreign Relations. Retrieved from http://www.foreignaffairs.com/features/letters-from/greenlands-rare-earths-gold-rush.

[4] The 17 rare earth elements are lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, yttrium and scandium

[5] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny

[6] Tse, Pui-Kwan. (2011). China's Rare Earth Industry. US Geological Survey, p.5

[7] Those restriction where not only imposed on rare earths but also on tungsten and molybdenum

[8] Jiji.(2014, March 24). Japan, US, EU win rare earths dispute over China, *The Japan Times*. Retrieved from http://www.japantimes.co.jp/news/2014/03/26/business/japan-u-s-eu-win-rare-earth-dispute-with-china/#.U0zgglcgRZg.

[9] Cf. Massari, Stefania and Ruberti, Marcello. (2013). Rare earth elements as critical raw materials: Focus on international markets and future strategies. Resources Policy 38, 36-43.

[10] Farooki, Masuma. China and mineral demand – more opportunities than risk?. *Polinares Working Paper.* n.75. Retrieved from http://www.polinares.eu/docs/d5-1/polinares_wp5_chapter5_4.pdf.

[11] WTO. (2014). China – Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum. Retrieved from http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm.

In recent years, much research has been conducted on the controversy of China's rare earth export restrictions. The case has been looked at from various angles: political, macro-economic, legal and technological analyses have demonstrated the complexity and multifacetedness of the topic. While most of the existing literature has provided descriptions or analyses of certain aspects of China's rare earth monopoly, this paper attempts to draw conclusions from rare earth trends and power shifts on the demand and the supply side of the rare earths market as well as the interplay between domestic policies and international market trends. The paper examines the Chinese rare earth controversy in light of the recent WTO ruling, thus adopting a post-August 2014 perspective, and provides future scenarios for EU-China rare earth trade. More specifically, the paper integrates the market and supply equation implications of the WTO decision and analyses developments and emerging alternatives in the European rare earth demand.

First of all, the paper explains the status quo of Sino-European rare earth relations, by providing reasons for China's quasi-monopoly and Europe's dependence on Chinese rare earths as well as a brief overview on the evolution of China's rare earth policies. After providing this status quo analysis, the paper concentrates on future perspectives and expected shifts in the rare earth market. On the one hand, the briefing paper attempts to analyse China's expected reaction to the recent WTO ruling, in other words, changes on the supply side of the market. On the other hand, it tries to examine future trends for Europe's role in the international rare earth competition dynamics, that is to say changes on the demand side. In the end, a brief future scenario analysis and a conclusion with the main findings are provided.

The paper makes use of recently published specialist books, academic journal articles, newspaper articles, reports issued by governmental and non-governmental institutions mainly in Europe and China, conference protocols as well as available statistics, graphics and empirical studies on the topic. Apart from the literature research, the paper draws conclusions from interviews with experts in the field of rare earths and EU-China minerals trade. In order to provide a non-biased analysis, interviews have been conducted with representatives from both the Chinese and the European side as well as from both the private and the public sector. Concretely, experts from academic institutions, think tanks, Chinese and European governmental institutions, private companies and independent researchers and trend analysts have been consulted. The full list of interviewees can be found in the appendix.

II. China's Quasi-Monopoly

Today, China is the world's biggest producer and exporter of commercial quantities of rare earth materials, accounting for over 85 per cent of the global rare earth output.[12] The Inner Mongolia Autonomous Region is well-known as China's leading rare earth producer, supplying between 50 and 60 per cent of China's total rare earth concentrate output since the early 2000s. However, other provinces such as Fujian, Guangdong, Jiangxi, and Sichuan have also become important producers of rare earth materials in China.[13]

In fact, rare earths are not as rare as their name suggests. Some of them are even more abundant than other minerals such as copper, lead, gold and platinum. However, their

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[12] Gravgaard, Anna. (2013). Greenland's Rare Earths Gold Rush. *Foreign Affairs.* The Council of Foreign Relations. Retrieved from http://www.foreignaffairs.com/features/letters-from/greenlands-rare-earths-gold-rush.
[13] Tse, Pui-Kwan. (2011). China's Rare Earth Industry. US Geological Survey. Open File Report 2011-1042, p.1.

extraction and processing requires high initial investments and advanced technology and produces toxic waste. Another problem is that rare earth elements are frequently not concentrated enough for their extraction to be economically viable.[14] Currently there are only two major producers of rare earths that can be found outside of China: the US-based company Molycorp and Australia's Lynas. Thanks to their recent production revival at the Californian Mountain Pass mine and Australia's Mount Weld, China's share of rare earth output has fallen from more than 95 per cent in 2010 to 85 per cent in 2013.[15]

The first rare earth deposits were discovered in 1787 in Sweden. It was almost 100 years later that rare earths were first used in commercial products. The early 20th century saw the dawn of large-scale rare earth production, with Brazil and India being the first countries to produce and export rare earths, followed by Australia and Malaysia who commenced their exports in the 1940s. The US started to extract rare earths for export, principally from the Mountain Pass Mine in California, in the 1960s and became the world's leading exporter by the 1980s. China did not enter the stage and penetrate the international rare earth market until the early 1980s. However, it quickly rose to become a major low-cost rare earth producer and overtook the US as the world's biggest exporter in 1988. This transition in the global supply chain of rare earths has entailed some dramatic changes in market terms. In the 1990s, the US, the EU, Japan and other rare earth producing countries decided that it was cheaper, hence more beneficial, and at some point even inevitable, to discontinue past production chains and instead source rare earths from the low-cost producer China. Ever since gaining momentum, China has increasingly dominated the global rare earth arena and today enjoys an almost monopolistic status.[16]

China's quasi-monopoly in the extraction, production and export of rare earths does not come as a surprise, considering some major competitive advantages the country benefits from in regards to its rare earth industry:

1. Home to over 50 per cent of the global rare earth reserves[17], China is the world's richest country in rare earth resources. Since China's first discoveries of rare earth elements in Bayan Obo in 1927, rare earths have been found in 21 of the 34 Chinese Provinces and Autonomous Regions. Besides China's abundant rare earth resources, large-scale deposits can only be found in a very limited number of countries, including the US, Russia, Brazil and the Democratic Republic of Congo. Although these countries have increased their rare earth production in recent years, they still cannot challenge China's quasi-monopoly.[18]

2. China's fast rise to a leading rare earth producer can furthermore be explained by the country's cheap labour advantage. Its access to low-cost human resources was crucial for its success as a cheap producer of rare earth materials and enabled the country to rapidly overtake the US production capacities and to establish a virtual global monopoly based on its cost advantage.[19] Despite the limited availability of price information due to rare earth contracts being negotiated between operators and not traded on stock or

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[14] Humphries, Marc. (2013). Rare Earth Elements: The Global Supply Chain. Congressional Research Service. CRS Report for Congress. p.2.
[15] Gravgaard, Anna. (2013). Greenland's Rare Earths Gold Rush. *Foreign Affairs.* The Council of Foreign Relations. Retrieved from http://www.foreignaffairs.com/features/letters-from/greenlands-rare-earths-gold-rush.
[16] Blakely, C., Cooter, J. et al. (n.d). Rare Earth Metals & China. Gerald R. Ford School of Public Policy, p.5.
[17] Statista. (2013). Rare earth reserves worldwide as of 2013, by country (in 1,000 metric tons of REO). Retrieved from http://www.statista.com/statistics/277268/rare-earth-reserves-by-country/.
[18] Blakely, C., Cooter, J. et al. (n.d). Rare Earth Metals & China. Gerald R. Ford School of Public Policy, p.6.
[19] Blakely, C., Cooter, J. et al. (n.d). Rare Earth Metals & China. Gerald R. Ford School of Public Policy, p.5.

future markets, there is strong evidence of a significant price discrepancy between Chinese rare earth prices and prices of producers outside of China.[20]

3. Moreover, China's tremendous economic growth, almost permanently in double digits for more than three decades, has equipped the country with sufficient funds not only to invest heavily in domestic mineral production but also to pour vast sums of capital into other countries' mining industries by acquiring mining licenses and establishing extraction and processing facilities abroad.[21]

4. Additionally, the country's continuous efforts to expand its geological and technological knowledge in the field of mining through research and development (R&D) and knowledge transfer have transformed China into a global leader for cutting edge technology and expertise in the mining sector. Since the US and Europe have been reluctant to invest equally high sums in their geological research and their mining technologies, China now dominates all four steps in the rare earth supply chain: extraction, processing, purification and production.[22]

5. China's lenient environmental laws have also played an important role in the country's conquest of the international mining sector.[23] In reaction to the toxic wastewater leaks of the 1990s and similar mining-related ecological scandals, industrialised countries imposed stricter environmental standards which have considerably impeded progress in the American and European mining sectors. While, for example, US mining companies such as Molycorp had to temporarily restrict or even stop their mining activities in order to fulfil new environmental requirements, China could further develop its supremacy in the international rare earth industry.[24]

6. China has benefited from a centrally planned, consolidated long-term minerals policy which is based on an interactive stakeholder consensus and integrates rare earth policies into the general resource management strategy. Contrary to China, the EU did not consider rare earths as strategically important resources until 2007, when it started to pursue a more comprehensive raw materials policy. Although first steps towards better defined European minerals policy have been undertaken in the course of the EU's Raw Materials Initiative of 2008, Europe is far from reaching a consolidated mineral resources policy or a concrete rare earth supply security strategy. Hence, China's farsightedness has seemed to pay off, as Europe and other rare-earth dependent countries are struggling to achieve what China has long had in place.[25]

