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China's Rare-Earth Elements Policy and its Implications for Germany, Japan and the USA

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Abstract

While the depletion of oil reserves and our dependence on oil have been already discussed for several years, regarding resource security and climate change, for first time in the last two years the dependence on the so called rare earth elements was brought to the public. Rare earths are essential foundation for the development of many high-tech products such as wind turbines, mobile phones and batteries for electric vehicles.

China's decision to reduce the export quotas for rare earths, allowed not only the prices for these elements to rise, but also showed to what extend the industrialized countries are dependent on China as a quasi-monopoly supplier of rare earths.

In the present UfU study will be analyzed from a political point of view China's rare earth policy and its implications on the three high-tech countries, Germany, Japan and the United States.

The study shows how China has used its power over the rare earths in order to build a world-dominant monopoly position, and this position is now targeted as a "political weapon" used to resolve conflicts in other areas. In addition, it is illustrated through what medium Germany, Japan and the United States have to reduce their dependence on China in order to achieve secure and safe access to rare earths. The study highlights resource availability, policies and research projects of the individual states. Further, it questions the sustainability of the "green" high-tech products, given the fact that in the exploitation of the rare earth elements immense amounts of waste are released, such as radioactive elements and toxic solutions, resulting in excessive environmental burden.

Abstract

Während die Verknappung der Erdölreserven und unsere Abhängigkeit vom Öl bereits seit mehreren Jahren in Zusammenhang mit Ressourcensicherheit und Klimawandel diskutiert werden, ist die Abhängigkeit von sogenannten seltenen Erden erst in den letzten beiden Jahren in das Bewusstsein der breiteren Öffentlichkeit gelangt. Seltene Erden sind die entscheidende Grundlage für die Entwicklung vieler High-Tech-Produkte wie Windräder, Mobiltelefone oder Batterien für Elektrofahrzeuge.

Chinas Entscheidung, die Exportquoten für seltene Erden weiter zu senken, ließ nicht nur die Preise für diese Rohstoffe steigen, sondern zeigte den Industriestaaten, wie abhängig sie von China als quasi Monopolanbieter für seltene Erden sind.

In der vorliegenden UfU-Studie werden aus politikwissenschaftlicher Sicht Chinas Seltene-Erden-Politik und ihre Auswirkungen auf die drei Hightech-Länder Deutschland, Japan und die USA analysiert.

Die Studie zeigt, wie China seinen Reichtum an seltenen Erden genutzt hat, um eine weltbeherrschende Monopolstellung aufzubauen und diese Stellung nun gezielt auch als „politische Waffe“ einsetzt, um Konflikte auf anderen Gebieten zu lösen. Darüber hinaus wird herausgearbeitet, welche Wege Deutschland, Japan und die USA gehen, um ihre Abhängigkeit von China zu reduzieren und einen sicheren Zugang zu seltenen Erden zu erlangen. Es werden Ressourcenverfügbarkeit, Politikstrategien oder Forschungsvorhaben der einzelnen Staaten beleuchtet und gefragt wie nachhaltig „grüne“ High-Tech-Produkte sein können, wenn der Abbau seltener Erden große ökologische Probleme hervorruft.

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List of Abbreviations

ARPA – Advanced Research Project Agency

BGR – Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)

BMBF – Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)

BMWi – Bundesministeriums für Wirtschaft und Technologie (German Federal Ministry of Economics and Technology)

CO_2 – Carbon Dioxide

DOD – Department of Defense

EEZ – Exclusive Economic Zone

EPA – Environmental Protection Agency

EU – European Union

FCC – Fluid Catalytic Cracking

FOREGS – Forum of the European Geological Surveys

GO – Governmental Organization

GTF – Geological Survey of Finland

IUPAC – International Union of Pure and Applied Chemistry

JV – Joint Ventures

NGO – Non-Governmental Organization

R&D – Research and Development

RE – Rare Earth

REACT – Rare Earth Alternatives in Critical Technologies

REE – Rare Earth Element

REM – Rare Earth Metal

REO – Rare Earth Oxide

UNEP – United Nations Environmental Programme

US – United States

USA – United States of America

USGS – United States Geological Survey

WST – World System Theory

WTO – World Trade Organization

WWF – World Wildlife Fund

Chapter 1

1. Introduction

On September 7, 2010 at approximately 10:15 a.m., a Chinese fishing boat collided with a Japanese patrol boat in waters near the Senkaku Islands, which are located in the East Chinese Sea between Okinawa and Taiwan (BBC News 2010). These islands are known to be claimed sovereignty by Japan, China and Taiwan, and they are currently controlled by Japan. Before 1970, China and Taiwan did not show any interest in the Senkaku Islands. After the mid 1970s and shortly after it was announced that possible petroleum resources could be exploited on the continental shelf of the Eastern China Sea, the question to whom these islands actually belong arose (MOFA 2012). Since then, the Senkaku Islands turned to be the “Golden Apple of Discord” between Japan and China.

The Japanese affirmed that the Chinese boat was fishing in Japanese waters and did not want to stop on a given signal from the Japanese patrol boat. As a consequence, the Chinese vessel crashed into the Japanese vessel. The Chinese captain of the fishing boat was arrested by the Japanese and taken to Japan to be judged. This action generated further problems between the Chinese and Japanese diplomacy, and the disputed Senkaku Islands. The Chinese government got disturbed and decided to block exports of rare earths to Japan if the Japanese government did not decide to release the Chinese captain. As a result, the Japanese authority released the Chinese captain on September 24, 2010. The rest of the world suddenly realized how dependent it is on the Chinese rare earth elements.

1.1. Problem Definition

At the moment, China produces 97 percent of the world’s rare earths and has about 48 percent of the world’s exploitable resources (Levkowitz et al. 2010). As a part of this, China is the largest worldwide producer of green energy technologies, such as solar panels, and is preparing to become the world largest producer for wind turbines (Bradsher 2010). For a decade, China has the total control on rare earths supply, after the second major producer of rare earths USA closed the Mountain Pass mine in the Mojave Desert, California, in 2002. It was not thought of different alternatives, as the prices of rare earths from China were very low, which did not stimulate the industry to invest in research for substitutes or recycling, and opening of new mines for rare earths extraction; in this way gave the opportunity to China to have the monopoly over these valuable metals.

Since 2006, China has started to tighten the export quotas on the rare earth elements (REE). This followed with a release of a white paper in 2009, or the so called “Five-Year Development Plan 2010-2015”, from the China’s Ministry of Industry and Information Technology, proposing a severe minimization and even stopping of the REM exportation. In 2010, the export quotas were 40 percent below the export quotas for 2009, and for the second half of 2010 the quotas felt to below 72 percent. From January to June 2011, are to be sold around 14,500 tones to the external market or 31 companies while in 2010, for the same period were sold around 16,300 to 22 companies (IBTimes 2011).

According to an article of the BBC News online, the “motives” of China to reduce the exports of these materials are evident: “they want Western users to do their manufacturing in China and they need supplies for their own ambitious wind energy program” (Heap 2010). The control over rare earth exports shows that China affirms its political and economical power in the world, which after the “fishing boat incident” is more than obvious.

China does not want to be a raw material supplier anymore, but the country wants to manufacture goods and is open to countries which want to buy these goods containing rare earths, without opposing any quotas on the exports. The problem is that the countries USA, Germany and Japan want to buy the raw material and not the final good, as they do not want to move their production to China. For this reason, there is an emerging disagreement between the four countries that is more political than trade issue.

1.2. Objectives of the Research

In this thesis a sociopolitical research will be performed to investigate, how the monopoly of China on the rare earths production and their high export quotas, affected the high-tech countries, in this case the USA, Germany and Japan. The reasons, why China has decided to minimize its export on rare earths, will be discussed, as well as their strategy on rare earths for the future. Then it will be looked on the affected parties, which own green-tech, high-tech and military-tech industries and depend on the rare earths import from China. Three countries will be studied the USA, Germany and Japan, as they are one of the most dependent on rare earths. For every country a research will be performed in particular, and seen how they are doing to become their independence on rare earths from China, and how this current process is affecting their economy and industries.

1.3. Research Questions

On the one hand, the shortage on rare earths is already producing a sharp increase in the rare earths prices. On the other hand, the world high-tech leader industries are facing already difficulty to satisfy their needs on rare earths for the production on high-tech, military-tech and green products. There are three parts of questions which this thesis will answer. The first part of questions is:

a) What are rare earths, and why are they so important to our modern society? Are there enough exploitable resources and is it possible the recycling of these materials for their further use? Is China the only country rich in RE resources?

   To answer these questions internet and literature research will be performed.

The other two parts of questions are concerning the Chinese policy and economy on rare earths on one hand, and on the other hand the affected countries in this case the USA, Germany and Japan. The second part of questions to be answered is:

b) Why China after almost 50 years of mining and production of rare earths suddenly decides to minimize and almost freeze the exportation of rare earths? Why China decided on protectionist policy, and what its economy is going to gain or lose? Was that a strategy to gain control over the rare earth market, and in this way can it control the "green" and high-tech market?

To answer this question a research will be performed looking into national policy acts, internet journals, and using specialized literature on Chinese policy and national development.

The third part of questions to be answered is:

c) What is the reaction of the three biggest high-tech industrialized countries against the shortage on rare earths provoked from China? Why the rare earths are so important to them? Are they looking for new alternatives, do they create controversial polices towards China, and how this entire situation is influencing their own economies? Aren't these three high-tech countries afraid to lose their monopoly on high-tech products in the world by letting China into the business?

To answer these questions a research will be performed mainly on internet journals and articles about latest information on the topic and national policy acts.

To sum up, in the research different sources of information will be used for different parts of the thesis. To get better understanding of the field, information is searched in online newspapers, websites of governmental and nongovernmental institutions, websites of companies, such as mining and manufactures using rare earths, online encyclopedias, and blogs written by experts.

When these questions are researched, discussed and answered, a better understanding can be obtained concerning China's decision on high quotas for rare earths. Further, it can be seen to what improvements, plans and policies the three developed countries have come in order to try to minimize the negative impacts of China's rare earths policy on their economies, and what are the socioeconomic positive or negative impacts in this process.

1.4. Structure of the Thesis

This thesis is a basic research that presents three main parts of questions which throughout the research will be answered. In brief, here will be discussed how the decision of China on minimizing exports on rare earths is affecting the high-tech countries the USA, Germany and Japan, and what solutions are they seeking to overcome the rare earths shortages.

The thesis will consist of five main parts. The first part is the introduction. The second part presents all information concerning REEs. The third part describes the position of China on the rare earth market, the reasons because of which China is increasing the quotas on REMs and the possible consequences of this behavior will be discussed. The forth part includes the response from Germany, the USA and Japan to the Chinese rare earth monopoly. These data is analyzed in order to understand if there is a potential concern for their high-tech, military and green industries, in the mentioned countries above, or other potential solutions are found to minimize their dependency on China for rare earths. The last part discusses the actual state of the problem and the proposed responses.

The main research data is gathered online and through books, most of them published online. Three international online newspapers have been used for the basis of the research. New York Times for USA, the Frankfurter Allgemeine Zeitung for Germany, and the Japan Times Online for Japan, as well as Google alerts with the key words “rare earths” and “seltene Erden”. Online blogs of experts on the rare earth topic are also in the basis of the research as the main blog used is Rare Metal Blog.

Chapter 2

2. Importance of REEs for the High-Tech Countries

2.1. What are the Rare Earth Elements?

The rare earths, rare earth metals (REM) or rare earth elements (REE) are seventeen chemical elements, as defined by IUPAC (International Union of Pure and Applied Chemistry), including the fifteen lanthanides elements plus scandium (Sc) and yttrium (Y) from the periodic table (Fig. 1). In 1787, the first mineral was discovered and extracted from a mine near the village Ytterby in Sweden by Lieutenant Carl Axel Arrhenius. The exceptionally heavy peace of black rock was called “Ytterbite” and was sent to various experts to analyze it. After more than a century, finally the REEs were separated from the original oxides (Wikipedia 2011a).

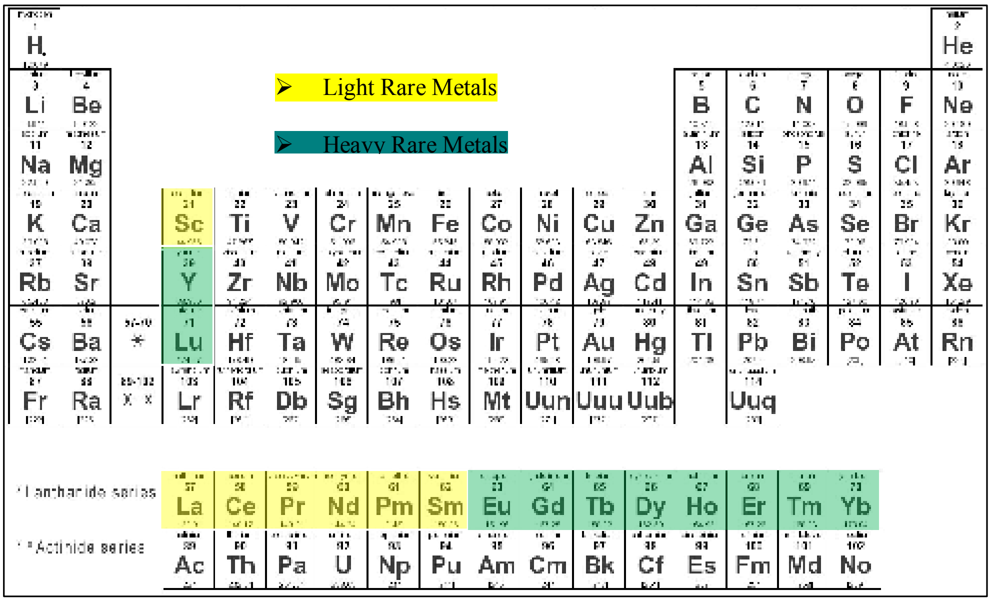


Figure 1. Periodic table and the rare earth elements. Source: Renaud 2010

The main fifteen rare earth elements with atomic numbers from 57 to 71 are: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). All of them are metals that have many similar properties and are often found together in geological deposits. They are usually divided according to their properties into light and heavy metals. Additionally, there are 12 more elements considered as other rare earth elements as lithium (Li), beryllium (Be), rubidium (Rb), caesium (Cs), zirconium (Zr), niobium (Nb), hafnium (Hf), tantalum (Ta), gallium (Ga), germanium (Ge), indium (In) and tin (Sn). Some of them like beryllium are very important for the military and nuclear industry.

The term rare earth comes from, until that time, scarcity of the metals and the difficulty to extract them from their oxides. The name does not reflect their abundance in nature. Actually, rare earths are not as rare as it was thought before (Wikipedia 2011a).

2.2. Rare Earth Reserves and Resources

Before starting with this section, it is good to give some definitions to understand better the difference between reserves and resources. “Reserves” refer to deposits that are legally, economically and technically feasible to extract, and only legal mining companies own the right to extract them (Wikipedia 2011b). “Mineral occurrences” or “Reserve base” are possible extractable deposits that at the moment are not of economic interest. “Resources” are the total volume of deposits found in the lithosphere for which possible projects of extraction may exist in the future if prices rise and make low concentration deposits feasible to extract (Kara et al. 2010).

According to the US Geological Survey (USGS) updated in January 2011, rare earth proven reserves are in total 113.8 Mt (Fig. 2 right). There are slight differences in the report from 2010, mainly for China and Australia (Fig. 2 left).As it can be seen from figure 2 right and left, the number for rare earth reserves for China has significantly increased from 36.0 Mt in 2010 to 55.0 Mt in 2011. Further, the number for rare earth reserves for Australia has decreased from 5.4 Mt in 2010 to 1.6 Mt in 2011. Reserve

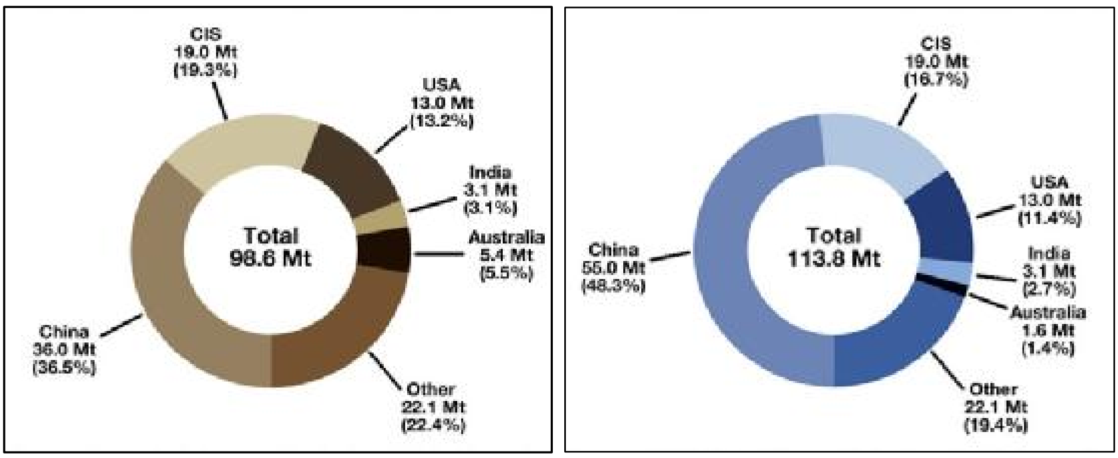


Figure 2. Global Rare Earth Oxide Reserves for 2010 (left) and 2011 (right). Source: Hatch 2011

data are very dynamic as they may increase, if additional deposits are found, or decrease as the ores are mined or the extraction possibility shrinks.