7. Another significant competitive advantage of Chinese rare earth producing companies arises from the strong governmental support they enjoy. Most Chinese mining companies operate as SOEs and are thus legally backed and financially supported by the government.[26] This also means that Chinese rare earth producers can quickly react to

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[20] Hayes-Labruto, L., Schillebeeckx, S. et al. (n.d.) Contrasting Perspectives on China's Rare Earth Policies: Refraiming the Debate through a Stakeholder Lens. Retrieved from http://www.academia.edu/2779606/Contrasting_Perspectives_on_Chinas_Rare_Earths_Policies_Reframing_the_Debate_through_a_Stakeholder_Lens.
[21] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[22] Xiaojing, Liu. (2014). China to Form Two Rare Earth Metals Conglomerates. Caixin Online. Retrieved from http://english.caixin.com/2014-08-07/100714129.html.
[23] Blakely, C., Cooter, J. et al. (n.d). Rare Earth Metals & China. Gerald R. Ford School of Public Policy, p.5.
[24] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[25] Ibid.
[26] Cf. Davis, Bob. (2014). China's State-Owned Sector Gets a Boost. The Wall Street Journal. Retrieved from http://online.wsj.com/articles/SB10001424052702303636404579396933232035544.

market changes such as spontaneous drops in the rare earth demand or unexpected competition on the supply side. As government subventions allow for substantial price reductions whenever needed, China seems to have almost complete control over the international rare earth market.

8. One last key advantage is China's large-scale production of iron ore. As rare earths are a by-product of iron ore mining, an industry in which China would invest in any case, rare earth investments appear to be less costly and less risky for Chinese mining companies than for European ones.[27]

To conclude, China's notable competitive advantages in the rare earth industry which have their source mainly in the favourable conditions underlying the country's mining sector, have contributed to the creation of a Chinese quasi-monopoly which can realistically not be challenged in the short-term. China's quasi-monopolistic presence in the rare earth market has equipped the country not only with enormous market power but has also been translated in considerable diplomatic and political power. This was particularly well reflected in the case of rare earth export restrictions targeting Japan after the Senkaku/Diaoyu conflict escalated with the boat collision incident in September 2010. China was blamed by the US, Europe and Japan for instrumentalising its control over the world rare earth resources and using it as leverage for the country's political purposes, especially in its dealings with Japan.[28]

III. Europe's Rare Earth Dependence

At the present moment, Europe has no access to domestic rare earth resources. Despite the existence of potentially mineable rare earth deposits in numerous European countries, such as the UK, Germany, Sweden, Finland, Greece and Greenland, geological constraints, economic unprofitability and strict environmental standards have hitherto hampered extraction. Soaring rare earth prices following China's export restrictions in 2011 and subsequently rising concerns about Europe's rare earth supply security have, however, resulted in intensified public as well as private investments in the exploration and assessment of Europe's rare earth deposits. Until now, exploration efforts are considered to be in an advanced stage only in Greenland (Kvanefjeld) and Sweden (Nora Kärr).[29]

Besides the unexploited European mining potential, there are also bottlenecks linked to the processing and the separation of rare earths, a key step in the rare earth supply chain. Sophisticated European separation facilities are currently only found in France and Estonia. Europe is therefore to a large extent dependent on the supply of concentrates from China and other countries, such as the US and Russia.[30]

In 2010, an Ad-Hoc Working Group on Defining Critical Raw Materials of the European Commission published the first analysis for raw materials, defining the rare earth elements as critical resources with a high supply risk. As shown in the following graphic, the working group divided the rare earth elements into two categories: light and heavy rare earth elements. The matrix below reveals a rather low economic importance of both the light and the heavy rare earth elements, as compared to other critical raw materials. Yet, it also

[27] Information received in the interview with Prof. Dr. Arnold Tukker
[28] Blakely, C., Cooter, J. et al. (n.d). Rare Earth Metals & China. Gerald R. Ford School of Public Policy, p.5.
[29] ERECON. (2014). Working Group I: Opportunities and road blocks for primary supply of rare earths in Europe. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/erecon/expertise/working-group-1_en.htm.
[30] Ibid.

illustrates the relatively high supply risk of light rare earth elements and the eminently risky nature of the heavy rare earth elements supply.[31]

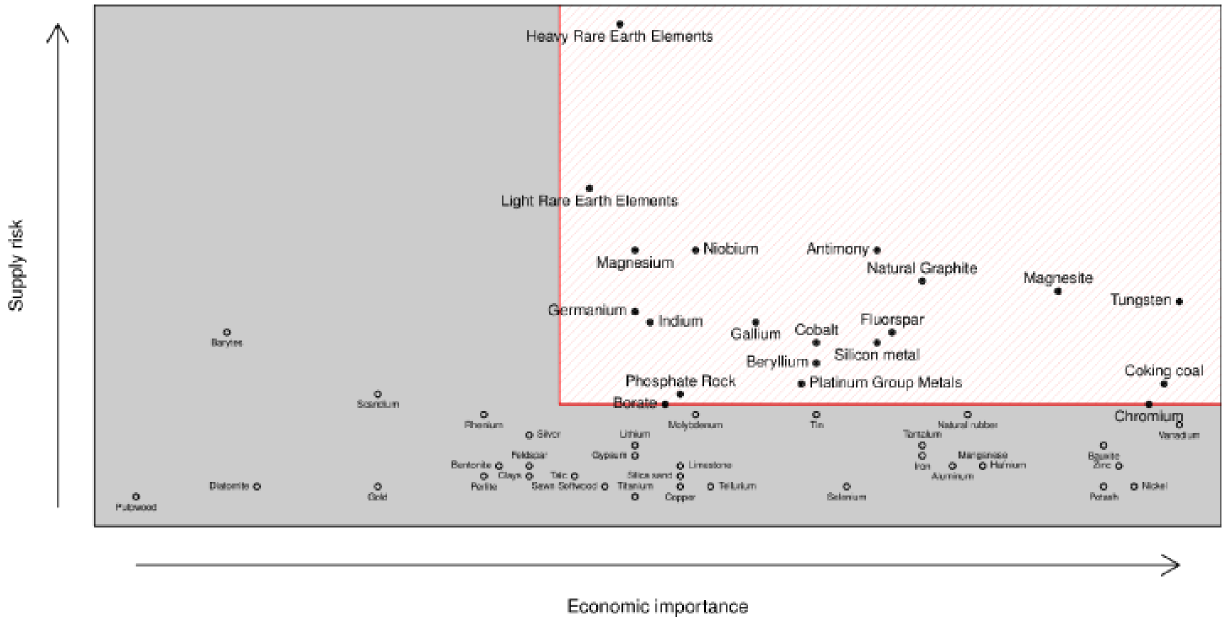

Figure 1: Raw Materials Criticality Analysis 2010, European Commission

With the EU's 2020 goals on lowering its use of fossil fuels, its growing demand for hi-tech devices and green technology products such as electric cars, solar panels and windmills and its ambitions to decrease its dependence on Russia's gas in the light of the Ukraine crisis, Europe is expected to experience climbing demand levels for rare earth materials.[32] In particular, the demand for neodymium, dysprosium and praseodymium is predicted to rise in the close future.[33] Since, until today, most rare earth products have no or few effective substitutes and their recycling rate generally remains low[34], a shortage in rare earths could have devastating effects for the European economy. Albeit progress made in the development of alternatives to rare earths, the concentrates are currently still indispensable for the European ICT and clean technology sector. Most likely, clean technology would be the first sector to be adversely affected by a potential rare earth bottleneck in the EU, owing to the fact that the demand is hardly predictable and that the quantities required today are incommensurate with those consumed some years ago. For example, this would apply to the rare earth element neodymium-iron-boron which is needed for the production of sintered permanent magnets used in wind turbines.[35]

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[31] European Commission. (2014). Defining 'critical' raw materials. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm.
[32] ERECON. (2014). Rare earth in Europe. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/erecon/index_en.htm.
[33] Wells, Steve. (2013). Emerging Alternatives to Rare Earth Elements. Futurium. European Commission. Retrieved from https://ec.europa.eu/digital-agenda/futurium/en/node/1637.
[34] Massari, Stefania and Ruberti, Marcello. (2013). Rare earth elements as critical raw materials: Focus on international markets and future strategies. Resources Policy 38, 36-43.
[35] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny

IV. The Evolution of Chinese Rare Earth Policies

Upon the introduction of the Mineral Resources Law in the 1980s, the Chinese government adopted a planned exploitation policy for strategically important minerals.[36] In 1990, the government further issued a declaration in which it defined rare earths as a protected and strategic mineral. Since then, foreign investors were no longer allowed to engage in any mining activity, unless they formed a joint venture with a Chinese company. Furthermore, all rare earth mining and smelting projects required permission from the State Development and Planning Commission (SDPC).[37]