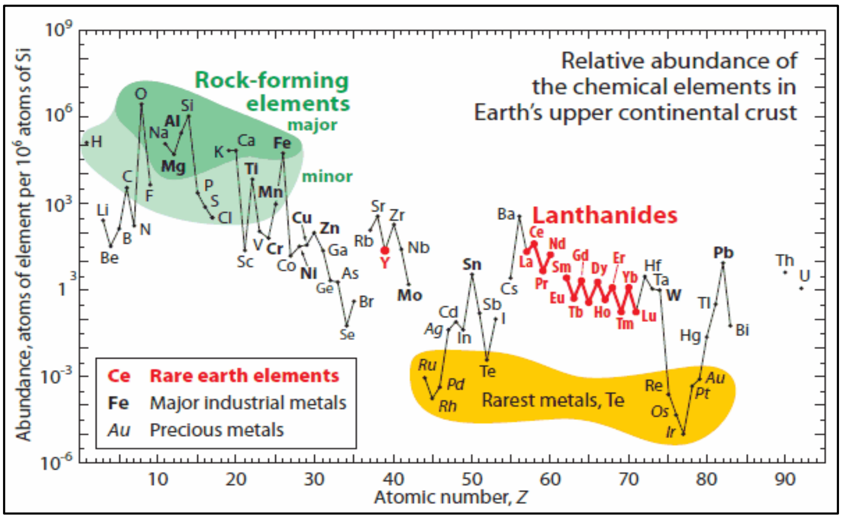


Figure 3. Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number. Source: USGS (Fact Sheet 087-02) 2002

It is already proven that rare earths in comparison to precious metals are relatively ample in the Earth's crust. From figure 3 it can be seen that the lanthanides are actually more abundant in the nature than lead (Pb) compared to cerium (Ce), lanthanum (La), neodymium (Nd), the most abundant rare earth elements, and the less abundant rare earth elements in the Earth's crust thulium (Tm) and lutetium (Lu), are more abundant than silver (Ag) and even gold (Au). The only rare earth metal which does not appear in the figure is promethium (Pm). It is a radioactive element first produced in 1945, which can be formed in nature "as a product of spontaneous fission of uranium-238 and alpha decay of europium-151" (Wikipedia 2011c), and only trace amount can be found naturally. Though rare earths are quite abundant in nature, they are still not as abundant as the major and minor industrial elements. Despite the relatively high abundance of rare earths (Fig. 4 left), they are less available in concentrated ore deposits worth to be exploited (Fig. 4 right). Today, the most of the world's supply of REM comes from few mines rich in concentrated ores.

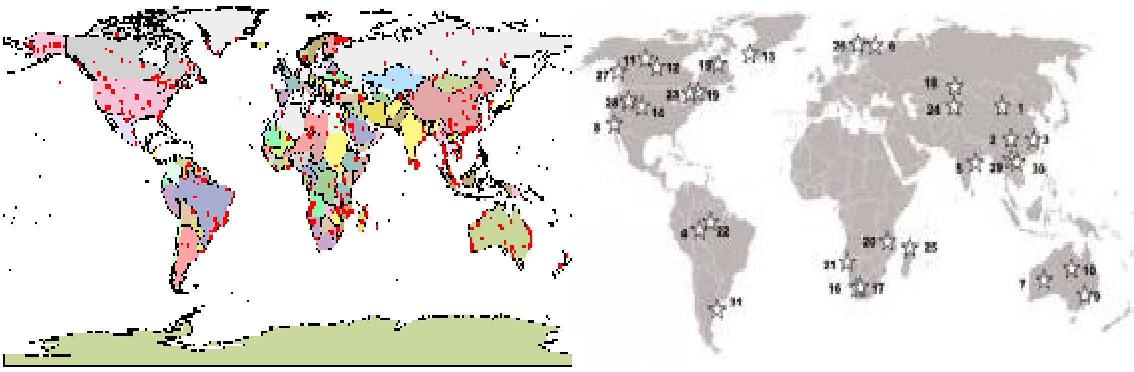


Figure 4. World map of rare earth elements abundance (left), exploitable resources of rare earths and mines (right). Source: Weisenthal 2011

There are more than 200 minerals containing REEs. The highest concentrations of rare earths are found in minerals like monazite, (Ce, La, Nd, Th)PO_4SiO_4; bastnaesite, (Ce, La)(CO_3)(OH, F); and xenotime, YPO_4 (Christie el al. 1998). About 95 percent of the light rare earths occur in monazite and bastnaesite. Monazite contains radioactive elements because of the presence of thorium (Th around 30%) and uranium (U around 1%) which can be a problem for its extraction if the radioactivity is high. Bastnaesite contains very low content of radioactive elements and is easier to be mined. Xenotime is the mineral of heavy rare earths and yttrium (Y) and has low to no radioactivity.

Mineral	Formula	Major Occurrences	REO max (%)
Bastnäsite	$LnFCO_3$	China, USA	75
Monazite	$(Ln,Y,Th)PO_4$	China, Australia, Brazil, India, Malaysia, Africa	65
Loparite	$(Na,Ca,Ln,Y)(Nb,Ta,Ti)_2O_6$	Former Soviet Union	32
Xenotime	YPO4	China, Australia, Malaysia, Africa	62
Apatite	$(Ca,Ln)_5[(P_2Si)O_4]_3$	Former Soviet Union, Australia, Canada	12
Ionic Clays	Weathered Xenotime and Apatite	China	n/a

Table 1. Composition of major rare earths minerals. Source: Kara et al. 2010

The world resources are primary contained in bastnaesite and monazite ores. Bastnaesite deposits in the United States (Mountain Pass in California), and mainly in China (Bayan Obo, Inner Mongolia) cover the largest resources of rare earths (Table 1). The second largest resources of rare earths are the monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand and the United States (Cordier 2011). According to the United States Geological Survey in its "Mineral Commodity Summary", the undiscovered resources of rare earths are considered to be very large and to meet the expected demand. Figure 2 shows the first six biggest world deposits known. This shows that rare earths are abundant in nature, but the sufficient concentrations are in the most cases difficult to find, and an economical feasible mining cannot be performed. Even if a potential site is discovered, it might last up to 10 years before the mining starts (Levkowitz et al. 2010). (Detailed data of 848 mines, deposits, and occurrences worldwide: Orris and Grauch 2002)

2.3. Rare Earth Production, Demand and Supply

Today, the biggest producer of REEs is China with 97 percent almost monopolistic share on the world market (Fig. 5). Not long ago, between the 1950s and the 1980s, the United States was the major producer of REEs in the world. In 1984, the Mountain Pass Mine accounted for one third of the global exports and 100 percents of the national demand (Lifton 2010). In

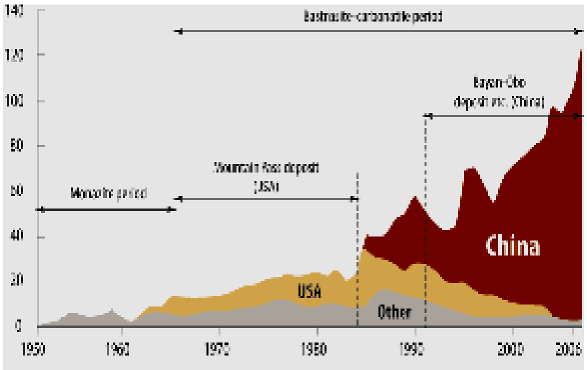
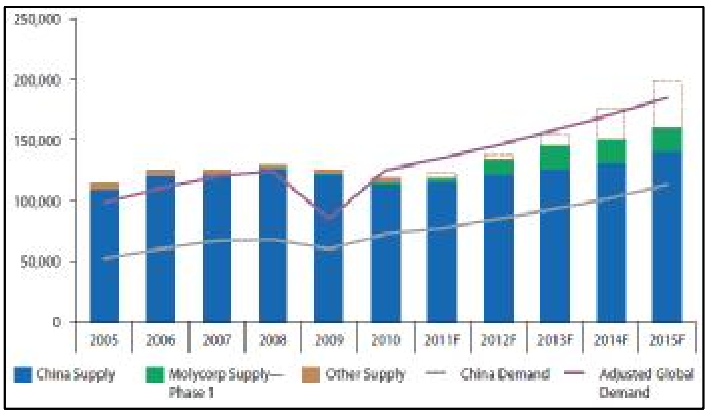


Figure 5. Global rare earth production for 2010. Source: USGS 2011

Figure 6. The World's production of REO. Source: US GS (Fact Sheet 087-02) 2002

2002, the mine shut down (Fig 6).

The demand for rare earths in the last 20 years has increased substantially. This demand will continue to increase as the development of high-tech products is demanding more REEs. However, a big uncertainty remains if the future supply will meet the future demand. According to the rare earths company Molycorp, the future total demand will not exceed the total supply (Fig. 7 left). Actually, as China dominates the world supply the rest of the world remains totally dependent on China's export. As stated by the US Congressional Research Service in the report "Rare Earths Elements: the Global Supply Chain" (Humphries 2010), the



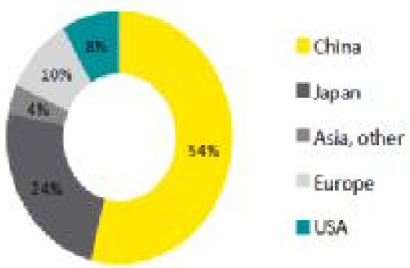


Figure 5. Global REE supply and demand (left), demand forecast by region for 2010 (right). Source: Molycorp 2010, Ernst & Young 2010

worldwide demand in 2010 for the rare earth minerals was 134,000 tons from global production of 120,000 tons, and it is expected to rise to 180,000 tons annually by 2012, and 225,000 tons by 2015. This forecast differs from the forecast presented from Molycorp in its “Annual Report 2010”, where in 2012, it is expected a global demand of around 150,000 tons, and for 2015 around 180,000 tons (Fig. 7 left).

Since 2006, China has started to tighten the export quotas on REM as an attempt to conserve the minerals for domestic use and to regulate the sector for sustainable and environmentally friendly production. This followed with a release of a white paper in 2009, from the China’s Ministry of Industry and Information Technology, proposing a severe minimization and even stopping of the REM exportation. In 2010, the export quotas were 40 percent below the export quotas for 2009, and for the second half of 2010 the quotas felt to below 72 percent. According to IBTimes (2011) from January to June 2011, are to be sold around 14,500 tons to the external market or 31 companies while in 2010, for the same period, were sold around 16,300 tons to 22 companies (Fig. 8). Nevertheless, these restrictions are only to raw REEs for exportation. There are no export quotas on manufactured goods containing REEs. On July 18, 2011, Reuters (Martina and Lian 2011) announced that China alleviated export restraints on rare earths by restoring them to 30,184 tons, which is near 2010 levels or 30,258 tons.

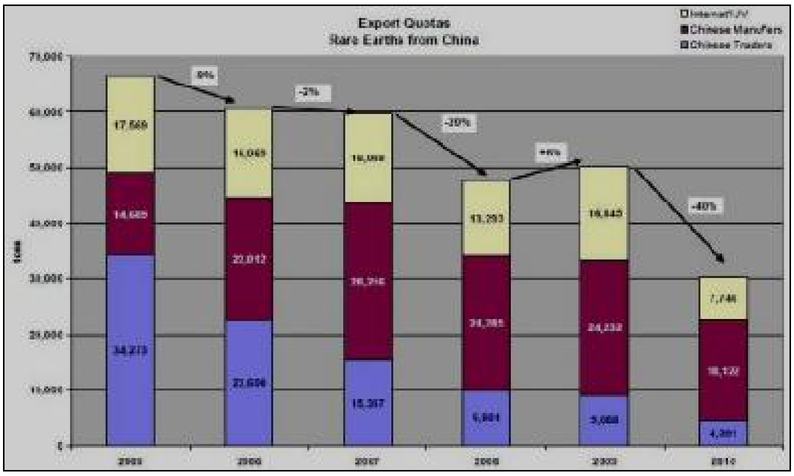


Figure 6. REEs export quotas from China. Source: DACHA 2011

2.4. Rare Earth Prices

The Chinese export policies led to rapid increase in the rare earth global prices (Table 2 and Fig. 9). But the Chinese domestic market prices of rare earths remained lower compared to the export market prices. According to Berry and Torsekar 2011, companies that produce rare earth products outside China must pay 31 percent more for raw rare earths than domestic companies.

Products	Export Prices US$/kg REO (FOB China)				
	Q2 2004	Q2 2005	Q2 2006	Q2 2007	Q2 2008
RECO3	0.80	0.60	0.70	2.20	4.35
La2O3 99%	1.80	1.40	1.45	1.70	8.50
CeO2 99%	1.65	1.35	1.35	1.30	4.35
Nd2O3 99%	5.75	6.00	11.20	28.20	32.40
Eu2O3 99%	315	290	260	280	480
Tb4O7 99%	405	300	450	550	730
Dy_2O_3 99%	30	36	70	80	120

Table 2. Export prices of REO in dollars per kilograms. Source: Lifton 2009

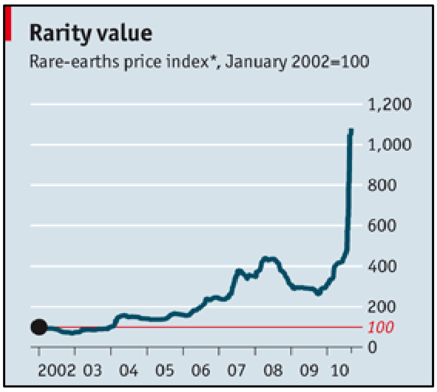


Figure 7. RE Price index composed of ten metals. Source: Levkowitz 2010

It is expected that in the next years the prices will continue to grow up to 30 percent (Robinson 2011). On the contrary, as reported by the online blog Barron's (Coleman 2011), the rare earth price "boom" is nearing its peak, and in 2013 a slight rare earth surplus will be developed, and prices will reach an average level of 83 dollars per kilogram in 2015. According to Bloomberg, and as it can be seen from Figure 10, the rare earth prices have begun to drop. Rare earth prices for some rare earth oxides started dropping for first time this year in May.

Figure 8. Bloomber Rare Earth Mineral Resources Index. Source: Bloomberg 2011

2.5. Risk and Opportunities

As a consequence, there are short-term and medium-term supply shortages for the countries dependent on rare earths. The high prices of rare earths are encouraging the development of new mining projects outside China, as consequently, countries such as the USA, Australia and Canada are looking for the opportunity to open or reopen rare earth mines on their national territories. On the one hand, this will help to alleviate the rare earth shortage problem, but on the other hand it will demand for significant investment, major part of which will have to be used to prevent the environmental impacts of extraction and production. (Bauer et al. 2010)

To develop a new mining project, it is estimated that it takes from 6 to 10 years given that important aspects such as financing are available. Sometimes, it can even take more years to launch a mine because of other complexities added to rare earth extraction. According to Kingsnorth report (Kingsnorth 2009) for the 5th International Rare Earth Conference in Hong Kong, there are 10 main steps to be fulfilled in order to assure rare earth production. The steps are as follows:

I. Provide resource: understand mineralogy, grade and distribution.

II. Define process and bench scale: beneficiation, extraction, separation, local availability of chemicals.

III. Pre-Feasibility study.

IV. Beneficiation.

V. Extraction.

VI. Separation.

Steps IV to VI are demonstration steps and collect data for the Environmental Impact Assessment procedure to prove that the technical, economical and environmental requirements will be performed in the best available and save method.

VII. Obtain environmental approvals.

VIII. Publish letters of Intent: important for long term customers relations.

IX. Complete a bankable feasibility study: important to secure project funding.

X. Construction and start-up.

Starting a new project is long and difficult process but not impossible. The problem here is that it is not a short term solution for a short term rare earth shortages. The possibility of new rare earth mining projects is a long term solution that will be possible in more or less 10 years and will give the possibility of independence from Chinese REMs.

If near-term worldwide shortages of rare earths are presented, they may affect the growth of the "green" and high-tech industries outside China, and in particular the renewable and energy-efficient-clean technologies, including solar cells, wind turbines, hybrid cars, military technology etc. As the world is trying to move on "green" energy supply, an unexpected shortage of these critical elements could lead to serious consequences that may affect the global economy, as the green sector is promoting economic growth, new jobs, and last but not least, it is fighting climate change.

2.6. The Supply Chain

To become a better understanding of how the rare earths come to the market, the communities should better understand the supply chain of the critical elements. The supply chain involves not only mining, but also other processes throughout its production, manufacturing, and final product. Figure 11 shows the critical material supply chain of REEs. The authors of the "Critical Materials Strategy" prepared for the US Department of Energy explain that "the supply chain provides a useful context in which to explore the technical, geopolitical, economic, environmental and intellectual property factors that impact the supply of these materials and the technologies that use them. In addition, the supply chain framework can inform where to target potential policy tools." (Bauer et. al. 2010)

The extraction step includes mining that can be open pit mining or underground mining. After extraction, the ore is send to separation facility where it is separated into oxides. The rare earths may be also co-products or byproducts of other mining activities. Further, the oxides are refined to metals and then alloys. After processing, the ready materials are used to manufacture component parts which later are assembled to end-use technologies. Recycling and reusing can be performed at any stage of the supply chain.