Later, in the 1990s and 2000s, the Chinese government made efforts to limit the country's rare earth production and exports in order to avoid high pollution levels caused by excessive mining. Since the economic development of many regions depended to a large extent on the rare earth sector, multiple local governments did not adhere to the new national guidelines, which led to output levels clearly exceeding the production quotas.[38] Moreover, a substantial percentage of the output was generated by investors extracting rare earths without proper mining licenses, hence often using old technical equipment which did not meet the industry standards and caused significant harm to the environment. As a consequence, Beijing has been tightening its measures to enforce the implementation of the national rare earth policies during the past decade, in particular by shutting down illegal mines in Guangdong, Jiangxi, and Sichuan.[39]

In recent years, China has further increased its control over rare earth mining and production volumes, by implementing a system of mining rights allocation plans. Since 2007, rare earths production is subject to mandatory planning and since the National Plan for Mineral Resources for the period of 2008-2015 was issued in 2008, the state exercises comprehensive regulation and control, restricts the rare earths exploitation and decides on their utilisation.[40] Under the label of environmental protection and resource conservation, China furthermore restricted rare earth trade in 2010 by imposing export quotas, duties and limitations on trading rights of enterprises with export permissions.[41]

In response to these restrictions, the US lodged a complaint at the WTO in March 2012, claiming that China's export policies were inconsistent with the WTO rules and China's protocol of accession. Japan and the EU, both similarly concerned about China's export constraints, joined forces with the US only a few days later.[42]

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[36] The State Council Information Office of the People's Republic of China. (2012). III. Effectively Protecting and Rationally Utilizing Rare Earth Resources. Retrieved from http://www.scio.gov.cn/zxbd/nd/2012/Document/1175401/1175401_4.htm.
[37] Tse, Pui-Kwan. (2011). China's Rare Earth Industry. US Geological Survey. Open File Report 2011-1042, p.2.
[38] China State Council. (2006). Instruction for mineral resource development: Beijing, China, China State Council Circular 108. December 31, 5 p. (In Chinese).
[39] Tse, Pui-Kwan. (2011). China's Rare Earth Industry. US Geological Survey. Open File Report 2011-1042, p.2.
[40] The State Council Information Office of the People's Republic of China. (2012). III. Effectively Protecting and Rationally Utilizing Rare Earth Resources. Retrieved from http://www.scio.gov.cn/zxbd/nd/2012/Document/1175401/1175401_4.htm.
[41] WTO. (2014). China – Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum. Retrieved from http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm.
[42] Ibid.

V. Implications of the March 2014 WTO Ruling for China's Supply Equation

In late March 2014 the WTO Dispute Settlement Body issued a panel report on the China rare earths case, concluding that China's export restriction measures indeed constituted a violation of China's WTO obligations.[43] While China did not make a plea against any of the final conclusions of the WTO panel, it appealed some intermediate judgments in order to "obtain clarification of the systemic relationship between specific provisions in China's Accession Protocol, and other WTO agreements, and of the rights of WTO Members to protect and conserve their exhaustible natural resources." [44] According to the Appellate Body Report issued on August 7 2014, most of China's appeals including interpretations and allegations that the Panel failed to comply with its duty were, however, declined.[45]

In reaction to the panel report, China's Principal of the Department of Treaty and Law of the Ministry of Commerce (MOFCOM) gave a speech, saying that he regretted the WTO decision on China's export restrictions. He furthermore announced that China will respect the WTO rules and act accordingly.[46] Indeed, China has a good record of implementing WTO rulings and has always respected WTO decisions, as Mr. Xie Wei, a MOFCOM representative to the EU, stressed in an interview.[47] Mr. Xie Wei, however, also pointed out that China will need time to implement the new WTO ruling and that China, Japan, the US and the EU will agree on a reasonable timeline, depending on how complicated the implementation is.[48]

The decision of the WTO Dispute Settlement Body has put China under severe pressure. It faces a multitude of conflicting interests, the most important ones being: fulfilling its WTO obligations, satisfying its domestic demand for rare earths, upholding its competitive edge and meeting its own sustainability and environmental protection targets.[49] Keeping the balance between those interests will not be an easy undertaking, in particular in view of the growing demand for rare earth products both on a domestic and on an international level. The consequences of the WTO decision for China on a macro-economic, micro-economic and environmental level are hardly predictable due to the highly complex nature of China's supply equation. It seems that neither Chinese rare earth supply decisions nor the impacts of the recent WTO ruling can be narrowed down to only one factor, be it industrial policy strategies, market domination calculus or environmental impacts, all of which – considered in isolation from the other factors – risk to oversimplify China's highly complex rare earths dilemma.

[43] WTO. (2014). China – Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum. Retrieved from http://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm.
[44] Ibid.
[45] Ibid.
[46] MOFCOM. (2014). Principal of Department of Treaty and Law of MOFCOM Gives a Speech on WTO's Panel Report on the Case of the US, EU and Japan's Action Against China's Export Management Measures of Relevant Rare Earth, Tungsten and Molybdenum Products. Retrieved from http://english.mofcom.gov.cn/article/newsrelease/policyreleasing/201404/20140400538135.shtml.
[47] Information received in the interview with Mr Xie Wei
[48] Ibid.
[49] Ibid.

a.) Implications for China's domestic supply

China's rare earths resource depletion is regulated in a comprehensive three level quota system, covering the country's mining quota (set up in 2006), the country's production quota (set up in 2007) and the country's export quota (set up in 2010).[50] In order to allow for a coherent rare earth policy that makes sense economically, politically and ecologically, China uses these three quotas simultaneously. This means that, if one quota is changed, China needs to readapt the other two quotas. In consequence, the WTO decision does not only impact China's export quota but indirectly also affects China's mining and production quotas. If the export quota is lifted, while the mining and production quotas remain in place, this could result in a domestic shortage. As rare earths are also needed for the Chinese ICT industry, China's production is likely to be impacted, in case the mining and production quotas are not increased adequately in order to meet domestic demand.[51]

Figure 2 illustrates global rare earths supply and demand for the year 2013. As demonstrated in the graphic, global supply is notably below global demand, indicating harsh competition resulting from the zero-sum nature of the current rare earths game. The chart also shows the proportion of China's rare earth production in comparison to production by the rest of the world. As suggested in previous chapters, rare earth production outside of China only constitutes a very small part of total rare earth production, rendering most countries dependent on Chinese rare earth supply. The graphic furthermore displays China's export quota of 30,999 metric tons of rare earth elements in 2013, as announced in two semi-annual statements by MOFCOM. The chart shows that with the export quotas in place, Chinese exports (30,999 metric tons) plus production in the rest of the world (11,740 metric tons) are slightly under the demand level for rare earths outside of China (44,640 metric tons). A lifting of the export quota seems to solve this problem at the cost of Chinese demand; it would ceteris paribus be likely to threaten China's own supply security. Already, Chinese demand cannot be met anymore due to the rapidly growing domestic consumption levels; in the long term constantly rising domestic and global demand for rare earth products would further exacerbate this problem.

[50] Information received in the interview with Mr Xie Wei

[51] Ibid.

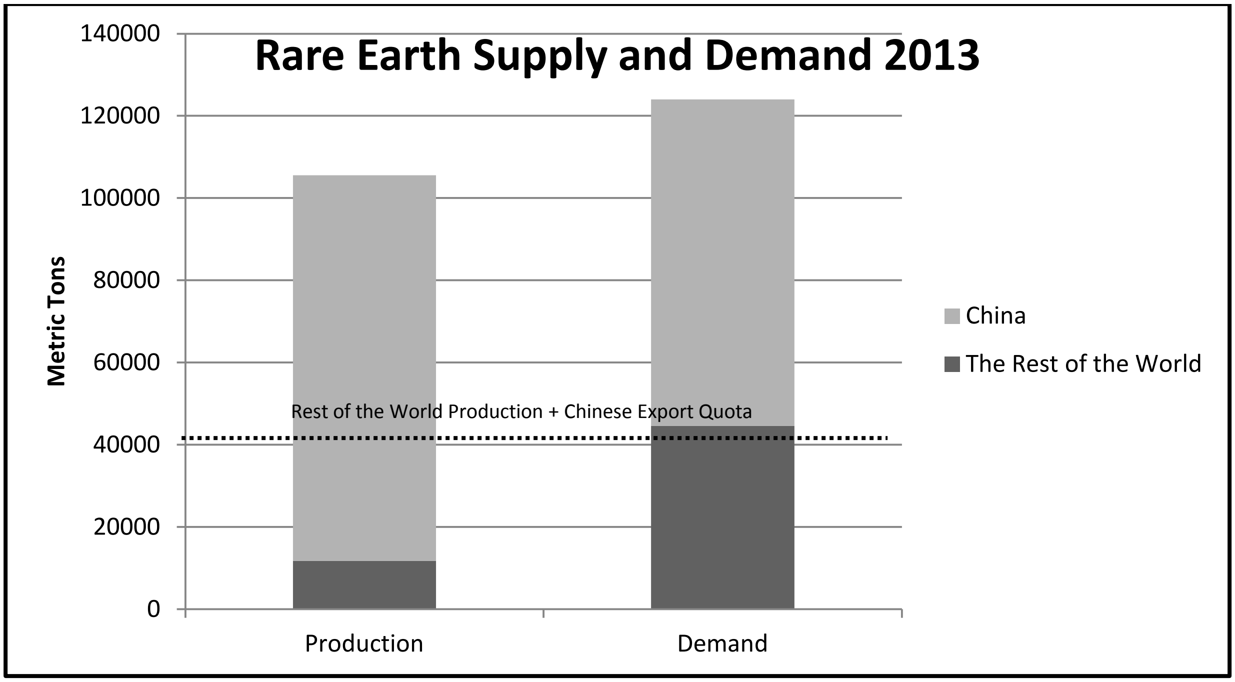

Figure 2: Rare Earth Supply and Demand 2013, author's compilation of data from USGS Mineral Commodity Survey 2013, MOFCOM, Arafura Resources Limited and Avalon Rare Earth Metals Inc.

b.) Implications for China's industrial production and FDI

A critical part of China's rare earth strategy and thus a key reason for the country's export restrictions during the past few years has been to avoid wasting the country's strategic resources by selling them off cheaply as primary goods to foreign countries and thereby running the risk of becoming a victim of what is often referred to as the "resource curse". Instead, it seems that China's goal has been to replace its exports of unprocessed rare earth oxide concentrates by exports of processed, high-value rare earth products. By restricting the export of rare earth oxide concentrates, China could make sure that major parts of the processing and value creation would take place on Chinese territory. The rare earth sector thus experienced a notable transition from purely primary sector activities of extraction to secondary sector activities of processing and manufacturing. This proved to be an effective strategy not only to upgrade the industry and to accelerate technological progress[52], but also to force companies operating in rare-earth-related industries to move to China, so as to gain access to "steady and affordable supply of rare earths". [53] For example, several German companies migrated to China when their supply chains were interrupted as a result of China's rare earth restrictions in 2010, according to Günter Tiess and Horst Hejny, experts on the European mining industry.[54] The Chinese rare earth strategy thus boosted FDI in China's mining sector and allowed for increased knowledge transfers from foreign countries, in particular due to China's strict joint-venture requirements.[55] If now export quotas are lifted as a result of the WTO ruling of March 2014, this could potentially result in decreased demand for Chinese processed rare earth products and an outflow of

[52] Conclusions drawn from the interview with Mr Duncan Freeman
[53] Buijs, B. and Sievers, H. (2011). Resource Security Risk in Perspective: Complexity and Nuance. Retrieved from http://www.nachhaltigwirtschaften.at/e2050/e2050_pdf/reports/20111111_resource_security_risks_in_perspective.pdf.
[54] Conclusions drawn from the interview with Dr Günter Tiess and Dr Horst Hejny
[55] Pinsent Masons LLP. (2013). Successful Joint Ventures in China. Retrieved from http://www.out-law.com/en/topics/projects--construction/projects-and-procurement/successful-joint-ventures-in-china/.

foreign companies in the mid- to long-term. As, however, companies operating in the field of rare earths are often embedded in rigid supply chains, their limited flexibility might prevent them, in particular in the short-term, from reversing their market entry.[56] Furthermore, as Günter Tiess pointed out, “companies still access rare earth elements in China at a significant discount” and “strategic downstream manufacturing such as magnet making continues to move to China, where access to rare earth elements remains cheapest and most secure”.[57]

c.) Implications for the global rare earth prices

Figure 3 illustrates the evolution of international rare earth prices between 2008 and 2012. The graph shows a slight drop in prices shortly after the Global Financial Crisis gained momentum but indicates a quick recovery already by the second half of 2009. The introduction of China’s export restrictions in 2010 was immediately reflected in skyrocketing prices peaking in Q2 of 2011. From then onwards prices, however, started dropping again and reached almost the level of before the price spike by early 2012.

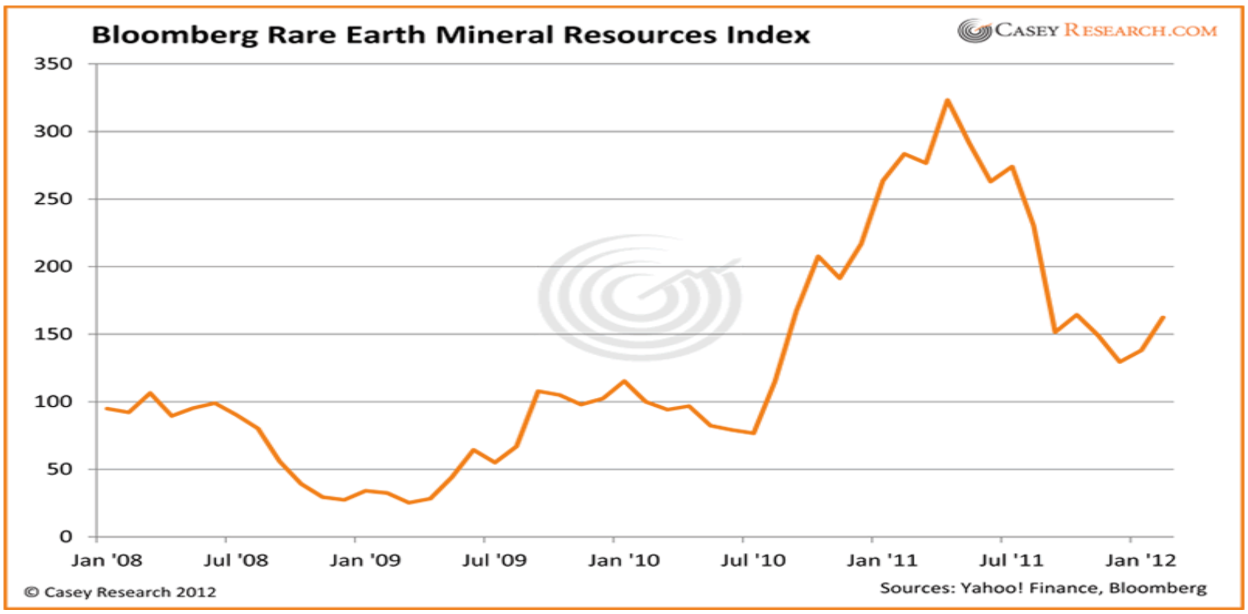

Figure 3: The Evolution of rare earth prices 2008-2012, Bloomberg

From a classical economic perspective, the removal of export quotas, hence an international supply increase in rare earth materials would, ceteris paribus, lead to dwindling prices. However, the past has shown that the rare earth market formula seems to be more complex and that there is no direct causal relation between China’s rare earth export rates and global prices.[58] Although the implementation of China’s export restrictions in 2010 were followed by a price spike in the international rare earth market, prices started falling again – contrary to prevailing expert predictions – before mining firms outside of China such as Molycorp and Australia's Lynas augmented their production.[59] In an interview with the investment platform InvestorIntel.com, the Australian expert on rare earth markets Professor Dudley J. Kingsnorth gave an explanation of this phenomenon. According to him,

[56] Conclusions drawn from the interview with Mr Duncan Freeman
[57] Information received in the interview with Dr Günter Tiess and Dr Horst Hejny
[58] Conclusions drawn from the interview with Mr Duncan Freeman
[59] Els, Frik. (2014). Rare earth prices have turned. Retrieved from http://www.mining.com/rare-earth-prices-at-turning-point-33322/.

China's announcement of rare earth restrictions and the subsequently skyrocketing prices in 2010 and 2011 caused panicked Western businesses to start a huge stockpiling of rare earths (perhaps equivalent to three or four years of consumption), partly by buying large quantities of illegal rare earth materials from China. In 2012, the Chinese MIIT reported an illegal rare earth mining output of over 40,000 tons at the fifth China Baotou Rare Earth Industry Forum.[60] These illegal mining and smuggling activities resulted in a significant oversupply and declining rare earth prices. As a consequence, China has become more proactive in locating and closing down illegal mining sites. In the meantime, the stockpiling of rare earth concentrates has led to lowered global demand for rare earths, as many companies have lived from their oversized inventories in recent years.[61] The imminent depletion of those stockpiles in combination with the lifting of China's export restrictions are key factors of influence which are likely to shape the rare earth prices in the close future. This means that, while the decreasing stockpiles would soon lead to rising demand levels and thus to a tendency towards recovering prices, the WTO ruling would rather suggest a downward trend in prices due to elevated supply levels. In the long term, other factors such as rising global demand levels for ICT and clean technology products, the implementation of laws integrating environmental costs into Chinese rare earth prices as well as the development of alternative rare earth supplies, substitutes and recycling processes will certainly play a crucial role in determining rare earth prices.