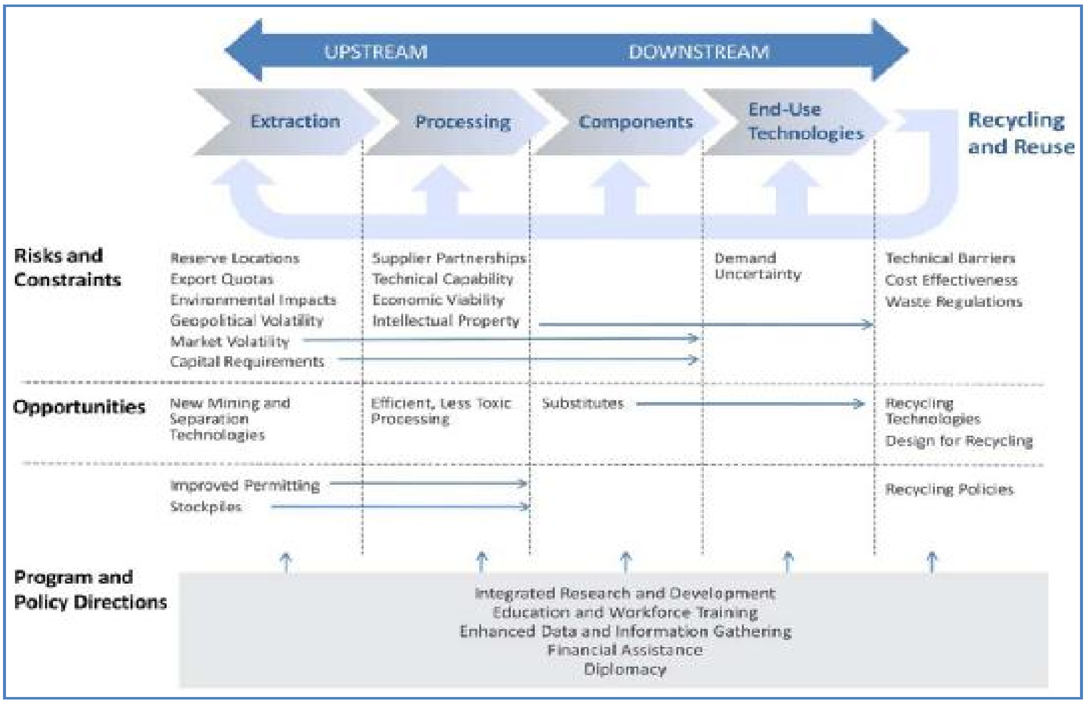


Figure 9. Critical material supply chain of REM. Source: Bauer et al. 2010

2.7. Rare Earths – Applications and Use

Even though our society is not realizing it, we have become entirely dependent on the rare earth metals. The main applications and uses of REEs according to the annual report of Molycorp (2010) include:

- Clean-Energy Technologies: hybrid and electric vehicles, wind power turbines, compact fluorescent lighting;
- High-Technology Applications: miniaturization of cell phones, personal digital assistant devices, digital music players, hard disk drives used in computers, computing devices, speakers and microphones, fiber optics, lasers and optical temperature sensors;
- Critical Defense Applications: guidance and control systems, communications, global positioning systems, radar, sonar;
- Advanced Water Treatment: industrial, military, homeland security and domestic and foreign aid applications. (Molycorp 2010)

Figure 12 shows the results of a Yale study that estimates the global use of rare

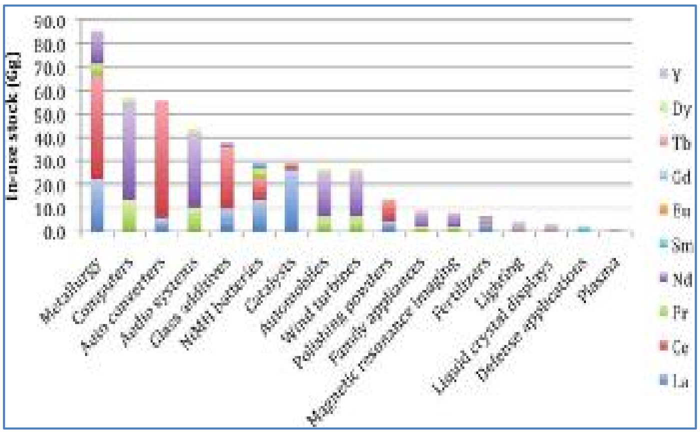


Figure 10. Principle applications by rare earth element. Source: Green Car Congress 2011

Rare Earths	Atomic	Commercial Use No.
Yttrium	39	Lasers
Lanthanum	57	Electric car batteries
Cerium	58	Lens polishes
Praseodymium	59	Searchlights, aircraft parts
Neodymium	60	High-strength magnets
Promethium	61	Portable X-ray units
Samarium	62	Glass
Europium	63	Compact fluorescent bulbs
Gadolinium	64	Neutron radiography
Ierbium	65	High-strength magnets
Dysprosium	66	High-strength magnets
Holmium	67	Glass tint
Erbium	68	Metal alloys
Thulium	69	Lasers
Ytterbium	70	Stainless steel
Lutetium	71	None

Table 3. Rare earth commercial use. Source: Bradsher 2009

earths. There are17 different sectors and products that use mainly rare earths. In figure 12 are presented only 10 from 17 rare earths. Table 3 shows the main commercial uses of the 17 elements.

For example, lanthanum (La) is used in alloys to produce batteries used to store the energy for electric vehicles, catalytic converters, laptops and much more. Europium (Eu) and yttrium (Y) are used in the liquid crystal displays where europium is important for the coloration of the TVs. Cerium (Ce) is used in the metallurgy and in the water purification from contaminants. Scandium (Sc) is applied for the manufacture of laser, X-rays technology and fuel cells. Neodymium (Nd) is essential for wind turbines, hard drives and others. The most commonly used REEs are cerium (auto convertors, glass additives), neodymium (computers, wind turbines), lanthanum (NiMH batteries, catalysts) and praseodymium (computers, audio systems). Most of the products we use every day, and especially those used for the green technology and military purposes, are impossible to be manufactured without the use of the rare earth elements.

2.8. Environmental Issues

"The green road always starts with black earth" said the independent expert, Jack Lifton for BBC News online (Heap 2010). He explained that we can't demand zero impact and if we want green technology then we need to mine.

Talking about clean and green technology there is not to be ignored the way rare earths are produced. There are many environmental issues surrounding the production of rare earths from its very begging, starting with mining, and separation to final product. The main risk is heaps and tailings ponds, which contain the waste and residues of rare earth production that are mainly radioactive. If 100,000 tons of rare earth concentrate is processed, then its slurry contains approximately 200 tons of radioactive thorium dioxide. In the whole production process are included energy and chemicals use, land devastation, waste and radioactive waste production. In the production process of REM a considerable amount of energy is used, which in China is mostly generated by coal power plants. Sulphuric and hydrofluoric acids, as well as other chemicals, are involved in the refinement processes. As a result of illegal mining practices in China, the local environment has been damaged causing land and water pollution and illnesses to the local population. Even after the discard as waste of a product containing REM, once released into the environment, there might be further consequences which are still unknown. (Houses of Parliament 2011)

According to Hurst (2010) the processing of rate earth ore is highly dangerous to the human health and is causing the most environmental damage:

"Under traditional technology means, refining rare earth elements requires such chemicals as ammonium bicarbonate and oxalic acid. The potential health hazards of ammonium bicarbonate include: irritation to the respiratory tract if inhaled, irritation to the gastrointestinal tract if ingested, redness and pain if it comes in contact with the eyes, and redness, itching, and pain if it comes in contact with the skin. Oxalic acid is poisonous and potentially fatal if swallowed. It is also corrosive and causes severe irritation and burns to the skin, eyes, and respiratory tract, is harmful if inhaled or absorbed through the skin, and can cause kidney damage. These and other chemicals often find their way into the Yellow River, China."

2.9. Recycling of REM and/or Substitution

At present, huge quantities of rare earth metals are used in products that at some point in the future will reach end of life stage. The Panel of UNEP in September 2010 highlighted concerns about the rare earth elements, as only one percent of them are recycled at the end of product life, and the rest is discarded (AFP 2011).

The practice of recycling materials is of great concern for our modern society in the process of its sustainable development. Unfortunately, most of the recycling is performed if it is economically feasible, in other words the materials' purity shall not be lost as well as its economical value. In the case of rare earths, the recycling and the production chain are still not very well developed if re-usage is not possible. This is because of the material complexity due to its alloys with other metals and chemicals, the high energy consuming recycling processes, the intensive dismantling from hard discs, electric motors and other electric devices. In shortly, a physical and chemical treatment is necessary. In most of the cases the problem is not only economical, but also the missing technology for the separation process. Regardless the prices for recycling, if the demand for rare earths increases even more, the recycling option might result even cost efficient. Along with the "Study on Rare Earths and their Recycling" by Schüler et al. (2011), several constraints for recycling of rare earths were identified. They are as follows:

- The need for an efficient collection system;
- The need for sufficiently high prices for primary and secondary rare earths compounds;
- Losses of post-consumer goods by exports in developing countries;
- The long lifetime of products such as electric motors in vehicles and wind turbines of 10 - 20 years before they could enter the recycling economy.

Of course, there are several advantages of recycling compared to the primary use of the rare earths. For example, in Europe the amount of waste products containing rare earths is increasing, which by urban mining of these valuable materials from the waste could be put back into the market. In this way the supply and import of primary resources will diminish. Further, the current luck of knowledge on recycling will be replaced by enterprises and scientific institutions, which will be working on new technologies and ways of recycling the "rare" materials. Another advantage for the recycling is that it is totally free from radioactive substances. Compared to the primary production, the recycling process will use less energy and chemicals and will be more environmentally friendly (Schüler et al. 2011).

According to the analysis of substitution for scarce rare earths reported by Schüler et al. (2011), the substitution of rare earth compound by another one is very rare and usually implies completely new product design. Research and development is needed in most of the cases for alternative sources and products. There is already a developed alternative recognized in the nanotechnology in some green applications by using nano-sized rare earth compounds for better efficiency, but still a risk assessment is to be performed.

Chapter 3

3. Short Chronology of the Rare Earth Conflict

'The Middle East has Oil, China has Rare Earths'

Deng Xiaoping, Former Chinese Premier

Almost 20 years ago, in January 1992, when Deng made his comment about rare earths the rest of the world could hardly understand its meaning. Today, the world is starting to realize his words. Now, China controls 97 percent of the global supply of rare earths and is a quasi monopolist in the international market for rare earths.

Chinese politics have also understood that the damage by mining in their country is irreversible. After more than 20 years of resource devastation suddenly they realized that they want to mine sustainably. As China is one of the top emitters of CO_2, it decided to turn "green" and has developed a national plan that has the aim to produce 20 percent of its energy from wind and solar renewable energy by 2020 (China Daily 2009), and as well to turn into the world top producer of green products. For this reason, a new quota policy on export of rare earth was developed and the exportations were minimized. However, China is also a country lacking production of high quality high-tech products. The country aims also to become trustworthy producer of high technologies as Japan is. Despite of its hope and effort to attract international high-tech producers to produce in China, the country remained the raw material producer and manufacturer of low quality products and low end products for the developed countries. This might be also one of the reasons why China minimized its exports of raw rare earths. China needs that the high-tech producers come and produce in the country giving its technological knowledge and stimulating its economy to grow further.

The Chapter below explains in details the development of the Chinese rare earth market, as well as the challenges that it faces and the old and new policy on rare earths.

Now, the USA, Germany and Japan have to find a solution to the supply shortages that they are facing. The response to the Chinese policy and the possible solutions that they are proposing are shown in the next chapter.

3.1. China's Resources of Rare Earths

In 1927, Chinese scientists discovered the largest Chinese rare earth deposits in Bayan Obo (Baiyunebo), Inner Mongolia, where in 1957, the first production of rare earths in China started. The reserves here are estimated at more than 40 million tons, the biggest world reserves of rare earths grading at 3-5.4 percent (Mindat.org 2011). At the moment, rare earth mines are found in 21 provinces and autonomous regions in China. Light rare earth metals are found in the northern region Inner Mongolia, while heavy REEs are found in the southern provinces Jiangxi, Hunan, Guangdong, Fujian, and Guangxi (Fig. 13).

Figure 11. Rare earth mining districts distribution. Source: Hocquard 2010

China's minerals are divided into reserves and resources. The reserves are subdivided into provided extractable reserves, probable extractable reserves and basic reserves. Further, the resources are divided into measured, indicated, and inferred (Tse 2011). In accordance with the data from the latest Estimate of Global Rare-Earth-Oxide Reserves issued by the US Geological Survey 2011, China's rare earths reserve is 55.0 Mt or around 48% of the global reserves of REEs.

According to the Baotou institute and reported by the New York Times online (Bradsher 2009a), deposits in southern China will have been exhausted in the next 15 years. China Daily reported, according to the depute Hongyu, that all of China's reserves might have been mined out within the next 20 to 30 years if they are mined at the present rate (Jiabao and Jie 2009).

3.2. China's Production, Supply and Demand of Rare Earths

There are two main production zones in China. The Northern Group including mainly Inner Mongolia, Gansu and Sichuan, and the Southern Group including Guangdong, Hunan, Jianxi and Jiangsu (Spooner 2008). The main rare earth production in China takes place in the autonomous region Inner Mongolia, which accounts between 50% and 60% of the total rare earth concentrate production (byproduct of mining) in China for the last ten years (Tse 2011). The Sichuan Province is the second biggest producer with up to 30% of production for the last ten years. Both regions are producing mainly light rare earth metals and the production is based mainly on bastnaesite. The Northern group includes ten companies, from which the leading are Baotou Steel and Baotou Rare Earth (Group) Co, Gansu Rare Earth Co. and the Sichuan Rare Earth Group (Spooner 2008). The Southern Group includes seven producers and is important for the production of heavy rare earths and mainly yttrium.

Only for ten years, from 1990 to 2000, the production of REM in China rose from 16,000 tons to 73,000 tons, while in the rest of the producing countries decreased to 16,000 tons from 44,000 tons. In 2009, the production in China reached almost 130,000 tons. In the same year the rest of the world production decreased with 3,000 tons (Tse 2011). China's rare earth total output in 2010 rose to 97 percent from 27 percent in 1990.

At present and in the last fifteen years, China has been the largest rare earths supplier and possesses the largest rare earth reserves in the world. For example, during the last fifteen years the United States has become 100 percent dependent from the Chinese rare earth supply (Humphries 2010). Due to the big competition of the Chinese rare earth producers and the struggle to maintain profitability supported by loans from the Chinese controlled banks, and while too many Chinese suppliers were selling REEs into the international market, allowed the prices to be kept low. Although the Government was trying to control the production and exports and to conserve the mineral resources and protect the environment in the years from 1990 to 2000, the high competition between local governments to provide employment and local economic development resulted in high levels of production exceeding the Government's production target (Tse 2011). This triggered reinforcement of the policies and regulations in mining where, as a consequence, many illegal mines were shut down.

While the production in China of rare earths was very high in the last ten years from the past century, the consumption did not undergo any changes until 2000 with consumption about 19,000 tons and rest of the world consumption of 72,000 tons (Fig. 14 and 15). In 2009, the Chinese consumption reached 73,000 tons from 52,000 tons in 2005. From 2005 onwards, China passed over 50 percent of the total rare earth consumption. It is believed that by 2020 the domestic demand of rare earths will reach 68 percent of the global total demand.