In fact, the Chinese rare earth industry has already been affected by the WTO ruling, as this year's profit drop of China's major rare earth producer Inner Mongolia Baotou Steel Rare-Earth Group illustrates. The company's profit saw a decline by more than 70 per cent to 69.38 million yuan (EUR 8.88 million) year on year in the first quarter of 2014, according to a Xinhua article released by MOFCOM.[62] The company's falling profit can partly be attributed to the WTO ruling: according to an executive from Baotou, producers feared a sharp decline in prices as a consequence of the abolition of China's export regulations, further deteriorating the already unstable sector.[63] Since investors were predicting falling prices, they started selling off their company shares, consequentially triggering a self-fulfilling prophecy. Dropping prices resulted in Inner Mongolia Baotou Steel Rare-Earth Group's profit drop which in return caused traded shares to fall by 4.14 percent (to 20.14 yuan per share).[64]

d.) Implications for China's environment

Although Western countries and the WTO consider China's environmental concerns as a "pretext for gaining advantage or increasing economic returns"[65], the environmental argument cannot be completely dismissed, as Duncan Freeman, senior research fellow at the Brussels Institute for Contemporary China Studies stressed. Even if China's industrial policy has played a key role in the country's export restrictions, the importance of China's

[60] China's rare earth industry sees progress, challenges. (2013). Xinhua. Retrieved from http://www.globaltimes.cn/content/802521.shtml.
[61] InvestorIntel. (2013). Professor Dudley Kingsnorth's bullish position on REE markets. Retrieved from http://investorintel.com/rare-earth-intel/professor-dudley-kingsnorths-bullish-positive-position-on-ree-markets/.
[62] MOFCOM. (2014). China's rare earth firm Q1 profit slumps by 70 pct. Retrieved from http://english.mofcom.gov.cn/article/newsrelease/counselorsoffice/westernasiaandafricareport/201404/20140400557267.shtml.
[63] Ibid.
[64] China's rare earth firm Q1 profit slumps 70 pct. (2014). Xinhua News. Retrieved from http://news.xinhuanet.com/english/china/2014-04/16/c_133267764.htm.
[65] Tanquintic-Misa, E. (2013). China's Rare Earths Export Restrictions Defy Rules – WTO. Retrieved from http://au.ibtimes.com/articles/518396/20131031/china-rare-earths-export-wto.htm#.VCVr3vmSx5I.

environmental concerns for shaping the country’s supply equation should not be underestimated.[66]

Despite the substantial comparative advantage China enjoys vis-à-vis other rare-earth producing countries thanks to its lax environmental policies, the Chinese government has lately become increasingly aware of the environmental costs excessive mining has induced. In its first White Paper on rare earth policies in 2012, Beijing confirmed that poorly regulated rare earth mining and the use of outdated technology have caused severe damage to the ecological environment, triggering water loss, soil erosion, acidification and other forms of pollution and environmental degradation.[67] For example, the centre of rare earth mining, Baotou, faces hazardous water pollution, as mines around Baotou generate around 10 million tonnes of highly acid and radioactive wastewater.[68] In particular, increased cancer rates, climaxing in the so-called "cancer villages" along the Yellow River, have led to public protests and stricter environmental standards.[69]

Negative externalities arising from rare earth mining are not yet reflected in China’s rare earth prices[70]. However, the integration of environmental costs is only a matter of time, according to Mr Xie Wei.[71] Once the integration of environmental externalities is included in the price, potential changes to resource taxes and the closing down of illegal mines will certainly render mining more expensive and thus less attractive for investors, the environmental dimension will tend to become a major trigger of change affecting China’s rare earth supply and thus the international rare earth market dynamics.

VI. Europe’s Role in International Rare Earth Market Dynamics

Chapter V has shown that China’s domestic and international mineral policies have dramatically influenced the international market dynamics of rare earths. This chapter aims at discussing Europe’s role in the international rare earth markets, addressing in particular Europe’s potential to enjoy a bigger rare earth production share and higher degree of independence in the future.

Despite all media-hyped pessimism, it is important to bear in mind that China’s rare earth monopoly is only temporary. Europe’s power as a consumer is of course rather limited, as is often the case in monopolistic and demand excess markets. This implies that only changes on the supply side could challenge China’s quasi-monopoly and contribute to a more competitive rare earth market. As a major and growingly important non-Chinese consumer of rare earths, Europe should theoretically have a high incentive to invest in the future of its rare earth supply.

In the mid- to long term, Europe could become more independent from China by taking proactive measures to increase its primary supply and/or to decrease its current demand for rare earth materials. First, Europe could promote and diversify its rare earth supply by

[66] Information received in the interview with Mr Duncan Freeman
[67] Information Service of the State Council of The People’s Republic of China. (2012). Situation and Policies of China’s Rare Earth Industry. Retrieved from http://ycls.miit.gov.cn/n11293472/n11295125/n11299425/n14676844.files/n14675980.pdf.
[68] Massari, Stefania and Ruberti, Marcello. (2013). Rare earth elements as critical raw materials: Focus on international markets and future strategies. Resources Policy 38, 36-43., p. 42
[69] Liu, Lee. (2010). Made in China: Cancer Villages. Environment Magazine. Retrieved from http://www.environmentmagazine.org/Archives/Back%20Issues/March-April%202010/made-in-china-full.html.
[70] Information received in the interview with Mr Xie Wei
[71] Ibid.

investing in rare earth resource exploitation, smelting and separating on European territory or by creating alternative supply chains through strategic cooperation with other countries such as the US, Japan and Australia. Second, Europe could decrease its demand for rare earths by enhancing resource efficiency, increasing the rare earth recycling rate and advancing research on potential substitutes. These strategies shall be examined in the following two subchapters.

a.) Trends in Primary Sourcing and International Collaborations

During the past few years, Europe has initiated projects related to both primary sourcing and international collaborations. There are currently two European rare earth extraction projects which are in an advanced stage, one in Greenland (Kvanefjeld)[72] and one in Sweden (Nora Kärr)[73]. Furthermore various smaller early-stage exploration projects are underway in multiple European countries.[74]

Thanks to Europe's abundant, albeit underexplored, rare earth deposits, the EU could decide to strengthen its position in the rare earth market, and thereby contribute to a more balanced market competition and guarantee European supply security[75]. Although the above mentioned mining projects in Northern Europe are the result of extensive geological, hydrometallurgical and environmental R&D, and although their mining potential is considered as very promising, there are still several key obstacles to Europe's primary rare earth supply. One of the biggest challenges is posed by the high uranium and thorium concentrations in these deposits. In addition to radioactivity-related problems, the EU has currently insufficient processing and separation capacities. As there are no markets for mixed rare earth element concentrates, mining companies would either have to build their own capital-intensive and technically complex separation plants or cooperate with existing facilities.[76] So far there are, however, only three rare earth separation and processing companies in Europe: Rhodia Electronics and Catalysts (France), Treibacher Industrie AG (Austria) and AS Silmet (Estonia).[77]

With adequate funding and the required permissions, European mining companies could start extracting rare earth concentrates before 2020.[78] It would, however, take investments totalling at least five to six billion EUR in order to effectively revive rare earth mining in Europe.[79] While being very committed on a political level and supporting research on better mining practices, the EU does not provide the financial resources to restart the European mining sector.[80] Therefore, finance of such investments remains another unresolved challenge; the question is: who would agree to finance the construction of new rare earth mining and processing sites against the background of the high degree of uncertainty and volatility of the rare earth market? Demand is hardly predictable and prices are unstable.[81] Besides, investments in upstream activities are always riskier for European companies than for Chinese companies due to their smaller size and the fact that they are not state-backed.

[72] Greenland Minerals and Energy Ltd. (2014). Rare Earth Elements in Kvanefjeld. Retrieved from http://www.ggg.gl/rare-earth-elements/rare-earth-elements-at-kvanefjeld/.
[73] Tasman Metals Ltd. (2014). Norra Kärr Rare Element Project. Retrieved from http://www.tasmanmetals.com/s/Norra-Karr.asp.
[74] ERECON. (2014). Working Group I: Opportunities and road blocks for primary supply of rare earths in Europe. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/erecon/expertise/working-group-1_en.htm.
[75] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[76] Ibid.
[77] Cf. Massari, Stefania and Ruberti, Marcello. (2013). Rare earth elements as critical raw materials: Focus on international markets and future strategies. Resources Policy 38, 36-43.
[78] Ibid.
[79] Information received in the interview with Prof. Dr. Arnold Tukker
[80] Ibid.
[81] Conclusions drawn from the interview with Prof. Dr. Arnold Tukker

As discussed in chapter II, China enjoys a wide range of comparative advantages over Western countries in regards to rare earth mining.

The Kvanefjeld project in Southern Greenland required a capital investment of USD 810 million and the Swedish Norra Kärr incurred costs amounting to USD 290 million, both not yet including rare earth separation plants.[82] Paradoxically, China has become involved in Kvanefjeld, a project aiming at promoting Europe's internal mining potential and decreasing the continent's dependence on external sources. In March 2014, Greenland Minerals signed a Memorandum of Understanding with China's Non-Ferrous Metal Industry's Foreign Engineering and Construction Co. Ltd. (NFC) regarding possible separation of the rare earth concentrates.[83] From a business perspective, a strategic cooperation agreement with NFC, global leader in rare earth separation technologies, could bring about various industrial advantages. In particular, benefits could arise from Chinese financial investments, technical cooperation and possible knowledge transfers. However, from a security perspective, the collaboration is questionable, as it could be seen as a move towards a new form of dependence on China and therefore as counterproductive for Europe's supply diversification goals.[84] A business partnership with NFC could potentially pave the way for future involvement of China in Europe's rare earth projects, helping China to gain even more power in the field of rare earth separation instead of challenging its quasi-monopolistic status quo. And yet, cooperation with China should not be dismissed altogether, as Europe could benefit from knowledge and technology exchanges as well as joint venture investments with the Chinese.