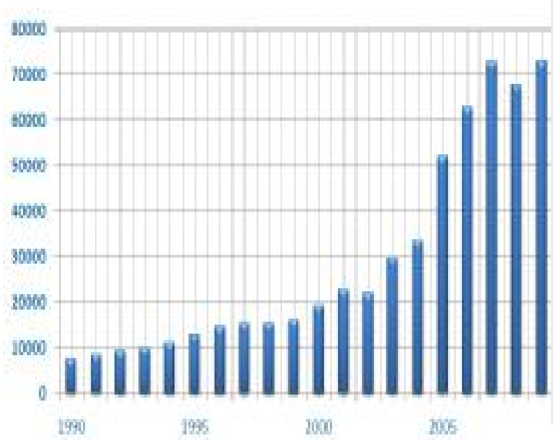


Figure 14. China consumption between 1990 and 2009. Source: Zahnheng 2011

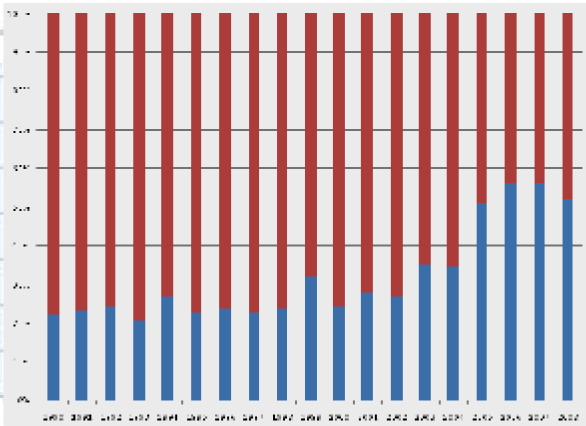


Figure 12. Relationship: rest of the world consumption (red) and China consumption (blue). Source: Zahnheng 2010

China's consumption structure here below (Fig. 16) shows the main areas of consumption of REM from 1988 to 2008. As it can be seen they are mainly used in five key industries as follows: metallurgy and machinery industry; petroleum and chemical industry; glass and ceramics; light and textile industry and agriculture; and in the newly emerged green industry including permanent magnets, phosphors, catalysts for autos etc. that

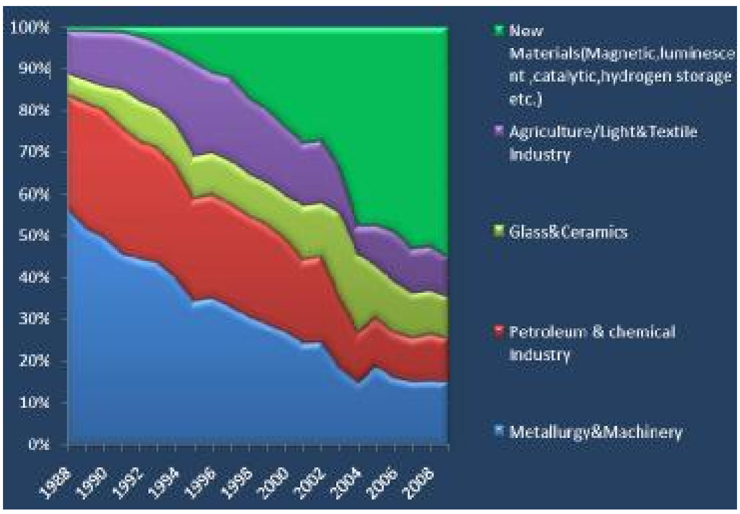


Figure 13. Consumption structure of rare earths by sector from 1988 to 2008. Source: Zahnheng 2011

now amounts more than 50 percent. It is expected that the consumption in China of rare earths will increase drastically in the following years having in mind that at the moment 30 percent of the rare earths are used by the magnet production sector, 15 percent by the metallurgical, 10 percent for ceramics and glass, 10 percent by the chemical and petroleum sector, another 10 percent by agriculture, 9 percent for hydrogen storage and 16 percent in other sectors (Tse 2011). From these facts it can be concluded that the rare earth materials and consequently products have became a key tool for providing growth of the Chinese rare earth industry. Nevertheless, according to Wang Guozhen, former vice chairman of China Nonferrous Metals Engineering and Design Institute, and as reported by China.org.ch "the country's downstream application technologies for rare earth materials currently stand at a low level of development" (Yan Pei 2011). Even though in the last years China has tried to trade resources for technologies, it still has not achieved the desired results. Chinese policy makers believe that now, after the introduction of the export quotas on rare earths, more international companies will orientate their production to China in order to secure a safe supply to rare earth metals (Hays 2011).

3.3. Challenges Facing the Chinese Rare Earth Industry

According to Dr. Chen, a Chinese rare earth specialist, the rare earth industry in China is "beset with environmental problems" (Hiscock 2011). That is why now, China wants to run the rare earth industry business sustainably "on a sound environmental footing and try to minimize any waste of the resources" (Foster 2011).

The Chinese rare earth industry is the biggest in the world and together with this faces many problems. The first problem to be solved is the smuggling. The illegal mining is difficult to monitor and is one of the biggest challenges for the rare earth industry. One third of the total amount of rare earths leaving China is from illegal mining (Levkowitz et al. 2010). Smuggling is one of the reasons why prices were low on the market and a basis for the fast consumption of the rare earth resources. The "Rare-Earth Industry Development Plan of 2009-2015" introduces polices and regulations on cleaning the illegal mining in the country. The large scale of the rare earth industry and its poor management led to almost impossibility to improve the safety and environmental measures in the industry (Hurst 2010).

The second problem waiting for an immediate response is the environmental damage caused by mining. Quarrying, everywhere around the world produces millions of tons of waste water, chemical spills, and radioactive waste which can be very harmful to the environment and men if not disposed the right way, followed by air emissions with harmful elements, and kilometers of toxic and radioactive tailings lakes. In China, the lack of mining regulations has permitted serious damages to the environment. In most cases to save production costs the environmental standards are not fulfilled.

Picture 1. Ground-level view of wastewater being pumped into a rare earth lake at Baotou. Source: McLendon 2011

Picture 2. Wind turbines (with two tons of rare earth magnet) producing green energy. Source: Environment Green 2008

According to an article published by the Chinese Society of Rare Earths and quoted by Hurst, "a ton of rare earth generates about 8.5kg of fluorine and 13kg of dust; up to 12,000 cubic meters of waste gas containing dust concentrate, hydrofluoric acid, sulfur dioxide, and sulfuric acid; about 75 cubic meters of acidic waste water and about one ton of radioactive waste residue" (Hurst 2010). In addition, "according to statistics conducted within Baotou, where China's primary rare earth production occurs, all the rare earth enterprises in the Baotou region produce approximately ten million tons of all varieties of wastewater every year and most of that waste water is discharged without being effectively treated, which not only contaminates potable water for daily living, but also contaminates the surrounding water environment and irrigated farmlands" (Hurst 2010). Statistics made by the WWF show that "10 percent of farm land is contaminated; 40 percent of river water is harmful to human health; and respiratory diseases resulting from air pollution are considered by some the main cause of death" (Rüttinger and Feil 2010).

In 2009, the Chinese official Wang Caifeng, deputy and director-general of the Materials Department of the Ministry of Industry and Information Technology, explained that one of the main reasons for the limitation of rare earth production and exports is to protect its environment, as to produce one ton of rare earths 2,000 tons of waste tailings are generated (Cars21 2009).

3.4. China's Policies on Rare Earths

"What we are pursuing is the sustainable development of rare earths, which is necessary to meet national needs, and also the needs of the world." Chinese Premier Wen Jaibao, Brussels 6th October 2010. (AFP 2010a)

3.4.1. Foreign Investment and Output Quotas

The first important act issued by the Chinese Government in 1990 is to protect the rare earth resources as strategic minerals and prohibits foreign investments in rare earth mining, smelting or separation, but gives the possibility for foreign firms to participate in joint ventures (JV) with Chinese companies. The participation of foreign firms must be approved by the Ministry of Commerce and especially by the State Development and Planning Commission. Since 1990, China is issuing output quotas for each province and mining company. One problem that still remains is the difference between the actual output, which is much higher than the output quota. The reason is that there still exist companies without license for mining REEs, and the local governments, which want to increase the economic growth and employment, do not have strict policy on output quotas. For this reason, during the last five years, the central Chinese government has decided to strengthen the administration of the output quotas (Yang 2011).

3.4.2. Importation and Exportation Quotas

All complying rare earth products with the Chinese standards can be imported; importation of radioactive rare earth minerals and scrap is banned. In 2003, the Chinese Ministry of Commerce got responsible for setting the export quotas. This decision was taken in order to cover a sure domestic supply. The export quotas are obligatory not only for the domestic producer but also for the JV companies. In 2006, 47 domestic companies plus 12 joint venture companies were allowed to export REM. This number was reduced in 2009, to 23 domestic companies and 11 JV that consequently fell to 22 domestic companies, and 10 and 9 JV companies for 2010 and 2011 (Zhanheng 2010).

3.4.3. Taxation Policy

In 1985, China applied a tax rebate policy to encourage its companies to export rare earths (Zhanheng 2010a). The refund of value-added tax continued until the year 2000; then the Chinese government reduced the export refund. This measure was taken due to the increased domestic needs not only for rare earths, but also for other strategic raw materials. In 2005, the tax rebate for exports was completely abolished and the trade of rare earth concentrate was not anymore allowed. An export tax was implemented which entered in force from June 2007, and in 2008, it doubled especially for REEs.

On one side, the Chinese government alleviated the taxes to encourage exportation, but on the other side, in 1993, was passed the “Provisional Regulation on Resource Taxation”. All REEs produces were obligated to pay natural resource tax. This tax was very low until April 2011; then the tax on REEs increased with more than 10 times and for light rare earths with more than 20 times (Yang 2011).

3.4.4. License for Mining and Access Conditions

Every company, which wants to mine rare earths, has to obtain a mining permit from the government. Since 2009, the Chinese government has started to prepare the Access Conditions of the rare earth industry. In 2010, it was published under the name of “Draft for Soliciting Opinions”. The production capacity of rare earths should not be increased before 2015, and no new projects on rare earth smelting separation should be approved. In order to achieve cleaner production, all existing rare earth companies should make more invests in research and development as well as best technology and equipment to improve product quality. The government supports companies using rare earths for the development of new applications in environmental protection, energy, information technology and recycling of rare earths (Tse 2011).

3.4.5. Environmental Protection

In 2006, China published a white paper on Environmental Protection (1996 - 2005) containing ten chapters with the basic efforts and results made by the Chinese government to protect the environment. This paper says that the Chinese Government "attaches a great importance to the environmental protection" (Information Office 2006). Further, the white paper states that "it believes that environmental protection will have a direct impact on the overall situation of China's modernization drive and its long-term development, and considers environmental protection undertaking that will not only benefit the Chinese people of today but also their children and grandchildren". The document explains that the Chinese government has prioritized the resource saving and the environmental protection as a part of achieving its development goals. "Three changes" will be made: the environmental protection should be understood as important as the economic growth; the environmental protection should be reached together with the economic growth; and legal, economic, technical and administrative measures should be used to solve environmental problems (Information Office 2006).

Furthermore, to assure the proper management of its environment, the Chinese government released on February 28, 2011 stricter environmental standards for rare earth producers, which came into force on October 1, 2011 as announced by China Daily (Jing and Qi 2011). There is a fear that in order to fulfill the new standards the producers will have to upgrade their technologies that will lead to increase in the production costs, as a result.

The main policies against environmental destruction and resource devastation in the rare earth mining are as follows: suspending new issue of new mining and rare earth processing license; setting new production caps and export quotas; and implementing the environmental standards (Ernst and Young 2011). The purpose of these policies is to protect the environment and to stop production involving environmental damage.

3.5. The Rare-Earth Development Plan of China

All these new policies that China is preparing and implementing are integrated in the "Rare-Earth Development Plant for 2009-2015". It contains 22 items with very strict policies on mining, waste emission standards, illegal mining regulations, preservation of the resources and the environment etc. The production rate is to be minimized to 130, 000 tons and the export quota will remain at about 35,000 tons, and only 20 domestic producers will be allowed to export REOs. The plan aims to control primary products of rare earths but encourages the export of new finished products containing rare earths (Tse 2011). Dysprosium and Terbium are not banned by the plan, but their exportation is restricted. According to the plan, new rare earth separation projects will not be approved before 2015. The monazite mining will be banned, as it is the main source of radioactive waste. All rare earth producers must meet the new environmental emission standards; if they do not comply with these norms, they will be closed. (Tse 2011 and China Rare Earths 2011)

3.6. China and REEs International Politics

3.6.1. "Price Dumping"- the International Predatory Pricing

The Chinese policy on rare earths, at the beginning of the 1990s, already acted as "price dumping" for rare earths. Predatory pricing is a term in economics to describe how a country or a company sells a product or services at a very low price in order to "drive competitors out" of the business and create obstacles of new entries. This predatory pricing policy leads to fewer competitors or even market monopoly. Later the merchants can decide to raise prices above the market price. For the international trade "price dumping" is used to explain this phenomenon (Wikipedia 2011d). That is what exactly China did with the rare earth prices on the international market. It could lower the prices of rare earths, because of cheap labor and lack of environmental protection, then because of this other competitors were eliminated, which followed to monopolization of the market, and later implemented protectionist policy, put export quotas and high export taxes, minimized exports, and as an effect prices went high.

It is interesting that nobody complained from the very low rare earth prices on the market in the beginning of the 1990s, and was happy to buy unrestricted quantities from China. From this follows that China is not responsible for monopolizing the market, it was just a natural effect of the free market, where companies chose the cheaper price. After the price went high, the rare earth rivals could not reenter the market at once because of barriers to entry. These barriers are explained by Korinek and

Kim in their report on "Export Restrictions on Strategic Raw Materials and Their Impact on Trade" (Korinek and Kim 2010) and are as follow:

- "Process technology is specific to each ore body.
- High capital cost: typically more than 30,000 dollars per ton of annual separated capacity.
- Marketing is customer specific – rare earths are not traded on any recognized exchange.
- Limited operational expertise outside China.
- Industry is dominated by China where input costs are low."

3.6.2. The Ban on REEs Exports as a Political Weapon

In September 2010, as a response to a political conflict China unexpectedly decided to cut off supplies to Japan, the European Union, and the United States. Japan was the first country to suffer the outcome of the political conflict. It is the main consumer of rare earths and its economy relies heavily on the supplies from China. As a result the Japanese Automobile and Electronics industry were the most affected (Kölling 2011). Although it stopped supplies, the Chinese government rejected that it had imposed an embargo to Japan, and that the decision of stopping exports taken by the 32 exporting companies was more "personal" and not controlled by the government (Bradsher 2010a). Japan could not file a case with the WTO against China as at that time no new regulations on REEs were issued by China.

In October 2010, the EU suffered for ten days block in the supplies of rare earths from China (Bradsher 2010b). The reason was that EU supported the Japanese shortages of REEs by selling to Japan part of its stockpile. Although Europe mainly buys from China already processed products and did not suffer that much the ban on exports, its economy was immediately affected as the green energy sector became unstable (Lackner and McEwen-Fial 2011).

At the same time that China stopped exports to the EU, it did stopped exports to the US. The reason was that the US started an investigation on China's green energy policies (Lackner and McEwen-Fial 2011). Fortunately or not the US is not dependent on raw rare earths, and it mainly buys already processed rare earths from China, Japan, Austria, and France. For the US the distortion was not economical, but more political as this conflict undermined its relations with China and was understood as a treat to US national security.

As a result, the prices of the REEs increased over 10 times and continued to increase because after the conflict China put severe quotas on the exports (Bradsher 2010a).

3.6.3. Rare Earths Export-Quota-System as a Protectionist Policy

The cheap rare earths prices in 1990s, made mining in the US, Canada, Australia etc. unprofitable. In the beginning of the 1990s, Chinas protectionist policy was concentrated on increased exportation and limited import. But, according to neo-mercantilism theory "the protection of national raw material resources is crucial in order to maintain economic competitiveness" (Bieling, cited in Lackner and McEwen-Fial 2011). China is performing a kind of neo-mercantilism protectionist policy in order to guarantee that its own national industry could meet its demand on rare earths at present and in the future.

As the Chinese rare earth resources are limited and valuable, China decided to preserve them and to increase the profit from them. On the one hand, with this export protectionist policy, China wants to protect its domestic producers of high tech and "green" products and give them the possibility to be strong competitors on the market. On the other hand, China wants to boycott the monopoly of the US, Germany and Japan on high-tech and "green" technologies (China Blog 2011). For example, the attempt of the Chinese technology company Huawei to enter the US market was unsuccessful as the American government decided that this could threaten its national security (Carr 2011).

3.6.4. The Response to the WTO

In 2009, the US, the EU, and Mexico filed a case against China with the WTO, accusing China for limiting exports on crucial elements not only the rare earths. China explained that this is a part of a plan for maintaining a sustainable production of its resources and for minimizing the environmental impacts, the mining industry is causing.

Further, China justified its decision with Article 20 of the WTO, where its 153 members can adopt policy measures in order to protect its environment, and most of all the human health. On July 5, 2011, the Wall Street Journal reported that the WTO rejected the policy arguments of China for export restrictions necessary to protect its environment, "given that the restrictions do not apply for domestic production and supply" added the New York Times (Miller 2011, NYT 2011). Reuters informed on August 24, 2011, that China will file an appeal to the WTO in September confirming that Chinese policies are not violating WTO rules (Chiang and Martina 2011).

3.6.5. Acquiring Rare Earth Resources outside China

Not only wants China to preserve its own resources of rare earths, but the country also wants to acquire new deposits and already existing mines outside its national boundaries. China has subsidized in the last years new and old mining projects in Brazil, the USA, Australia, and South Africa.

For example, in 2005, China almost acquired the closed Mountain Pass mine in California (USA), which was sold to Chevron and latter, in 2007, to Molycorp Minerals, a private American company (Bradsher 2009b). Further, between 2008 and 2009, China invested in 26.6 billion dollars in Australia for rare earths according Keenan (Keenan 2011). In 2009, China also tried to take control of one of the richest rare earth deposits in Australia offering 252 million dollars for 51.6 percent stake in Lynas Corp. China is also the biggest buyer of Australian mineral exports. On July 26, 2011, China Daily announced that Great Western, a Canadian mining company owning a rare earth mine in South Africa, will join with the Chinese Ganzhou Qiandong Rare Earth Group to build a separation plant close to the mine, which will give the possibility the ore to be separated from its oxides on the production place. The Chinese company will own 25 percent of the joint venture (China Daily 2011).

This shows how China is still seeking to acquire mines overseas in order to preserve its own resources of rare earths exploiting on first place the foreign resources. This model is also seen in the US resource policy. Since 1986, the rare earth resources are claimed strategic resources by the Chinese government (Hurst 2010).

3.7. Summary and Conclusion

In less than 30 years, China turned the rare earth mining and production into a national monopoly. In the beginning of 1980's China was already planning its future as a world leader in high-tech technologies. In 1986, was adopted the Program - 863, proposed by four Chinese scientists, which was aiming to accelerate the high-tech development of China (Program 863). Slowly but surely, China went to number one producer of rare earths not only as raw material, but also as processed materials. From the beginning of 1990's and by 1997, its biggest rival, the Mountain Pass mine in the state of California, was forced to interrupt mining because of the decreased prices on the international market and environmental problems which the mine was facing. In 2002, the mining operations of the mine were finally stopped. That gave China the possibility to turn into the biggest producer and exporter of rare earths products and to take almost monopolistic place on the world marked with almost 97 percent world production of rare earths. Before the year 2000, also other world mine were closed unable to compete with the low prices of the Chinese rare earth products. At that time, China had also invested in new technologies for refinement and production of rare earth metals, which resulted to be far cheaper than the processes used for refinement in the USA (Foster 2011).

In 2004, China closed 18 rare earth processing plants because they did not meet the environmental standards and also imposed a new value added tax on rare earth exports equal to 12 percent. From 2006, the state started to reduce the export quotas sharply. For the second half of 2010, China reduced the export quota with 72 percent. This last move caused the prices of several rare earths to go up and generated supply shortages (Spooner 2008).

The Chinese boat incident, in September 2010, provoked a great debate on China's dominance of the rare earth market. This conflict let to reconsideration of China's rare earth monopoly, and the high prices for rare earths triggered new rare earth mining projects, reopening of mines, and research for substitutions and recycling.

Chapter 4

4. Political Responses in Three Different High-Tech Countries

As a major producer of rare earths China has taken already a strategic position and is developing its high technology industry. There are some companies which are transferring their operations to China in order to secure that they will not run out of supply on rare earths. Nevertheless, the three biggest high-tech and green-tech producers are looking already for alternatives on rare earth supply. In this part of the thesis a research is performed to report and understand the political reaction and responses of the affected countries: the USA, Germany and Japan.

4.1. The U.S. Response to China's Rare Earth Monopoly

Twenty years ago the USA was the major producer of rare earth oxides followed by China, Australia, India, and Malaysia. The USA is also the second country in the world with the most rare earth resources. Even though, in 2002 shut down the last US rare earth operating mine, the Mountain Pass Mine in California.

4.1.1. Background

Like in China as well in the US, the rare earths oxides are produced mainly from bastnaesite minerals. Small amounts are recovered from monazite, and the yttrium and other heavy rare earths are obtained from xenotime and ion-adsorption clays. Except the Mountain Pass, all other rare earths are produced as byproduct of the production of metals as tin, iron, zirconium, and titanium. The first mined monazite mineral in the US, North Carolina, was reported in 1887. Consequently monazite mining began in 1903, in South Carolina (Hedrick 2010). In 1949, the Mountain Pass deposit was discovered and two years later it started production of rare earths. From the 1960s to the 1980s, the US was the main producer of REEs. In 1985, China stared production of rare earths on large scale and this led to crack of the US rare earth industry, where in 2002, it closed its last rare earth production mine.

4.1.2. The US Resources and Reserves of Rare Earths

The US resources of rare earths account for 13 percent of the global rare earth resources or around 13 million metric tons. Table 4 and Figure 17 show the US proven and probable rare earth reserves and resources. Various deposits presented in Table 3 have been sampled and analyzed by core drilling. Only few were analyzed if their minerals are economically feasible to mine. For the rest of the deposits, it is still necessary more exploration through drilling, metallurgical testing, and economic analysis. At the moment, only one deposit meets every criterion for exploitation, and it is the deposit in Mountain Pass, California. Various deposits, such as Iron Hill and Wet Mountains in Colorado are already owned by U.S. Rare Earths, Inc. the company is already exploring the possibility of exploitation of the deposit.

4.1.3. U.S. Production, Supply and Demand on Rare Earths

In the period between 1950s and 1980s, the US was the major producer and supplier of rare earths for the rest of the world. Due to low market prices of the REOs and many environmental problems, the production at the largest deposit of rare earths in Mountain Pass, California was ceased in 2002. The peak yield of the mine was 20,000 metric tons per year between 1985 and 1990. In 2009, Molycorp announced that in 2012, Mountain Pass mine will be able to produce 19,500 metric tons (Long et al. 2010). All yttrium products fabricated in the US are imported mainly from China.

In 1984, the Mountain Pass mine production accounted for one third of the global supply and 100 percents of the national demand (Lifton 2010). At present more than 90 percent of the total supply of rare earths products comes directly from China. Although the US is not importing raw rare earths, but already processed materials, its national market is not facing direct supply problems. Nevertheless, The US demand for rare earths is likely to rise. By 2012, the demand for permanent magnets is projected to rise with 10 to 16 percent and rare earths in catalysts and with 6 to 8 percent per year. The demand situation for medical and defense applications will be also complicated such as the rare earths used in flat displays and hybrid cars (Humphries 2010).

Deposit		Tonnage (metric tons)	Grade (percent TREO)	Contained TREO (metric tons)
Reserves—Proven and probable				
Mountain Pass,	California	13,588,000	8.24	1,120,000
Resources—Inferred				
Bear Lodge,	Wyoming	10,678,000	3.60	384 ,000
Resources—Unclassified				
Bald Mountain,	Wyoming	18,000,000	0.08	14 ,400
Bokan Mountain,	Alaska	34,100,000	0.48	164 ,000
Diamond Creek,	Idaho	5,800,000	1.22	70 ,800
Elk Creek,	Nebraska	39,400,000		
Gallinas Mtns.,	New Mexico	46 ,000	2.95	1 ,400
Hall Mountain,	Idaho	100 ,000	0.05	50
Hick's Dome,	Illinois	14,700,000	0.42	62 ,000
Iron Hill,	Colorado	2,424,000,000	0.40	9,696,000
Lemhi Pass,	Idaho	500 ,000	0.33	1 ,650
Mineville,	New York	9,000,000	0.9	80 ,000
Music Valley,	California	50 ,000	8.6	4 ,300
Pajarito,	New Mexico	2,400,000	0.18	4 ,000
Pea Ridge,	New Mexico	600 ,000	12	72 ,000
Scrub Oaks,	New Jersey	10,000,000	0.38	38 ,000
Wet Mountains,	Colorado	13,957,000	0.42	59 ,000

Table 4. US proven and probable reserves and resources of rare earths, heavy minerals and phosphates are excluded. Source: Long et al. 2010

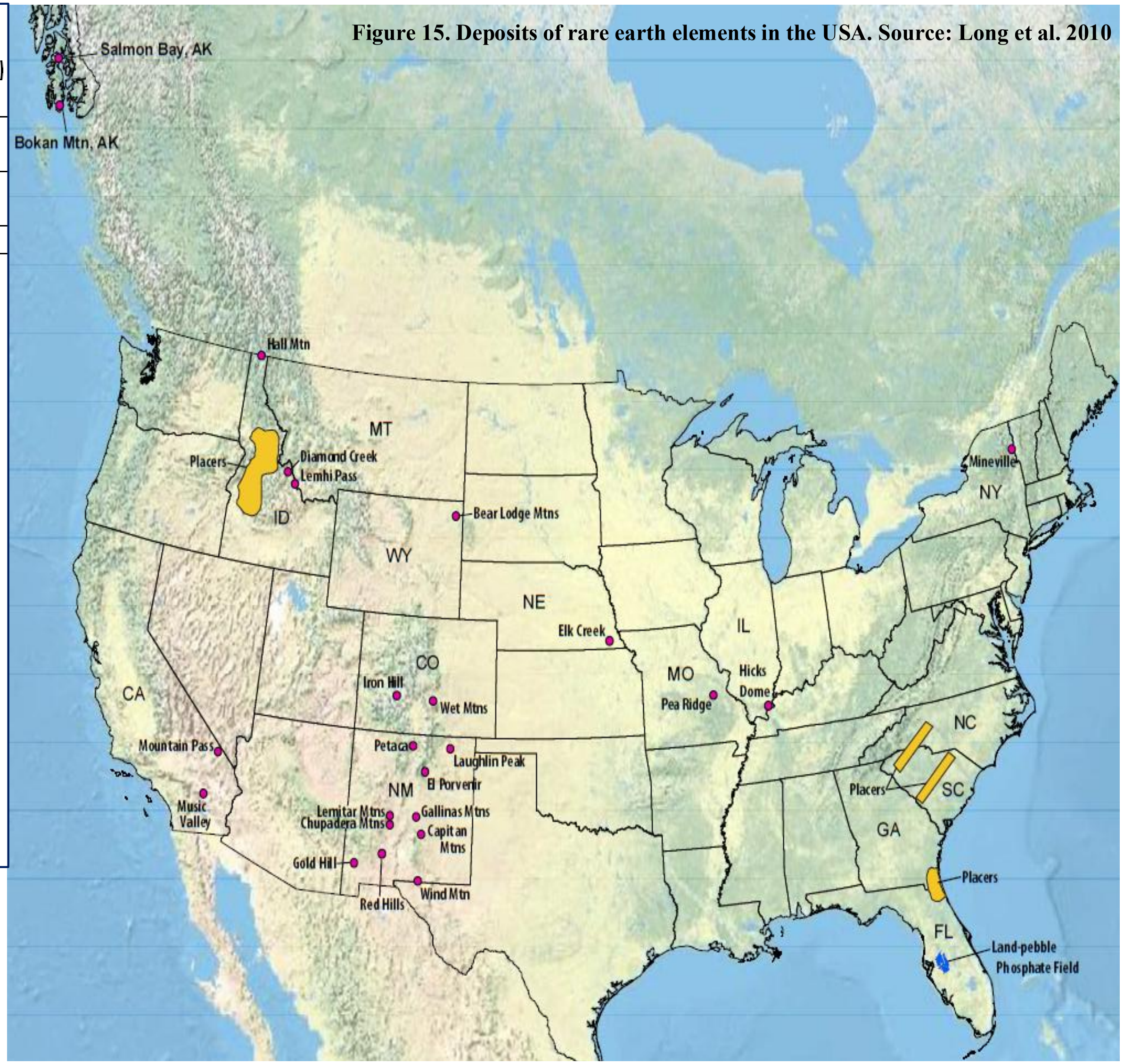


Figure 15. Deposits of rare earth elements in the USA. Source: Long et al. 2010

There are five main exporters of rare earths to the United States. They are as follows: China, France, Japan, Austria, and Russia. According to the US Geological Survey (Cordier et al. 2011) the US import of rare earths for consumption amounted 20,663.5 metric tons in 2008 (Fig. 18), and 14,967.5 metric tons in 2009. During 2009, the demand for REEs decreased because of the world economic crises in 2009. China exports to the U.S for 2008 was 19,270.6 metric tons (93.4 percent), where in 2009, it fell to 13,077.6 or 87.4 percent of the total import. The imports in 2009, from Japan and Russia, decreased as follows: 0.8 percent and 0.02 percent. Austria's imports increased to 3.2 percent and the imports from France decreased with 105 tons. Rare earth oxides, nitrates, hydroxides and other compounds such as mixtures of rare earth chlorides, mixtures of rare earth oxides, and cerium compounds were mostly imported in the US in 2008 and 2009.

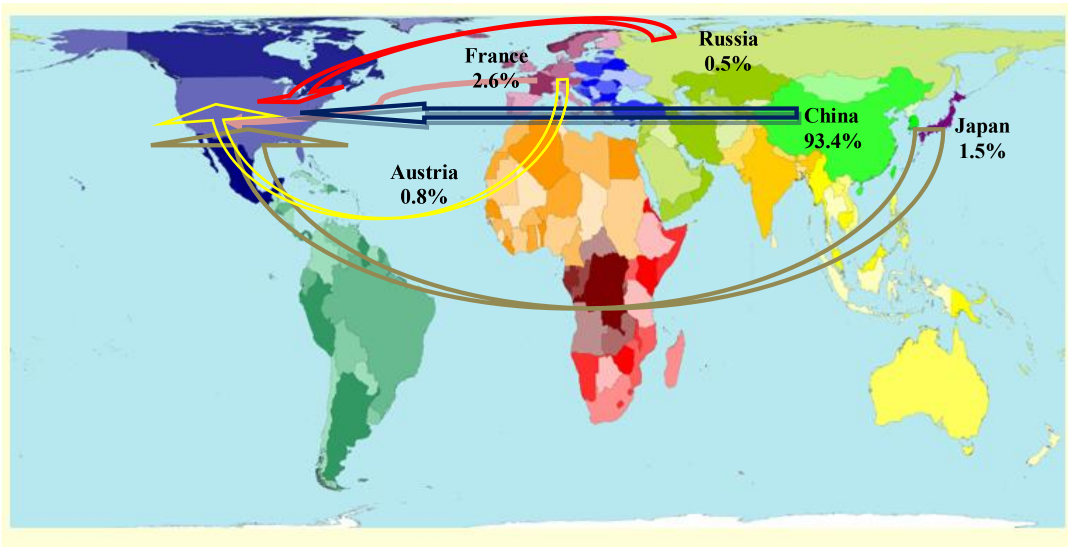


Figure 16. REEs exports to the US for 2008. Source: US Geological Survey, Cordier et al. 2011

From the five countries mentioned above the only country producing its rare earths from its own soil is China. France, Japan, and Austria for example, do not have rare earth mines. They import rare earths from China and small amount from other countries and then manufacture rare earth products in their countries and ship them to the US. Russia produce some of its own rare earths, but the amount exported is very small, and it is not clear if it is final product or raw material (Cordier et al. 2011).

In the US, the REEs are used in three main sectors. The first and more important use is in the automotive catalytic converters (25 percent), its second use is in petroleum refining catalysts (22 percent), and the third use is in metallurgical additives and alloys (20 percent). The REOs are used in the ceramics and glass industries, and in the metallurgy. A small number of the mined REEs are processed to individual metals (25 percent) the rest is processed to alloys. The most common individual metals are: cerium, europium, gadolinium, neodymium, samarium, and terbium (WPI 2011).

4.1.4. Problems and Challenges Related to REE Supply Chain in the US

In order to develop rare earth supply chain system, the US has first of all to open rare earth mines and allow production. Second, separation, refining, alloying, and manufacturing have to be developed in order to complete the supply chain circle. In the US completely lack the refining, fabricating, metal-making, alloying, and magnet manufacturing facilities that could fulfill a total rare earth production. The US Company Electron Energy Corporation is the only one producing samarium-cobalt permanent magnets but the alloys needed for the production of these magnets are imported from China (Electro Energy Corp. 2007). Neodymium-iron-boron ($Nd_2Fe_{14}B$) magnets are the most desirable magnets for the defense, energy and electronics applications. Unfortunately they are not produced by US manufacturers, but by a Japanese company operating in Tolleson, Arizona (Grasso 2011). At the moment, China produces 75 percent of the neodymium magnets and 60 percent of the samarium magnets and only a small amount of these magnets is produced in the US.

The cell phones, i-pods, energy saving devices all of them use rare earths and their production is at risk. The energy security of the US is also under a potential risk. The rare earths are used in electric motors and batteries, wind turbines, petroleum refining, optical displays, fluorescent lighting etc. The US military security depends on rare earths namely the U.S. weapon system for example optical displays, computers, neodymium-iron-boron for permanent magnets etc. For the US military technology it might take up to 15 years to develop independent supply chain from China, according to the “Critical Materials Strategy” report released by the US Department of Energy (Bauer 2010). Supposing that the independent supply chain is given one problem remains, and it is that the US reserves are lacking in rich heavy rare earths deposits, which are more important for the high-tech and military applications. The largest US deposit of rare earths, the Mountain Pass mine, is rich in light rare earths. The deposit at

Diamond Creek, Idaho, owned by US Rare Earths is likely to have heavy rare earths, but the deposit is still not operating.

Because of a possible rare earth shortage and risk for the US national security, the Congress Camera prepared and released a report on June 8, 2011 named “Rare Earth Elements in National Defense”. According to the report, the problem comes from the lost capacity of the US to produce these strategic and critical materials and not because of China that has cut its rare earth exports and restricts the world’s access to rare earths (Grasso 2011).

4.1.5. US Congress Legislation

The 111th Congress has introduced “Rare Earth Legislation” to encourage quick development of rare earth mines in the US. There are several Acts addressing the issue of rare earth management and preparing the US through the development of national supply chain for rare earths “from mine to magnets”. Below are three of the most important Acts for rare earths management.

4.1.5.1. Rare Earths and Critical Materials Revitalization Act of 2010

This Act was introduced on September 20, 2010 and approved on September 29, 2010. The bill announced development of Research and Development program, within the Department of Energy, which has to guarantee the long-term supply of REMs through identifying better processing, extraction, recovery and recycling technologies, as well as finding potential substitutes. An Information Center will be launched to assists scientists and engineers with important data not only from the US but also from the European Union to collaborate and share mutual interests. This is a five-year period program (2011-2015) with a budget of 70 million dollars. Further, “a Rare Earth Materials Loan Guarantee program for commercial application of new and improved technologies for the separation, and recovery of rare earths, the preparation of rare earths (i.e., oxides, metal, and alloys) and the application of rare earths in the production of magnets, batteries, optical systems, and electronics, among other things” will be launched (Humphries 2010).

4.1.5.2. The Rare Earths Supply-Chain Technology and Resources Transformation Act of 2010

The Act was introduced on March 29, 2010 and aims to introduce special stuff from the Departments of Commerce, Defense, Energy, Interior, and State as well as from the US Trade Representative and the White House Office of Science and Technology Policy in order to create an inter-agency working group. These representatives will have the assignment to determine which rare earths are critical to national and economic security. According to the degree of a critical element, the rare earths will be stored in the National Defense Stockpile and will be managed by the Defense Logistics Agency. For more information see Humphries 2010.