In the meantime, Europe has rather been leaning towards the developed world for possible collaborations: there are initiatives of enhancing cooperation between the EU, Japan, the US, and potentially also Australia and Canada. This could span from pure research cooperation to the joint creation of an alternative supply chain. Since October 2011[85], four US-Japan-EU trilateral workshops on Critical Raw Materials have been organised by the European Commission (EC), the US Department of Energy (DOE), Japan's Ministry of Economy, Trade and Industry (METI) and the Japanese New Energy and Industrial Technology Development Organization (NEDO) in order to jointly address shortage problems associated to rare earths and other critical materials. Participants suggested cooperation on research-related and technological matters including geological mapping, environmental-friendly extraction, separation technologies, recycling along the entire value-chain including eco-design, end-of-life management, urban mining, rare earth substitutes, etc.[86]

These cooperation efforts between developed countries convey the image of a competition for rare earths between China and the West. By teaming up with the US, Japan, Australia and Canada and thereby marginalising and isolating China, Europe could miss out on potentially beneficial opportunities for cooperation with China. The Chinese White Paper on

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[82] ERECON. (2014). Working Group I: Opportunities and road blocks for primary supply of rare earths in Europe. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/erecon/expertise/working-group-1_en.htm.
[83] Reuters. (2014). Greenland Minerals Signs Memorandum of Understanding with China's NFC, to form Fully-Integrated Global Rare Earth Supply Chain. Retrieved from http://uk.reuters.com/article/2014/03/24/idUKnMKWYY46va+1f0+MKW20140324.
[84] Conclusions drawn from the interview with Mr Duncan Freeman
[85] Trilateral EU-Japan-US Conference on Critical Materials for a Clean Energy Future. (2011). Summary Report. Retrieved from http://energy.gov/sites/prod/files/2013/05/f0/TRILATERAL_CRITICAL_MATERIALS_WORKSHOP_SummaryReportfinal%2020111129.pdf.
[86] Conclusions of the Third EU-US-JP Conference on Critical Minerals. (2013). Retrieved from http://ec.europa.eu/research/industrial_technologies/pdf/trilateral-conclusions_en.pdf. p. 2-3

rare earths[87] states that China is committed to technology and knowledge exchange with industry experts from the US, the EU, Russia, Japan and other countries. Of course, the fact that China benefits from its powerful position in the rare earth market and therefore only has very limited incentives for cooperation with Europe[88] should not be dismissed in the debate. However, the EU could seek to enhance mutual trust on the rare earths issue and establish reciprocally beneficial forms of cooperation with China. Potential areas of cooperation reach from knowledge and technology transfers to shared initiatives in rare earth rich regions across Europe, China or elsewhere. The following table shows potential advantages of a bilateral cooperation on rare earth development for both the EU and China.

Advantages EU	Advantages China
Chinese investments could help to revive the EU's dormant rare earth mining sector and solve the question of financing rare earth projects	Chinese collaboration with the EU and investments in Europe's rare earth development could create good returns in the long term without further increasing its environmental burden
Knowledge transfer from China on cutting edge mining technology could enhance the EU's mining capacities and competence	Knowledge transfer from the EU on sustainable mining and environmental-friendly technology transfers could help China to make its own rare earth industry more sustainable
Joint development of mining potential in remote areas of Greenland or other countries could decrease the EU's supply security risks	By participating in projects abroad and assisting other countries in developing their mining potential in the role of an advisor China could make use of its competitive advantage

b.) *Recycling, Substitutes and Emerging Alternatives in Europe*

According to the European Rare Earths Competency Network (ERECON), the EU's goal is to achieve a higher degree of independence not only through enhancing primary supply but also through decreasing the demand for rare earths. European countries have therefore intensified their efforts to find solutions for more efficient use, end-of-life recycling or re-using of rare earths as well as potential substitutes.[89]

The past few years have brought about significant innovations in Europe's mining and refining sector and in the field of nanotechnology which could help to recycle, re-use and replace rare earths from electronic products in the mid- to long term. For example, developments such as the shift from tri-phosphor lightening to light-emitting diodes (LED) have led to lower use of yttrium, europium and terbium, all of which fall under the category of heavy rare earths. The use of heavy rare earths per unit was also substantially reduced in permanent Neodymium (NdFeB) magnets.[90] Furthermore researchers at Northeastern University have developed strong magnetic material in 2012 which does not require the use

[87] Information Service of the State Council of The People's Republic of China. (2012). Situation and Policies of China's Rare Earth Industry. Retrieved from http://ycls.miit.gov.cn/n11293472/n11295125/n11299425/n14676844.files/n14675980.pdf.
[88] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[89] ERECON. (2014). Working Group II: European rare earths resource efficiency and recycling. Retrieved from http://ec.europa.eu/enterprise/policies/raw-materials/erecon/expertise/working-group-2_en.htm.
[90] Sims, Jim. (2014). EIAS Briefing Seminar Europe's Rare Earth Dependence on China: Future Perspectives. Retrieved from http://eias.org/sites/default/files/EIAS_Presentation_Sims_updated_14.10.2014.pdf.

of rare earths.[91] And yet, although rare earth substitutes are available for many products, they still tend to be less effective. [92] For example, common electromagnets are used to replace permanent rare earth magnet for induction motors but they are significantly larger and heavier.

Likewise, rare earth recycling is still in a very early stage. At present, recycling rates and alloys from end-of-life products tend to be very low (less than 1 per cent), mainly as a result of technical and economic hindrances.[93] Currently there are recycling processes for phosphors, permanent NdFeB magnets, industrial residues, nickel metal hydride batteries and various other rare earth containing products.[94] And yet, so far only phosphors and batteries can be recycled on an industrial scale. Theoretically, the recycling market for rare earths in Europe has great potential, as the EU is a significant consumer of rare earth containing products. However, an integrated recycling process would require a detailed market analysis of EU's rare earth consumption, taking into account historical as well as predicted future sales. As there is, however, only limited data on the consumption of products which contain rare earth materials (especially in regards to rare earth magnets), market analyses are currently not available for the EU.[95]

According to an expert on recycling from the private sector, who wanted to remain anonymous, the biggest challenge for recycling rare earth elements is still posed by collection. Rare earth elements are usually dispersed everywhere in little units. For example, the magnets used in cell phone speakers only contain very small quantities of rare earths; this naturally renders collection logistics very difficult and often not economically viable.[96] Despite these challenges, companies such as Umicore (Belgium)[97], Saubermacher (Austria)[98] and others have initiated projects for the recycling of electronic devices such as phones and laptops.

An advanced rare earth recycling system would not only provide the EU with advantages related to a higher supply security but also with lower environmental burdens compared to primary production, cheaper sources of material and less radioactive waste.[99] Strategies and methods for recycling (urban mining) are therefore explored both at the EU level and at a private company level. In 2011, the EU-Japan Science and Technology Agreement entered into force and paved the way for intensive research collaboration on rare earths. In 2013, 320 research teams participated in projects with the aim of finding rare earth substitutes funded jointly by the EU and Japan.[100]

An example for innovative projects in the private sector is Umicore's and Rhodia's (now Solvay) joint development of a recycling process for rechargeable batteries. The process

[91] Wells, Steve. (2013). Emerging Alternatives to Rare Earth Elements. Futurium. European Commission. Retrieved from https://ec.europa.eu/digital-agenda/futurium/en/node/1637.
[92] US Geological Survey. (2014). Mineral Commodity Summaries. Rare Earths. Retrieved from http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/mcs-2014-raree.pdf.
[93] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[94] Binnemans, K., Jones, P. et al. (2013). Recycling of rare earths: a critical review. Elsevier Journal of Cleaner Production. Retrieved from http://www.kuleuven.rare3.eu/papers/JCLEPRO_Binnemans_REE_Recycling_May2013.pdf.
[95] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[96] Information received in an interview with an expert on rare earths recycling from the private sector
[97] Umicore. (2014). Rechargeable Batteries (storing energy). Retrieved from http://www.umicore.com/en/cleanTechnologies/batteries/.
[98] Saubermacher. (2014). Leistungen: Entsorgungslösungen. Retrieved from http://www.saubermacher.at/de/leistungen/#elektroaltgeraeteentsorgung.
[99] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[100] Rhode, Barbara. (2013). The EU-Japan Science, Research and Innovation coopearation under the EU-Japan S&T Agreement. Retrieved from http://www.concertjapan.eu/system/files/TheEU-JapanScienceResearchInnovationCooperation_EUDelegationJapan%20%5BUyumluluk%20Modu%5D.pdf.

allows for the recovery of rare earths from Nickel Metal Hydride (NiMH) rechargeable batteries.[101] Umicore first separates the nickel and iron from the rare earths and processes them into high grade concentrate at its new battery recycling plant in Antwerp (Hoboken). The rare earth concentrate is then refined and transformed into rare earth materials at Rhodia's plant in La Rochelle. According to Sybolt Brouwer, General Manager of the Battery Recycling and Recycling Development at Umicore, "this is the first industrial process that closes the loop of the rare earths contained in NiMH batteries." The recycling process can be applied to different kinds of NiMH batteries, ranging from portable applications of rechargeable AA and AAA batteries used in cordless phones, toys and games to batteries used in hybrid electric vehicles.[102]

Despite all these improvements, recycling can currently only contribute a small part to a coherent raw materials policy.[103] A circular economy for rare earths is not possible at this point, as the demand for rare earth elements applications is still growing and new materials have to enter the economy. This means that recycling can only happen up to a certain level (about 25-30 per cent) due to the discrepancy between the materials needed and the materials which can currently be recycled.[104] It can be concluded that although there is still potential for more innovations in the area of rare earth substitutes and recycling, primary domestic production or external sourcing will be needed to meet the growing demand for rare earth products in the European economy.