4.1.5.3. National Defense Authorization Act of 2011 and 2012

In this Act the Secretary of Defense has to "determine if any of the materials were strategic or critical to national security", and if so a plan has to be developed to guarantee their long-term availability. Further, it should be determined which specific military weapon systems are dependent upon certain REMs and if their sources could be interrupted or disrupted. The Department of Defense (DOD) has created plans for action against any potential risk to the national security as the "Rare Earth Material Inventory Plan", which establishes a government economic stockpile. For more information see Humphries 2010 and Terry 2011. On February 01, 2011, the American Security Project released a report named "Rare Earth Metals and US National Security", in which it is represented that the US is under a potential national security risk if it relies on China as sole supplier of rare earth metals (Coppel 2011).

4.1.6. The US Strategy: Military vs. Climate Security?

The US strategy is to become more energy independent, prosperous and secure. For this reason in the last years the US has invested billions of dollars in high-tech military products. Only in 2010, the DOD spent 15.2 billion dollars for energy costs. Almost half of this amount of money (7.37 billion dollars) was spent in 2008 for the Climate Change program. In the same year 647.51 billion dollars were spent on the Defense program (Pemberton 2009). Hopefully, after the American Recovery and Reinvestment Act were passed by the US Congress in 2009, for 2010 were budgeted for the Climate Change plan 10.61 billion dollars plus 68.86 billion dollars from the

Recovery Act. For the military budget went 687.24 billion dollars and from the Recovery act 3.26 billion dollars. From 1 percent in 2008 for Climate Change program, in 2010 were spent 10 percent more from the budget. From this data we can see that US have made a small progress on spending money towards the "greener future" (Pemberton 2009).

It is interesting to see that in 2010, the US imported rare earth for the amount of 1.14 billion dollars (Scissors 2011), where most of the rare earths were used for military technology and mainly dysprosium and neodymium were "used in magnets that make direct precision-guided munitions (e.g., Joint Direct Attack Munitions, Joint Air to Ground Missiles, Joint Common Missiles), enable stealth technology in helicopters, and withstand vibration, impact, and G-forces in aircraft, tanks, missile systems, and command and control centers" (USMMA 2011). At the same time China spends 1/6 more than the military budget of the US for military technology but twice as more for green technologies (McGowan 2011).

Lately the Pentagon admitted that actually the Climate security is of greater defense concern. To save mainly energy now the US Military will invest 10 billion dollars annually till 2030 on green technology for military use (Lombardi 2011). Compared to the total military defense budged this investment in green technology seems insignificant.

As the USA new economical plan is to invest in energy efficient and green technology, the Department of Energy is preoccupied if the US manufacturers will be able to compete on the world market given that the rare earth supply continues to shrink. This concern could be now even bigger after the US Military Forces have decided to turn into the US "green" Military.

4.1.7. Challenging China on its Export Policy

In 2009, the US accused China for limiting exports on crucial elements (rare earths and others) and imposing high taxes for exports, by filing a case against it with the WTO. The WTO rules ban export taxes but China has charged them for the last five years. Further, the WTO allows export restrictions if environmental damage is involved but only if the domestic consumption is also restricted, which is not China's case (Bradsher 2010c). Some experts claim that China imposes these restrictions to meet its own demand for REM and other materials and to force the production chain of end-use products to be transferred to China (Venter 2009).

4.1.8. Reopening of Old Mines and New Mining Projects

4.1.8.1. Molycorp's Mountain Pass Mine

The Molycorp Company owning the Mountain Pass mine in California is executing an expansion project for modernization of the mine. The 531 million dollars project aims to construct a complete rare earth mine-to-magnets manufacturing supply chain in the US. The environmental problems are said to be resolved as Molycorp received its permits to start the expansion and construction of the new facility. An average of 700 jobs will be available for the construction period, which is estimated to continue 18 months, and 200 to 300 permanent jobs after the construction (Business Wire 2010). As soon as the processing facility is constructed it is expected that the mine will produce up to 19,500 tons of REO per year. Unfortunately Molycorp will not be able to refine the REO into REM, and for this reason they will have to export it. On April 04, 2011, the Industrial Minerals journal announced that Molycorp has acquired a smelt plant in Estonia with a total stake of 90 percent (Watts 2011). This means that when Molycorp starts to process the REOs they will be processed in Estonia and not in China.

Several end-producers are already signing supply contracts with Molycorp in order to secure rare earth in their production. Such an example is W.R. Grace & Co., a US company that signed with Molycorp a five-year supply contract of lanthanum in 2010.

4.1.8.2. Rare Element Resources Ltd. Project

The second most promising project is that of Rare Element Resources Ltd. (RER). It has to develop the rare-earth-gold deposit in Bear Lodge, Wyoming, one of the grade deposits in North America. The inferred resources are estimated of 17.5 million tons at 3.46 percent REO. The REE distribution is high in neodymium (Nd) and praseodymium (Pr) – light rare earths, and europium (Eu), dysprosium (Dy) and terbium (Tb) – heavy rare earths. Four of these elements, excluding europium, represent 44 percent of the deposit and essential for the production of high strength permanent magnets. It is estimated that the mine life will be 15 years with total production of REOs per year of 11,400 tons (Rare Element Resources 2011).

4.1.8.3. Ucore Rare Metals Inc. Project

The Bokan Mountain deposit is the third promising project in Alaska, the U.S. According to the Company the deposit is the "most critical US deposit for dysprosium, terbium & yttrium" (Ucore 2011). There are 19 REO perspective zones and the richest is the Doston deposit with 3.70 million tons at 0.7 percent REOs, of which almost 40 percent are rich in rare earths. The expected begin of production is between 3 to 5 years.

4.1.8.4. Elk Creek Niobium & Rare Earth Project, Nebraska USA

Elk Creek, one of the largest carbonatite deposits in North America, was a former Molycorp project, which the Quantum Rare Earth Developments Corp. acquired on May 4, 2010. Quantum is a Canadian company focused on exploring niobium and rare earths resources that are economically feasible. The deposit is located approximately 75 km south of Lincoln, Nebrasca, and 5 km west of the village of Elk Creek. The resource contains 39.4 million tons of 0.82% Nb_2O_5 (niobium oxide). The re-sampling program started in November 2010, and a 6,000 m diamond drilling program is planned to begin in the second quarter of 2011 (Daigle 2011).

4.1.8.5. Other Projects in the USA

There are several other projects that are developing in the US. The deposits, which at the moment are under investigation and question of future projects are shown in Table 4 on page 28.

Pentagon officials and US geologist have discovered an enormous deposit of lithium, gold and REEs in Afghanistan. In 2007, was published a preliminary USGS report assessment estimating 1.5 million metric tons of probable REE resources in all of Southern Afghanistan. In September 2011, the USGS published an official release of the REEs estimates in Afghanistan. It is estimated that within the Khanneshin carbonatite of the Helmand province are found 1 million metric tons of REE resources. This project was funded by the DOD's Task Force for Business and Stability Operations. The US plans to support the development of the REE resources of

Afghanistan through private sector investment in order to promote regional prosperity and to benefit the Afghanistan people. (USGS 2011a)

Let us go back to the year 1970, when Haskin et al. (1970), University of Wisconsin, published a study named “Rare earths and other trace elements in Apollo 11 lunar samples”. In the study, the authors revealed that the lunar samples contained 12 REEs in nine samples from Tranquility Base. In 2010, the scientist Carle Pieters, Brown University in Providence, US, confirmed that on the moon there are local concentrations of REEs (NASA 2010). The private company Moon Express, based at the NASA Ames Research Park in Silicon Valley, is working on a robotic device, which will be able to operate and mine samples with valuable materials on the moon (Moon Express 2011). The device should be ready to land the moon in 2013. NASA and Moon Express have signed an agreement for cooperation and development of a lunar lander system. The private company believes that the Moon is the future “goldmine” of REEs. Still potential mining on large scale and ore separations shell be studied such as the economics of the possible lunar mining.

4.1.9. Environmental Concerns

The US potential of mining is very high but the environmental costs come to be even higher. In the US, the twentieth century was very important in recognizing the importance of the environmental protection for sustainable economy and one healthy society. Today the environmental control system has become very sophisticated and in particular for mining. All new mines are required to perform Environmental Impact Assessment in order to evaluate each environmental concern at every stage of the mine planning and design. Every stage of the mining process should be carefully controlled to prevent a possible threat to the environment and human health. The threat from radio-decaying elements is well known but the threat from rare earths elements in soil, water and human body is still unidentified.

In Afghanistan was established for first time in 2005, the National Environmental Protection Agency and the first Environmental Law was passed in 2007. There is no history on environmental protection from mining as the country has no developed heavy industry. It will be a great challenge for the country to develop further its environmental policy on mining otherwise it can suffer strong environmental degradation if the rare earth deposits are mined in the future.

4.1.10. Recycling and Substitution Projects

As a result of the Chinese control over rare earths, recycling projects have been considered as an option. For this reason the Rare Earth Industry and Technology Association in the US was established to "facilitate and foster the creation of a commercially sustainable Rare Earth industry and technology base to meet the growing global need for Rare Earth materials and products for Clean Energy, energy independence and defense applications critical to the economic and national security interests of developed nations" (REITA 2011). In order to fulfill this objective, the Center for Resource Recovery and Recycling was found to assist in this process. There are currently two institutes working together in order to develop new rare earth recycling technologies, Worcester Polytechnic Institute and the Colorado School of Mines. The Colorado School of Mines is currently developing a project named "Production & Recovery of Rare Earth Metals". The project aims to recover "neodymium from wastes generated during magnet manufacturing and separation of rare earth metals in intermetallic alloys, e.g. Nd-Fe-B and Sm-Co" and to reduce the energy consumption and cost production from recovery (WPI 2011).

The Ames Laboratory integrated with Iowa State University is the US National Research Center for Rare Earths and Energy, and is funded by the Department of Energy. The objective of the center is to train future scientists and engineer, to discover, synthesize and process alternative energy sources or substitutes and new materials for the critical materials. (Ames 2011)

The recycling and recovery of rare earths at the moment is still not very economically feasible. In the future, projects must be designed in such a way so that at the end-of- life cycle the rare earths are easy to recover and recycle.

The Advanced Research Project Agency (ARPA), which was established in 2006, within the US Department of Energy, is now responsible for new grant program called "Rare Earth Alternatives in Critical Technologies" (REACT). In the REACT program, 14 rare earth substitute projects are funded with 31.6 million dollars in awards that range from 400,000 to 3.4 million dollars. For more information on the projects see De Guire 2011.

In a project between General Electric and the US Department of Energy, nanotechnology will be applied to reduce the rare earths content by 80 percent in the production of permanent magnets (Ernst and Young 2011).

In an article from Financial Times, General Motors announced that they have already developed products without rare earth magnets. An example is the eAssist hybrid engine that will be available in the 2012 Buick Lacrosse (Lemer 2011).

4.2. The German Response on China's Rare Earth Monopoly

On October 26, 2010, the Wall Street Journal announced that the German Economics Minister Rainer Bruederle reported rare earth supply shortages in the country for first time (Preuschoff and McGroarty 2011). He further mentioned that this is not anymore only an economic problem but a political problem in addition.

4.2.1. German Resources and Reserves of Rare Earths

Between 2006 and 2008, the Saxonian Ministry of Economy and Labor funded the project ROHSA (Rohstoffe Sachsen) in order to gather available data on important occurrences and deposits of metals. A probable resource of about 40,000 t REO with an average grade of 0.5 percent was reported. It is the carbonatite intrusion at Delitzsch/Storkwitz, near Leipzig (Fig. 19), (Lehmann 2010 and Schüler et al. 2011). The deposit was actually discovered in the mid-1970 years in the presence of uranium exploitation work. The most common rare earths in the deposit are as follows: Ce (48%), La (27%), Nd (14 %) and Pr (5%). The deposit contains yttrium at 450 tons yttrium oxide. Recent studies showed that on the territory of the Erzgebirge significant concentration of scandium was found near Sadisdorf, Altenberg (Ad-hoc-AG Rohstoffe 2010). The Keiserstuhl carbonatite volcano in Baden-Württemberg is a possible rare earth element location, where in 1952, examinations of the so called Koppit marble we performed and showed that it contains around 3 percent of lanthanides.

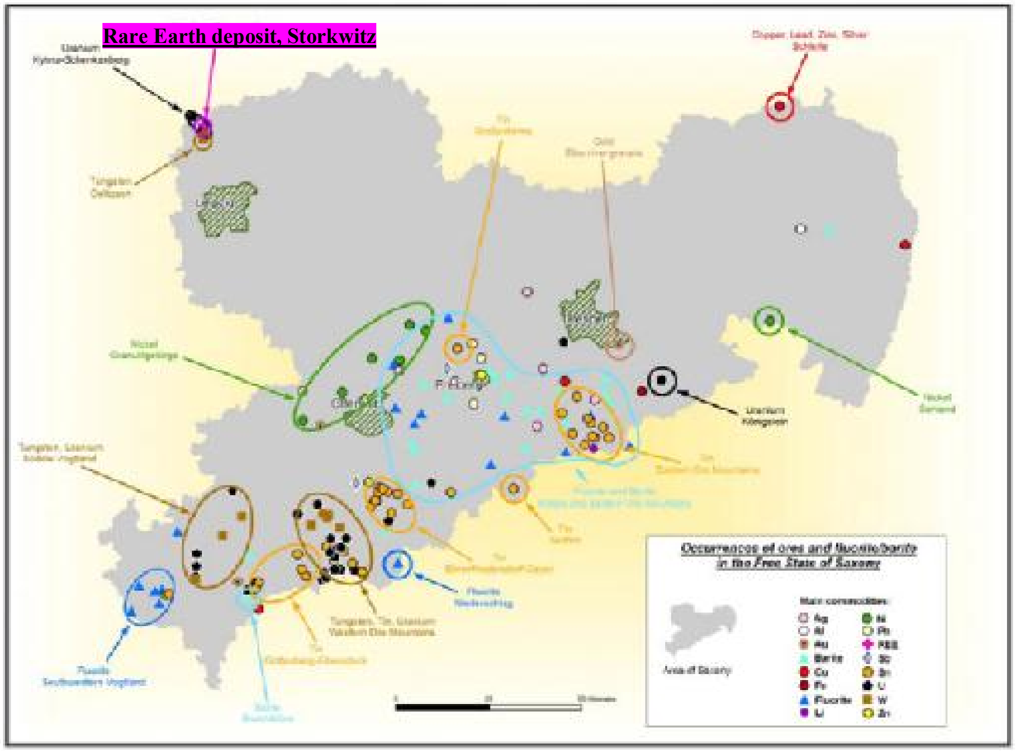


Figure 17. Geographic distribution of the most important ore and fluorite/barite occurrences in Saxony. Source: Lehmann 2010

According to the Geological Survey of Finland (GTF) and the Forum of the European Geological Surveys (FOREGS) (Salminen et al. Part1 2005, De Vos et al. Part 2 2006), cerium (Ce) is the most common rare earth element in the subsoil on the territory of Germany with around 75-86 mg/kg and is found in the loess/palaeoplacer area of Germany as well as in the central South-Eastern parts of the country. On the territory of Saxony the sample shows 130 mg/kg Ce. Cerium is very important for Germany’s optics and laser engineering industries, where the cerium oxide “is used in compounds to polish high-tech optics used for microscopes, cameras or binoculars and scandium, lanthanum, and neodymium are used for the coating of optical components” (Wetzlar 2010). Cerium can be found together with the light rare earths (La, Nd, Pr) which are more similar in atomic weight and ionic radius. Figure 20 shows the four most abundant REE in the subsoil on the territory of Germany and Europe (Ce, La, Nd, Y).

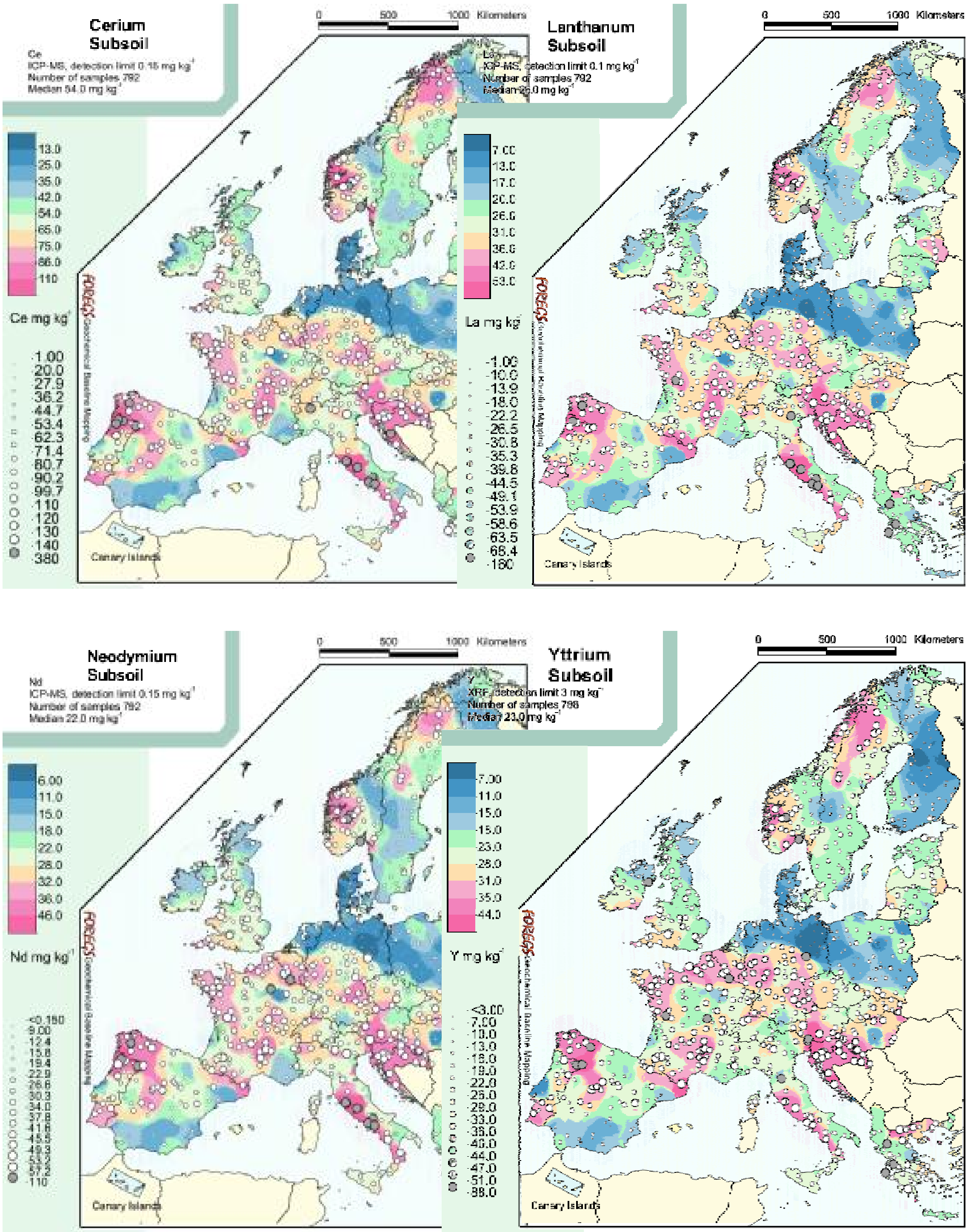


Figure 18. Subsoil contents of Ce, La, Nd, and Y on the territory of Europe. Source: Salminen et al. Part1 2005, De Vos et al. Part 2 2006

4.2.2. German Production, Supply and Demand on Rare Earths

Germany produces mainly magnets from rare earths. There are several companies in Germany producing magnetic material that is later on sold to companies producing permanent magnets. These are such as Schamberg Magnet und Kunststofftechnik GmbH in Schamberg and Vacuumschmelze in Hanau that also have production in Beijing, China. (Schramberg 2011 and Vacuumschmelze 2011)

In a report named "Kritische Rohstoffe für Deutschland" (Critical Raw Materials for Germany), prepared from Adelphi and IZT (Institute for Futures Studies and Technology Assessment), was shown that the consumption of rare earth oxides in Germany for 2008 was estimated to 3,000 metric tons, one part of it enters as industrial metal in processes and other part as individual metals in products (Erdmann et al. 2011). The import of rare earths is 100 percent, because Germany has not an own rare earth mining production in the country. On the contrary, a study on rare earths and their recycling published from the Institute for Applied Ecology, Germany, showed that in 2008 the total import of rare earth compounds for EU27 were 23,013 metric tons, from which 8 percent accounted for Germany; converted in metric tons this is 1,841 Mt (Schüler et al. 2011). Further, the German Agency for Raw Materials (DERA) together with the Federal Institute for Geosciences and Mining (BGR), published in 2010, a report on the current situation of the raw materials in Germany and provided information for the import and export of rare earth components showing that the total import for 2008 of rare earth components was 1,185 metric tons (BGR 2010). It seems that the import data do not coincide with the consumption of rare earths of Germany in 2008. The information is taken from different sources but all studies are performed in Germany.

According to the report "Critical raw materials for Germany" (Erdmann et al. 2011) rare earth have high supply risk and vulnerability as the demand on rare earth metals and oxides will continue to increase.

4.2.3. Problems and Challenges Related to REE Supply Chain in Germany

Currently the supply of lanthanum is at stake as the Federation of German Industry (Bundesverband der Deutschen Industrie, BDI) informed. The metal is used in the manufacture of catalytic converters, compact fluorescent lamps, flat-screen monitors and batteries for hybrid cars. Neodymium is important component for the production of the very powerful permanent magnets. One-sixth of the wind turbines constructed in 2010, contained neodymium magnets, which are also used in the reading heads of computer hard disks, mobile phone headsets, and the engines of electric cars (Siebert 2011).

Rare earths are important ingredient for achieving the aim of the Climate policy of Germany. Germany has not its own "mine to magnet" supply chain because 100 percent of the rare earths are refined abroad and imported. Currently Germany is negotiating with Russia, Mongolia and Kazakhstan to secure supply of rare earths outside Germany. Many German companies are also looking for partnerships with non-Chinese producers of rare earths to secure rare earths for their products. Tradium GmbH, located in Frankfurt/Main, is a manufacturer and trading company of metals of different purity levels as well as rare earth metals and it delivers them as semi-finished products, alloys, granules and powders not only to Germany but also to Europe. (Tradium 2011)

4.2.4. The Green Example

Although Germany enjoys more clouds through the whole year than sun, it has more than half of the world's solar generating capacity. In 2010, Germany invested over 10 billion Euros in green technology. It is expected that by 2020, Germany's green industry will be larger than its automobile industry. In the last 5 years, in Germany have been developed more than 50,000 wind-power jobs and more that 200,000 other green jobs, related with the renewable energy production. Germany has plan to close its 17 nuclear power plants until 2020, and for this reason needs to invest now in the development of new wind-energy farms. Germany has also plan to reduce its dependency on fossil fuels by switching to bio-fuels and alternative energy. (Oakes 2009)

4.2.5. The Raw Materials Strategy of Germany

As we have already discussed in the point above, Germany has started to secure its supply chain looking for new supply partners in the face of former Soviet countries. There are also several governmental plans published to secure the national supply of strategic metals and in this case the rare earth metals. Special attention is given to recycling and substitution. Stockpiling is also seen as an option.

The need for the development of environmental technologies has increased the demand for rare earths. As a response to the increased demand and the shortages of rare earths supply forced by the Chinese monopoly, the German Federal Ministry of Economics and Technology published in October 2011, the "The German Government's Raw Materials Strategy". The strategy starts with the statement "a policy for a sustainable raw materials supply is an integral component of our economic policy" and continues with "the Federal Government aims to put a political, legal and institutional framework in place to foster a sustainable and internationally competitive supply of raw materials to German industry" (BMWi 2011).

4.2.5.1. Action against Trade Barriers and Distortions in Competition

The German government will, within the EU trade policy, urge that an action is taken against distortions in the international trade in strategic raw materials. A bilateral dialogue will be performed with countries that distort trade and competition "in order to achieve a reduction in the level of political intervention in the market" (BMWi 2011).

4.2.5.2. Measures for Secure Resource Supply of Raw Materials

To support the secure supply of strategic raw materials Germany has prepared the following measures in its strategy (BMWi 2011):

- Guarantees for untied financial loan - to finance raw materials projects abroad and in return to receive a long-term supply of raw materials.
- Investment guarantees – already used to secure German raw materials supply. Offer protection from political risks.
- Export guarantees (Hermes insurance) – German export is insured if foreign clients do not pay.
- Geological studies prior to commercial exploration – the Federal Institute for Geosciences and Natural Resources performs geological work, especially in the area of the oceans and in so-called frontier areas, carrying out an important contribution to improve the knowledge of potential new resources.

- Promoting exploration – the Federal Government will support projects which are exploiting strategic raw materials. Loans will be given to companies exploring rare earths and the companies will start to give the money back only when the exploration is successful. This approach is taken only in Germany.
- Domestic extraction of raw materials – extraction of raw materials in Germany has to be improved.

4.2.5.3. Recycling, R&D, and Material Efficiency

A new resource technology institute is planned within Helmholtz Association by the Federal Ministry of Education and Research (BMBF). This institute will research and develop efficient raw materials technologies. R&D is performed mainly by the Federal Institute for Geosciences and Natural Resources (BGR) for new mining technologies and extraction methods and also highly-skilled young scientist will be trained to face the future challenges in the raw materials supply chain (BMWi 2011).

Germany will update its Closed Substance Cycle and Waste Act in order to establish better recycling of domestic waste and recovery of mineral waste. The Federal Economy Ministry is promoting subsidies for research on recycling technologies and substitution technologies for critical raw materials (BMWi 2011).

A national resource efficiency program is currently developed by the Federal Ministry of Environment that will propose a plan for minimizing the environmental damage from mining and processing of raw materials (BMWi 2011).

4.2.5.4. Raw Materials Partnerships

The raw material partnership is also a very important point from the German raw materials strategy. According to the strategy a balance should be established between the countries producing the raw materials and the countries buying them. Germany is already establishing partnerships with several countries to secure the rare earth supply for its industry (BMWi 2011).

4.2.6. Rare Earth Mining Projects and Co-operations

On January 10, 2012, the Spiegel online announced that the German group Deutsche Rohstogff AG will develop the RE deposit at Storkwitz, Saxony (Seidler

2012). Seltenerden Storkwitz AG, which will be responsible for the development of the resource, is a new company established by Deutsche Rohstogff AG. The investors are only from Germany and have gathered a capital in the amount of EUR 2.2 million. The Chairman of the new founded company, Bernhard Giessel said that important factors for the mine development were the support of the new commodity policy of the Federal Government of Germany and the planned “Alliance for securing raw materials”.

Tantalus Rare Earths AG is a rare earth mining company situated in Dusseldorf, Germany, and its principal project at the moment is the TRE project, north-western Madagascar. The project is currently under exploration and the drilling has begun in 2010. The results obtained until now, indicate a relatively high ratio of the more valuable heavy rare earths, of 21 percent of total rare earth oxides. Further the results showed low levels of uranium and thorium content, which from environmental point of view is encouraging, as the environmental damage will be less and the project could develop in the future. At the moment, Tantalus Rare Earths AG is negotiating with China Non-Ferrous Metal Industry Foreign Engineering & Construction Company co. LTD to form a Joint Venture company for production and processing of the rare earth ore in Madagascar. China Non-Ferrous Metals is a leading company in production and processing of rare earths utilizing its own technology (Tantalus 2011 and Presseportal 2011).

The next big exploration and mining project is concerned with the recently found big deposit in the Pacific Ocean from Japanese scientists. In the 1970s, the German company Preussag has tasted in a plot project to mine 500 tons of manganese in the Pacific, which ended successfully (Beyerle 2011). Since 2006, Germany holds license for exploration in two large areas (75,000 km^2) in the Pacific between Mexico and Hawaii. The geology specialist from the German Agency for Raw Materials, Michael Wiedicke, is encouraging that mining there is possible in the near future. Mining could be possible from 2021 onwards, and the expert claims further that mining in the Pacific will secure the strategic raw materials for Germany even if the price raises more and the export countries limit the export (Beyerle 2011). Another specialist, the Professor Franz Mayer from the University of Aachen, is skeptical and says that underwater mining is difficult and may last much longer to star compared to a normal mining project (Leslie 2011). Other experts are skeptical if this under water mining would not result in the next environmental disaster.

New York Times announced on July 19, 2011, that Russia and Germany will increase their economic and political cooperation. This means that German companies will be able to exploit the Russian rare earth deposits (Dempsey 2011). Further, the Finanzwirtschafter published on October 14, 2011, that the German Chancellor Angela Merkel has secured an access to Mongolian rare earth deposits (Finanzwirtschafter 2011). Kazakhstan is a country that has also large deposits of rare earth minerals, and also a lot of REE are contained in the tailings from the uranium mining. Germany has proposed a technology to recover the metals from the tailings. In May 2011, Germany and Kazakhstan agreed a commodity partnership which includes rare earths.

Further, Germany and the EU are looking to stabilize economic relationships with many African countries, as a lot of raw materials have remained below the optimal production, and mining and exploration projects could be further developed. EU has a strategy to use development policies in Africa for “sustainable supply of raw materials” (Ramdoo 2011).

4.2.7. The Response of the German Industry

Siemens, Germany’s largest engineering company was first to announce in its growth strategy its endeavor to secure supply of rare earths for its production. The company also is initiating a program to reduce its dependence on Chinese rare earths. Instead of going to China, Siemens will invest its money in projects across Russia, Australia, Greenland and California, US. Further, the company is developing a prototype of a wind turbine that is not using rare earths (Sadden 2011). On July 7, 2011, Siemens announced that have signed a letter of intent to establish a Joint Venture company with the Australian mining company Lynas Corporation Ltd. in order to secure the strategic raw materials necessary for the production of wind turbines. This partnership will be a “sustainable mine to magnet” supply chain where Siemens will have 55 percent share of the joint venture (Siemens 2011).

The world’s biggest chemical company, BASF has also passed a negotiation to form an alliance with the steel company ThyssenKrupp AG in order to combat possible raw materials including rare earths shortages and high prices (Matthews 2011). There are altogether 12 German companies that prefer to form alliances in order to prevent shortages on raw materials and secure their business for raw materials.

4.2.8. Substitution and Recycling Projects

According to the EU report on "Rare Earths and Their Recycling" from the Institute for Applied Ecology, there already exist alternatives for permanent magnets in motors containing REM for electric vehicles. Such an example is the asynchronous motor. It is less efficient and less compact compared to the conventional "rare earth motor", but at the same time is simple in construction and have low costs of production (Schüler et al. 2011). Germany has already included this alternative in its plan for National Electromobility Development and will invest in this option for further research and development (BMWi 2009). Another option, also included in the research plan, is the reluctance motor. It is a type of permanent magnet motor but using less rare earth than the usual permanent magnet motor. For the wind turbines substitution are proposed the gear and asynchronous generators. Of course, they are not as efficient as the gearless wind turbines with Nd-magnets. According to European magnet experts, at the moment there are no commercially available substitutes for dysprosium in Nd-magnets where the dysprosium improves the corrosion resistance in magnets and the coercivity (Schüler et al. 2011).

Lanthanum is used in the automotive catalysts; the so called FCC (fluid catalytic cracking). According to BASF experts, at the moment there is no suitable substitute of lanthanum for FCC as it has unique properties, but as price raises lanthanum could be reduced or substitute with other technology. At the moment, for catalyst no substitution to REMs are known. In the energy efficient lightening systems the know substitutions are rare and further R&D will be performed. Nanotechnology is also considered as an option. (Schüler et al. 2011)

At present, very small quantities of rare earths are recycled. The reason was the insignificant prices of the rare earths raw material. As price rises, new project for recycling of rare earths are emerging. One option is the recycling of rare earths from magnets. Technologies for recovering production waste of rare earths are to be developed. This option is mainly investigated in Japan. In Germany scientist are researching the option of recovering rare earths from old batteries by a hydrometallurgical process. The German company OSRAM patented in 2007, a recycling process of yttrium and europium from discharged fluorescent lamps (OSRAM 2011). Additional investigation on FCC recycling will be performed.

4.2.9. Environmental Issues

While opening of new mines and underwater mining might increase the environmental concerns, recycling and substitution could be a better way to combat the shortages of rare earth as in this way resources extraction is minimized, energy use and chemical use are also reduced. The only problem is that new technology for recycling is still missing and is under R&D, and there are no suitable substitutes.

While Germany is investing on mining projects abroad, there will be no environmental damage and problems on the territory of Germany. Depending on the environmental policies of the countries hosts, this will determine how much pollution and environmental damage will be presented in the end. It is wide known that third world countries suffer from weak environmental policies and high level of corruption.

4.3. The Response of Japan to the Chinese Monopoly on Rare Earths

After the Chinese boat incident in 2010, and the cease of rare earth exports from China to Japan, ten months later Japanese scientists announced the discovery of an immense deposit of heavy rare earths in the Pacific Ocean.

4.3.1. Resources and Reserves of Rare Earths

Japan is the typical example of a country poor in non renewable resources. Nevertheless it is one of the most industrialized countries and developed economies in the world. On the territory of Japan rare earth deposits are not found.

4.3.2. Japanese Production, Supply and Demand on Rare Earths

Japan imports 100 percent rare earth materials that are essential for its high-tech industry. The imported rare earth compounds in 2008, accounted for 34,330 tons, from which 91 percent were imported from China (Nakamura 2009). The imports in 2010 and after the cease from the Chinese government, accounted at 28,564 metric tons from which 82 percent were imported from China (Mogi 2011). Sojitz is a major rare earth importer for Japan, which has estimated that for 2011 Japan will demand 30 percent of the total world demand on rare earths or around 32,000 metric tons. It is already expected that for 2011, there will be a gap between the supply and demand on rare earths in Japan (Global Trade 2011).

Most of the permanent magnets for hybrid and electric vehicles are produced in Japan and 95 percent of the Ni-HM batteries are also produced by Japanese manufacturers in the country (Eriksson and Olsson 2011).

4.3.3. Problems and Challenges Related to REE Supply Chain in Japan

In September 2010, the supply of rare earths to Japan was temporally cut by China. Although later China continued to supply rare earths to Japan the quantity supplied was much lower.

Japan has processing industry of rare earths but not its own mining. For this reason it is looking for partnerships with countries rich in rare earths to invest in their mining and secure its own supply. The online Chinese newswire (China.org.cn) published on August 17, 2011 that "Japanese manufacturers have started to relocate their operations to China in an effort to resolve their lack of rare earth materials" (Yan Pei 2011). But China will allow this relocation only if there is technology exchange from the side of Japan for raw materials, and if there is only production of low-end technologies there will be no deal.