VII. Future Predictions and Scenario Analysis

Most future market predictions for the annual growth of rare earth consumption range from 5 to 9 per cent over the next 25 years. [105] In total figures this would mean a worldwide rare earth demand amounting to 160,000-208,000 metric tons by 2020. However, estimations made in a research report on the future of China's rare earth industry are far less optimistic, with rare earth demand predictions of 0.3 million metric tons for 2020[106], hence exceeding estimated production rates for 2020 (210,000 metric tons) by far.[107]

Figure 4 takes into account these divergent future estimations by illustrating different scenarios. While the best case scenario of global demand shows the lower end of expert predictions, the worst case scenario shows the very upper end of expert estimations. The chart displays that in the best case demand scenario the expected global production for the years to come would be sufficiently high, while the worst case scenario raises concern about a potential inequality between the growth of demand and the growth of production. Still, even the best case scenario does not necessarily mean that the demand for every rare

[101] Rhodia, Solvay Group. (2011). Umicore and Rhodia develop unique rare earth recycling process for rechargeable batteries. Retrieved from
http://www.rhodia.com/en/news_center/news_releases/Umicore_rare_earth_160611.tcm.
[102] Rhodia, Solvay Group. (2011). Umicore and Rhodia develop unique rare earth recycling process for rechargeable batteries. Retrieved from
http://www.rhodia.com/en/news_center/news_releases/Umicore_rare_earth_160611.tcm.
[103] Information received in the interview with Dr. Günter Tiess and Dr. Horst Hejny
[104] Information received in an interview with an expert on rare earths recycling from the private sector
[105] Alonso, E., Sherman, A. et al. (2012). Evaluating rare earth element availability: A case with revolutionary demand from clean technologies. Environmental science and technology, 46, 3406-3414. Retrieved from http://pubs.acs.org/doi/pdf/10.1021/es203518d.
[106] Research Report on Rare Earth (RE) Industry in China, 2014-2019. (2014). China Research and Intelligence. Retrieved from http://www.rnrmarketresearch.com/research-report-on-rare-earth-re-industry-in-china-2014-2018-market-report.html.
[107] Rare earth production in China and outside. (2014). Statista.com. Retrieved from http://www.statista.com/statistics/279953/rare-earth-production-in-china-and-outside/.

earth element can be met, as this chart only shows the aggregate rare earth demand and supply. Especially, demand for neodymium and dysprosium is expected to soon exceed global supply[108], potentially resulting in price instabilities for high tech and clean technology products dependant on these materials.

It is important to note that demand for individual rare earth elements does not grow at equal pace. Instead, the growth for each rare earth element is usually in accordance with the growth in markets for the respective derivative products. Nonetheless, supply increases or decreases for certain rare earth elements often translate directly into supply increases or decreases for other rare earth elements as a result of co-mining.[109]

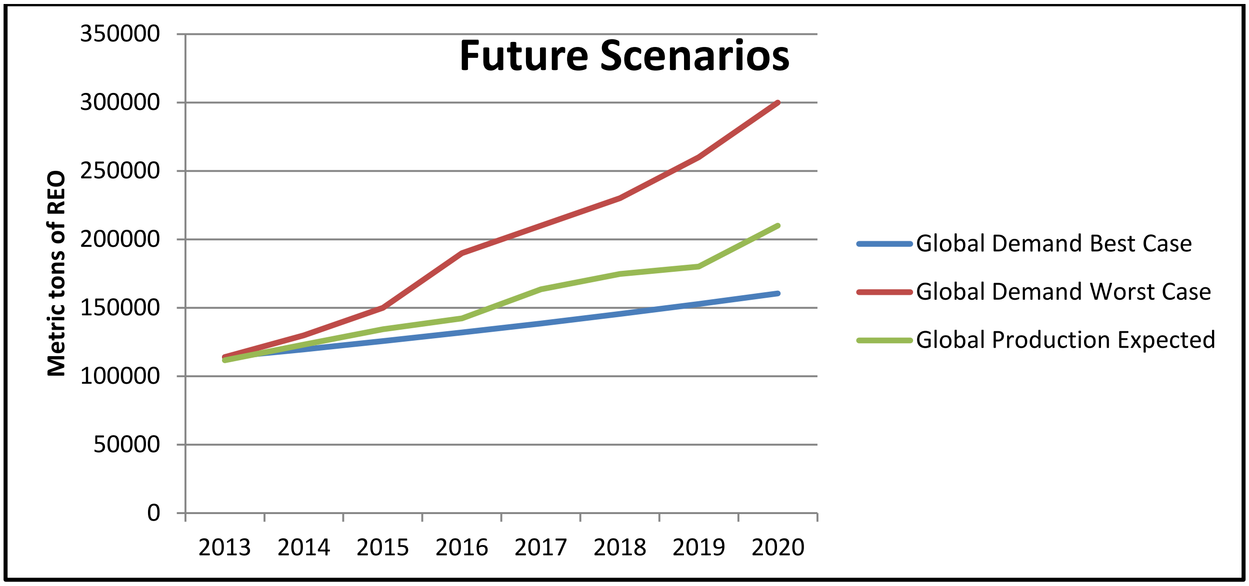

Figure 4: Future Scenarios of Rare Earth Supply and Demand 2013-2020, author's compilation of Alonso et al., Statista.com and China Research and Intelligence

As discussed in chapter V, China's targets to promote sustainability and better environmental standards in its mining sector could lift production costs and ultimately result in a general surge of rare earth prices. In addition to that, Chinese heavy rare earth reserves are expected to be depleted in about two decades. [110] Although rare earth production outside of China will most probably increase during the next few years (mainly due to the reopening of the US' Mountain Pass mine and Australia's Mount Weld mine), heavy rare earths can only be mined in very small quantities. At both Mountain Pass and Mount Weld, the light rare earths Cerium, Lanthanum, Neodymium and Praseodymium account for at least 95 per cent of the extracted materials. Once launched, the Kvanefjeld site in Greenland could become an important future source of heavy rare earth production: about 12 per cent of its rare earth deposits consist of heavy rare earth elements.[111] New sources for primary supply, albeit promising, might not be enough to avoid shortages and high costs in the rare earth market. Additional measures aiming at decreasing the demand for rare earths and in particular heavy rare earth elements should be taken proactively. The

[108] Wells, Steve. (2013). Emerging Alternatives to Rare Earth Elements. Futurium. European Commission. Retrieved from https://ec.europa.eu/digital-agenda/futurium/en/node/1637.
[109] Alonso, E., Sherman, A. et al. (2012). Evaluating rare earth element availability: A case with revolutionary demand from clean technologies. Environmental science and technology, 46, 3406-3414. Retrieved from http://pubs.acs.org/doi/pdf/10.1021/es203518d.
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[111] UNCTAD. (2014). Commodities at a Glance. Special issue on rare earths. Retrieved from http://unctad.org/en/PublicationsLibrary/suc2014d1_en.pdf. p.36

costs of insufficient supply of heavy rare earth elements such as dysprosium were already demonstrated in the price spikes between 2006 and 2011.[112]

According to British trend analyst Steve Wells, it is not unlikely that rare-earth dependent industries will see an increase in innovations for rare earth substitutes during the next decades. Restrictions in the supply chain can be a possible trigger for innovation and thus an accelerator for the supply of alternative technologies, approaches or materials.[113] The innovation concept of S-curves, as shown in Figure 5, suggests four possible patterns for technology transitions, depending on whether radical or incremental innovations occur and on whether there is a fluent or a disruptive transition. This concept used in innovation studies is particularly interesting when looking at current and potential future trends in the field of rare earths.