The Japanese Ministry of Trade, Economy and Industry is already giving subsidies at around 15.2 billion yen to its national companies such as Toshiba Corp. and Hitachi Metals Ltd. to work on projects for the minimization and recycling of rare earths of projects. The aim is to minimize the rare earth imports from 30,000 metric tons to 20,000 metric tons (Nakamichi 2011).

4.3.4. Japanese Rare Earth Policies on Secure Future Supply

The key policy of Japan is securing a stable supply. In 2005, a "Resources Strategy Committee" was found on the behalf of the Japanese Agency for Natural Resources and Energy. In 2006, the Agency published a report on "Strategies for Securing a Stable Supply on Non-Ferrous Metal Resources" (Kawamoto 2008) emphasizing four main points:

- Encouraging exploration and development;
- Encouraging recycling;

- Encouraging development of substitute materials;
- Stockpiling that is already performed.

To secure a stable supply the following actions are considered:

- Adopting a diplomatic approach with countries rich in raw materials by supporting their exploration and development of resources;
- Recycling of raw materials through the whole production chain;
- Developing of recycling technologies and mainly for problematic materials that difficult to be recycled;
- Developing of substitutes for materials that are critical for the supply chain;
- Gathering of information – geopolitical and resource data.

There are two main projects for R&D launched by the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry that have a special emphasis on the rare earths. The first project related to the Ministry of Education, Culture, Sports, Science and Technology is called "Elements Strategy Project". This project will promote the development of high efficient substances and materials without the use of rare metals and hazardous elements, which can be used as substitutes to these elements. Also a new product design will be implemented. The project will last for five years where in the end it should give complete substitution technologies and reduce use of rare metals in products (Kawamoto 2008).

The Second project from the Ministry of Economy, Trade and Industry is called "Development Project on Rare Metals Substitution". This project aims mainly to find substitution technologies and reduction of the usage of three main types of ores. Indium used in transparent electrodes should be reduced with 50 percent, dysprosium used in magnets reduced with 30 percent, and tungsten (wolfram) used in carbide tools also reduced with 30 percent (Kawamoto 2008).

4.3.5. Development of Seabed Rare Earth Metals as an Option for Japan

As Japan has an extremely large Exclusive Economic Zone (EEZ), the country has seen in this a possibility to explore its seabed. On July 20, 2007, the Japanese government implemented the "Basic Ocean Law" and a "Basic Plan on Ocean Policy" was published in March 2008. The law and the plan promote the development and the use of energy and mineral resources that exist on and below the ocean floor, and at the same time give priority to the preservation of the marine environment and reduction of the environmental load by promoting enhancement of the scientific knowledge of the sea (Kawamoto 2008).

In April 2011, Japan started its national research program for undersea raw materials. Three months later BBC news online reported on July 4, 2011, that “Japan finds rare earths in the Pacific seabed” with already estimated quantities from 80 billion to 100 billion metric tons (Fig. 21) (BBC 2011). The minerals will be recovered from

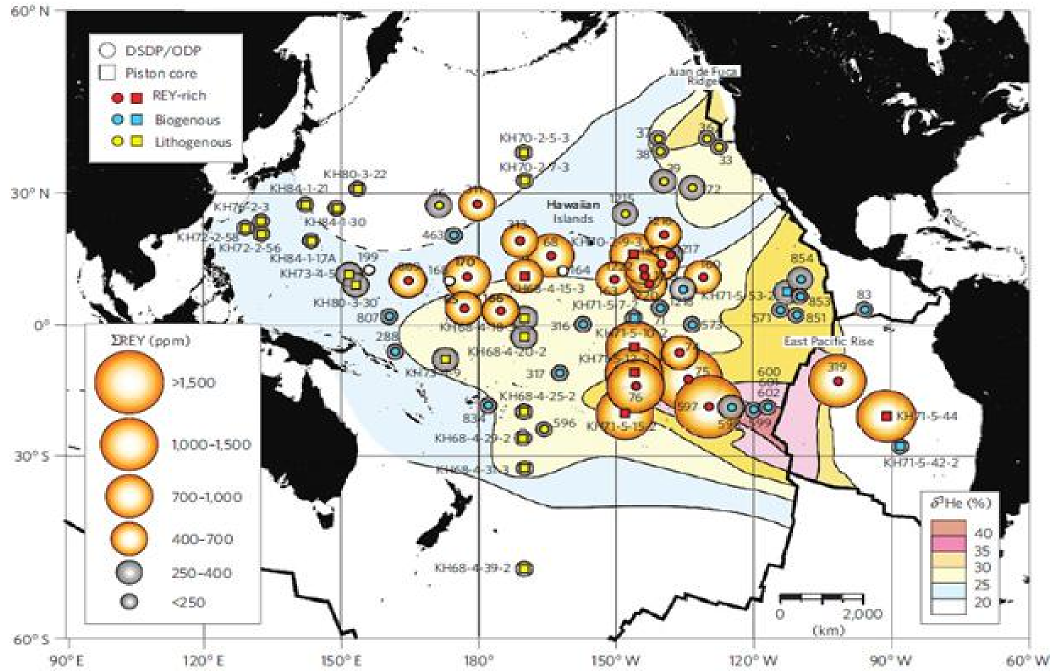


Figure 19. Distribution of seabed mineral resources in the Pacific Ocean. Source: Response 2011

the mud by acid leaching. This news arose many controversial opinions from environmentalists fearing for the damage that can be caused to the marine ecosystem because of mining in the Pacific. The deposits found are of heavy rare earths and at depths between 3,500 and 6,000 meters below the ocean surface. Experts are already skeptic if mining is economically feasible at all considering the depths, as no one has still mined at this profundity (Leslie 2011). Nevertheless, 10 countries have already a permit to start mining exploration in the Pacific, from which one is Germany and other is China (Beyerle 2011).

4.3.6. International Cooperation and Searching for Resources

Already in 2007, Japan was looking for international cooperation with African countries at the same time as the prices of rare earths started to increase. In November

2007, Japan and South Africa agreed to cooperate in the search for rare earths on the territory of the African country, as announced by the Japan Times online (Japan Times 2007). In return to the Japanese technologies and know-how, South Africa will provide a secure supply of rare earths to Japan. In November 2010, two months after the boat incident, the Foreign Minister of Australia assured that Australia will remain a secure long-term supplier of rare earths to Japan. In November 2010 again, Korea and Japan agreed also on cooperation for joint development of rare earth mines in third countries. Japan is also negotiating with Mongolia and Vietnam to open a supply opportunity.

There are several projects that Japanese companies are investing in their development. The first project that plans to produce 7,000 metric tons of light rare earth oxides is the Dong Pao project in Vietnam. The production is planned to start in 2013, and the cooperation is between Vinacomin, Toyota Corp, and Sojitu. In return Japan has to help with the construction of two nuclear reactors in Vietnam. Japanese Atomic Power Co. has agreed already to perform the feasibility study for nuclear plant. Financial help will be provided as well in the form of low-interest loans, and about 1,000 Vietnamese will be trained to control the nuclear facilities (Hirokawa 2011). In 2012, the research center in Hanoi will start operation, which will be working on new technology for separation and refinement of rare earth ore by minimizing the environmental damage from the ore procession (NPD 2011).

The second project, called Orissa that is planned to start in 2012, is in cooperation with India Rare Earths Ltd. and Toyota Corp. This project is planned to yield between 3-4,000 metric tons of LREO and thorium. India stopped producing rare earths in 2004, because of lack of competitiveness. In 2009, the Indian government invested around 32 million dollars on the Orissa 5,000 metric tons capacity plant. (Mukherjee 2010). Matsumura reported on October 29, 2011, in the Asahi Shimbum that the Foreign Minister of Japan and the Indian Minister of External Affairs agreed on joint development of rare earth metals between both countries and on negotiation for nuclear energy treaty. The precondition for “cooperating on nuclear energy technology would be for India to refrain from conducting nuclear weapons tests” informed Matsumura (Matsumura 2011).

The third important project, mainly because of the heavy rare earth production, is in Kazakhstan. A joint-venture company was set up in March 2010, between Kazakhstan’s National Nuclear Company Kazatomprom holding 51 percent and

Sumitomo Corporation of Japan holding 49 percent (SARECO). From 2012 onwards, it is planned a production of 3,000 metric tons HREO from uranium tailings (Watts 2011a). A joint-venture was also signed between Kazatomprom and Toshiba Corp. for research, exploration, production and sales of rare and rare earth metals and materials. Japan and Kazakhstan, from some years now, have already cooperated with each other on nuclear energy and uranium supply for the Japanese power plants. Japan has already agreed to provide technological assistance to Kazakhstan in order to build uranium reactors (Kassenova 2008).

4.3.7. Recycling and Substitution Projects

Japan has very developed recycling industry for a country poor in resources. Its aim is to become leader in the field of recycling. The Japan stockpiles of used electronics rich in valuable metals are even compatible to the world's leading resource nations. The Japanese National Institute for Material Sciences claims that the used electronics hold around 300,000 metric tons of rare earths. Development of more efficient recycling methods for rare earths could help Japan to reduce its dependency on China for REE.

A Japanese mining company in Kosaka, Dowa Holdings, has started a project for recycling rare earths from used cell phones and other used electronics (Tabuchi 2010). Hitachi Ltd., the third biggest Japanese company, has decided to recycle old products containing rare earths and expects to meet 10 percent of its needs by 2013. On December 6, 2010, the company announced that it has developed technologies for recycling rare earths from magnets of hard discs, motors, and air conditioners (Hitachi 2010). Other Japanese companies are also to follow the example of Hitachi as Mitsubishi Materials Corp. and Shin-Etsu Chemical.

After the Japanese-Chinese boat incident and the rare earth shortages, many Japanese companies have started projects on rare earth substitutions. Most of the projects are for rare-earth-free magnets. Japanese researchers at Tokyo University have developed an electric car that does not consist of any rare earth element (Toto 2011). Further, Reuters announced that Japan, EU, and the US will work together on a project to develop substitutes for rare earths (Bismarck 2011).

4.3.8. Environmental Concerns

Although in Japan there is no rare earth mining, recycling is taking place as "urban mining" option. Then it should be considered that through the recycling process environmental pollution is possible by liquid solutions used in the recycling. Further, it must be considered what environmental impact will produce the mining and processing in the third countries as hosts for rare earth mining. There should be studied what environmental laws, acts and standards they have in order to understand to what extend mining can cause environmental impact. Last but not least is the dilemma about the deep underwater mining that will be performed consequently in the Pacific. Underwater mining is further more dangerous and of great peril for the marine ecosystem (the oil spill in the Gulf of Mexico).

Chapter 5

5. Conclusion

Until now, the four main countries, China, the USA, Germany and Japan, which are the actual actors in this paper, have been studied separately in order to understand better the reasons for their decisions and actions in the complex world seen as a world economic system by the sociologist Wallerstein.

China's policy on REE, using its advantage of quasi-monopolist, has been developed in order to promote China's economic and national development. Firstly, the country needs the rare earth elements to develop its green sector, and it aims to become the world largest producer of green technologies. Secondly, it wants to develop its high-tech sector and to reach the quality level and full production chain of the high-tech products, which Germany and Japan possess. Keeping RE prices lower in the country and offering unrestricted supply are the main incentives for foreign companies to shift their production to China, which is China's key strategy; to attract foreign investors who want to produce their technologies in the country. But, this production has to be of high-tech products, otherwise companies, which want to produce low-end technologies, will not be allowed to invest, as the example with Japan. The third reason for China's policy on RE is that its resources will become scarce in the future. If they are mined at the present rate, then they will last for not more than 15 years. This is because China wants to create a sustainable use of its resources. The last reason for this policy is the environmental problems that the government has to resolve now, because of the unrestrained and illegal mining in the past years. Protection of the environment is one of the social objectives that China wants to achieve. These last two objectives, the sustainable use of its resources and environmental protection will not be achieved by export restrictions policy, but by reduction in the production of REEs in the country. The first step done is the closure of the illegal mines and the processing plants that do not comply with the environmental standards.

China's policy on RE was developed as an offset to the developed countries monopoly over the high-tech sector. China believes that the high prices of rare earths in the international market and the decreased supply will convince foreign companies to move their high-tech production to China. There were some companies that did exactly what China expected. But, all together the three developed countries the USA, Germany and Japan opposed the Chinese policy. They are already investing in new mining projects and in R&D of more efficient ways of substitution and recycling of these valuable metals. This hopefully, will lead to further modernization where no or only small amount of REEs will be needed to produce green and high-tech products.

In the US, the Chinese policy on rare earths and the increase of the global market prices have motivated many new and one old mining projects as well as the development of one deposit in Afghanistan, which will be subsidized by the US Government. The exploration of the Moon for REEs has been seen also as a future possibility. New projects in the recycling and substitution sectors for rare earths have been started and are subsidized by the US Government. It can be seen that the national production of REEs is encouraged and a complete development of rare earths supply chain is planned. A lot of capital is invested in these new projects stimulating the Research and Development, where new working places are created and are to be created. Also the best available techniques will be used to minimize environmental and human health damage. The goals of the US are to create a competitive domestic rare earth industry and to assure the long–term availability of rare earths by 2015. The key polices are the Rare Earth Supply-Chain Technology and Resources Transformation and National Defense Authorization Acts, as well as stockpiling and information gathering policies. As a conclusion, it seems that the Chinese monopoly on rare earths has stimulated the development of the national US economy and has awakened many more initiatives. It will be interesting for further investigation to be studied the impacts that will come from the mining and processing of the rare earth ore in the country, because to remind in 2002 the last rare earth producing mine was closed mainly because of the environmental problems as radioactive and chemical contamination.

Germany is a country with small resources of rare earths that could be developed in the future, as prices continue to rise. Exploration and development of Germany's biggest RE deposit near Leipzig has already started. Further, Germany's strategy is to limit the impacts of rare earth shortages on its economy. To secure constant supply on rare earths, a policy has been developed on creating partnerships with countries rich in rare earth resources. Providing financial assistance and knowledge on resource investigation and exploitation in the host countries, in return Germany is expecting to have unlimited access to the raw materials.

Germany's strategy on raw materials aims to invest in new R&D projects, development of old and new mines abroad, to increase cooperation between countries, create and support specialized stuff, create jobs in the mining sector, improve the environmental and social situation of the countries in the partnership. Recycling and substitution is already considered as an option for minimizing rare earth shortages and an option for sustainable raw materials policy.

It seems that the negative effect of the Chinese policy on rare earths on the German industry did not last for long, but on the contrary for very short time good strategies have been elaborated on governmental level cooperating with the high-tech and green-tech German manufacturers to minimize the shortages. Good policies are developed and international relationships for cooperation are tied.

The rare earth shortages in Japan have developed much more projects and international cooperation to help overcome it. The Japanese Government has developed a strategy to follow and is subsidizing many new projects on recycling and substitution together with many Japanese companies. Japan also secures rare earth supply from third world countries, but in the return for nuclear technology. This is very controversial point and might be interesting for a further research.

Nevertheless, we do not have to forget that China possesses one of the most important technologies, which are the highly developed processing technology of rare earths with a purity of 99.9999 percent. This technology is still not developed in other countries. For example, the French processing companies process rare earths to purity of 99.999 percent and the Japanese to 99.9 percent (Luca 2010). China has a greater advantage as its national RE supply chain is well developed. Germany, Japan and the USA still have to develop their complete supply chain once they have started the exploitation of their and foreign resources.

In our modern world the rare earth elements have became a strong political and economical weapon. And, China confirms to know how to use this "weapon" to suit its interests: more industrialization; switching to green technologies; technological independence from other countries; economic growth; and last but not the least, to possess political and economical power. The US, Germany and Japan just realized how dependent they are on China for the rare earth supply. However, these powerful countries are not waiting for a miracle and are already contra-acting the rare earth export-quota-policy of China by refusing to move their industries to China and looking for non-Chinese supply from third countries. The three countries affected share similar policies on rare earth supply and similar programs on research and development of substitutes and recycling technologies. They are also creating relations with less developed countries, offering them knowledge and technology in order to be allowed to exploit their resources. Many national companies from the US, Germany and Japan are trying to cooperate with non-Chinese rare earth producers to minimize their dependence on China. International cooperation is one of the main solutions. The three countries have agreed in a mutual cooperation against Chinese dependence on rare earths. The US and the EU are trying to use their political power with the help of the WTO to influence on the protectionist policy of China.

Chinese policy on rare earths seems one well and patiently designed strategy to gain monopoly over the metals, and in this way international power and wealth. We have seen this example of exercising power over Japan, with the "boat incident" between China and Japan. It looks as if China wants to change the "world system" order, using its hegemony over the countries dependent on rare earths. In the short term China will be able to influence on the international political and economic scene, as the developed countries are unable to respond to its "ban" on rare earths. This has resulted in a negative impact on the national economies of the three countries affected. However, in the medium and long term the situation is likely to stabilize, because new mining projects and reopening of old mines worldwide (the US, Canada, Australia, Brazil, India etc.) has started. Recovery and recycling will be improved such as possible substitutes will be developed. There have been already developed alternative magnets for wind turbines and electric cars, without the use of rare earths.

In conclusion, China as a sole country against the experienced developed countries will be very difficult to gain the total monopoly over the RE market in the long term. China's desire for power has shown to the developed countries that it is not a reliable economic partner, and they will orientate their production to other developing countries with cheap labor and less environmental policies. But, if China suddenly decides to change its policy on rare earths and removes the export quotas, then this may result in decreased world prices for RE that on the other hand may make all these investments until now unprofitable. And then China may gain the monopoly over the REEs again. Whether this will happen is a big uncertainty that only the future can show.

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