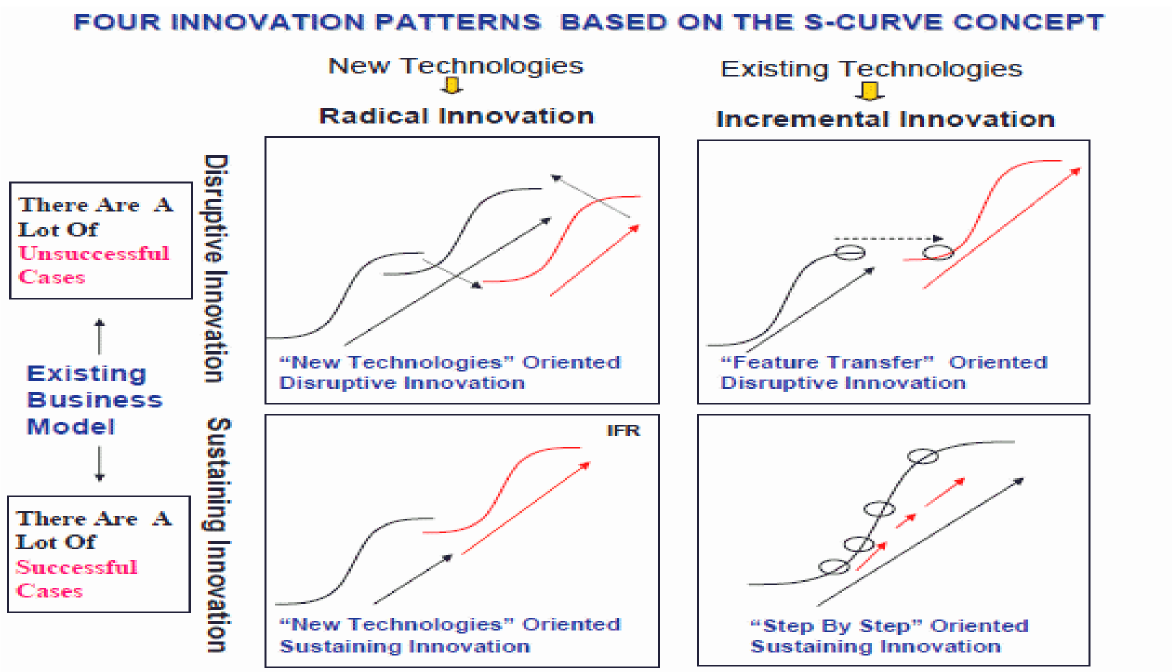

Figure 5: Innovation Patterns, ETRIA

At the current stage it seems that all transitions are still possible in the rare earth market, though the consequences would potentially differ greatly: while sustaining innovation would tend to have positive effects on the rare earth market dynamics in both the case of radical or incremental innovation, any disruptive form of technology transition could have fatal consequences on rare earth supply security and global rare earth prices. It would imply that the markets for rare-earth dependant products would see a stagnation before production could be resumed thanks to radical or incremental innovations in reaction to such an acute rare earth crisis. Whereas incremental innovations would build on the enhancement of existing alternatives, radical innovation would provide the clean technology and high tech sector with completely unprecedented solutions. This second case could mean that China would almost instantly lose its powerful status as a quasi-monopolistic provider of rare earth elements.

[112] Moss, R., Tzimas, E. et al. (2011). Critical metals in strategic energy technologies. JRC scientific and technical reports. Retrieved from http://setis.ec.europa.eu/newsroom-items-folder/jrc-report-on-criticalmetals-in-strategic-energy-technologies/at_download/Document.
[113] Information received in the interview with Steve Wells

VIII. Conclusions and Recommendations

Like in any market, the future of the rare earth market depends mainly on the changes of its supply and demand side. The previous chapters have examined recent trends on both sides of the market and will therefore serve as a basis for the conclusions drawn in this scenario analysis. The following scenario analysis (Figure 6) explains the four possible combinations of supply and demand developments in the rare earth market and attempts to draw conclusions for each scenario.

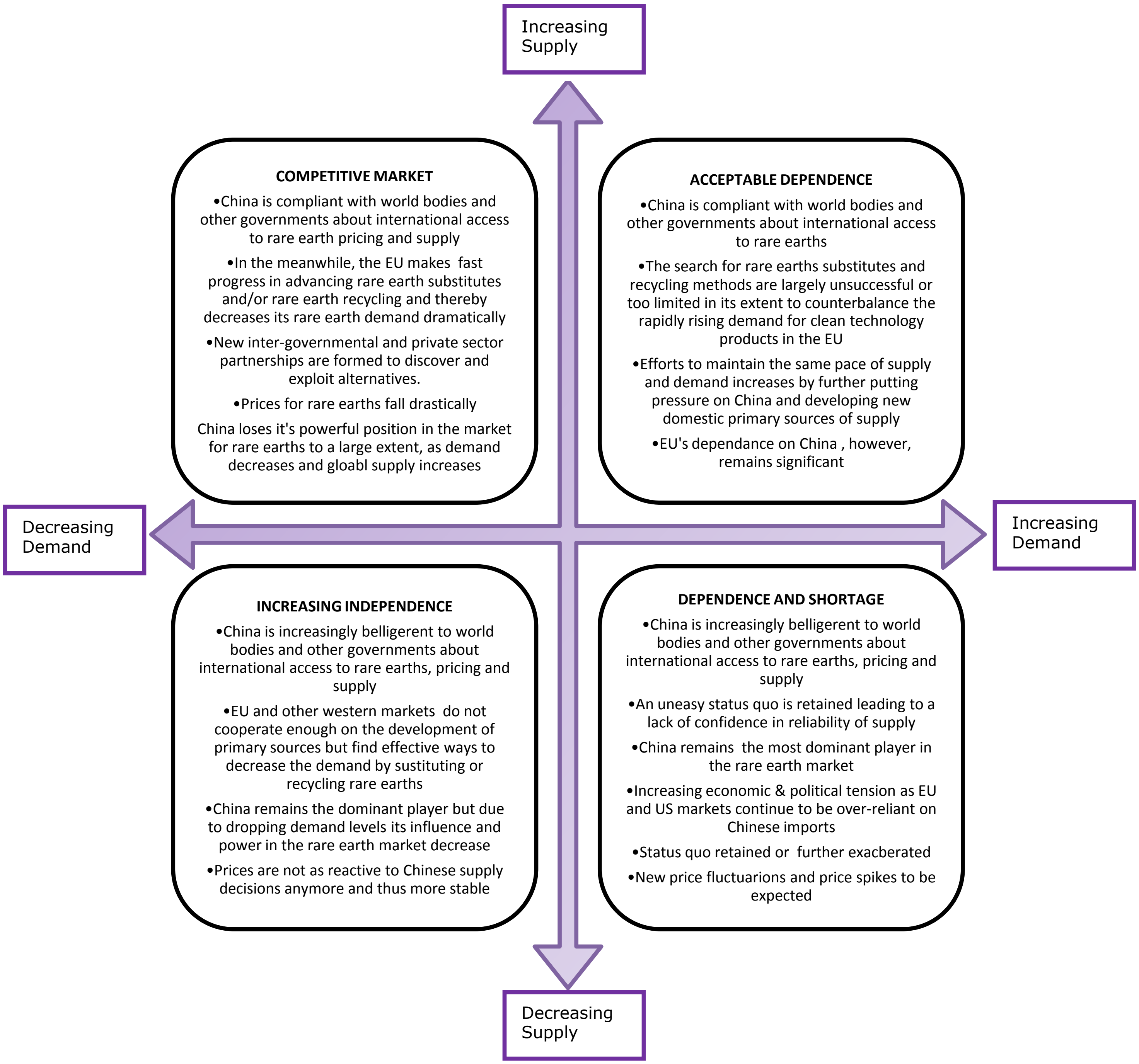

Figure 6: Scenario Analysis, author's compilation

To conclude, Europe is confronted with an increasingly delicate situation regarding its mid- to long-term rare earth supply security mainly as a result of rising global and domestic demand levels for rare earths. In particular, Europe's clean technology sector is at stake due to global shortages of heavy rare earth elements, sensitivity of the rare earth market and limited availability of sustainable substitutes and effective recycling methods. Although the recent WTO ruling against China will certainly decrease current pressure on the international rare earth market, Chinese heavy rare earths could be depleted within the next two decades. Therefore relying further on China's rare earth supply (even against the background of the WTO decision in favour of Europe, the US and Japan) cannot be a sustainable strategy. This makes it necessary for the EU to take measures on an EU level but also on an international level in order to secure its future access to rare earth materials.

On an EU level, it seems important that Europe seeks to create a consolidated mineral policy and integrates its rare earth policies into a broader resources strategy. It should furthermore make better use of existing expertise across the fields of research, politics and business by interlinking sectorial findings. In order to avoid shortages and hefty price fluctuations, investments in new rare earth deposits should be coupled with the development of more effective substitutes and recycling processes. Finding sustainable substitutes for rare earths, creating higher resource efficiency and increasing recycling rates could help to decrease Europe's strongly rising demand for rare earths.

On an international level, European cooperation with other countries and diversification of supply can provide solutions for the threat of sudden supply shortages or price spikes. Although Europe is currently upgrading its cooperation with Australia, US, Japan and Canada to jointly develop an alternative supply chain, it should also seek to enhance Sino-European cooperation on the development of new rare earth sources. Building an anti-China block with the US, Japan and Australia could make China even less cooperative, while building mutual trust, establishing knowledge and technology transfers and initiating joint rare earth projects could help Europe to gain funding and expertise for the development of its rare earth sources. For example, the EU should seek to encourage the formation of Sino-European joint ventures and provide China with adequate incentives to further increase its investments in Europe's re-emerging rare earths sector. As shown in chapter VI, Sino-European cooperation could result in mutually beneficial agreements for rare earth mining, processing and separation operations.

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XI. List of Interviewees

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Coraline Goron, PhD Candidate at Erasmus Mundus GEM PhD School, focusing on Chinese environmental policies

Duncan Freeman, Senior Research Fellow at Brussels Institute of Contemporary China Studies, speaker at the Conference "EU-China Economic Trade Relations: Cooperation or Competition for Raw Materials" in 2012

Xie Wei, Second General at the Economic & Commercial Counsellor's Office of the Mission of China to the European Union

Steve Wells, working at Fast Future/Informing Choices Ltd, Futurium of the European Commission

Anonymous expert on rare earths recycling of a leading private sector materials technology group

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