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Rare earth elements and a resource nexus perspective

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Introduction

Recently, there has been a renewed interest in the security of supply of non-energy minerals, especially in the context of technology metals used for manufacturing of low-carbon energy technologies. One of the most discussed is the group of elements called rare earths. The recent surge in their demand has been driven by the increased deployment of electric vehicles and wind turbines. In particular, the demand for dysprosium and neodymium, the two rare earth elements used for the production of neodymium-iron-boron permanent magnets, has been projected to increase by 2600% and 700% respectively, by 2035 (Alonso et al., 2012). Additionally, the rare earth supply side is concentrated in China, which currently holds a monopoly of 85% of total market share (U.S. Geological Survey, 2015), and is further skewed due to some resource nationalist policies, along with the inability of the other consumer countries to set up domestic supply chains. Taken together, the increasing demand and the institutional inefficiencies of the market, adversely affect the stability of rare earth supply and pricing.

From a broader resource management perspective, besides resource nationalist policies, the imbalance between rare earth supply and demand is driven by the stovepiped approach to climate change policymaking. In fact, increasing the share of low-carbon technologies within the energy mix (low-carbon energy transition) without considering the implications for raw material availability (used in manufacturing of low-carbon technologies), might create bottlenecks along the global supply chain, and also exacerbate environmental and social costs from dirty production processes, and geopolitical uncertainties from import dependence of the consumer countries. In order to reflect the complexity of the interlinked resource flows and systems, a more interconnected thinking in policymaking is required, as advocated by resource nexus approach (Andrews-Speed et al., 2015). Such approach allows examining the interconnections, tensions and trade-offs between different resources in a wider context of climate change (The Nexus Network, 2015).

In this light, the aim of this chapter is to shed light on the rare earths debate from a resource nexus perspective. The chapter goes beyond the traditional supply–demand discussion, which has been extensively put forward by earlier literature (Alonso et al., 2012; Elshkaki and Graedel, 2013; Habib and Wenzel, 2014; Hoenderdaal et al., 2013). Instead, it offers a more systemic perspective on the interconnections between low-carbon technologies and mineral resources.
from political economy and environmental perspectives. In particular, it provides insights into how the rare earth import dependence for the production of low-carbon technologies comes with high environmental costs and geopolitical uncertainties, when the extraction and production of the former are carried out in a few developing countries, in an often less efficient and environmentally unsound fashion.

The rest of the chapter is structured as follows: the second section offers a brief introduction of rare earths, and their supply and consumption trends. The third section discusses the environmental implications of their mining and processing, and contrasts these with their uses in manufacturing of low-carbon technologies. The fourth section analyses individual countries’ supply chains and considers strategies to securing a stable and equitable access to rare earths. The final section offers conclusions on how sourcing minerals through environmentally dirty processes for the manufacturing of low-carbon technologies causes a dilemma in transitioning to a renewable future. It also points out how the lack of equitable and stable access to minerals by manufacturers of low-carbon technologies poses barriers to innovation in these technologies. This chapter therefore argues for better coordination of climate change policies beyond sectoral stovepipes within and across countries.

Rare earths

The “not so rare” metals

Rare earths are a group of 17 chemical elements. As opposed to what their name suggests, they are neither rare nor earths. They rank among a group of transition metals, also called lanthanoids, which can be further split into two sub-groups of heavy and light rare earths. The data on crustal abundance indicates that rare earths as a group are not any less abundant than other industrial metals: the most abundant are in the same range as nickel and zinc, while the least abundant are more than a hundred times more abundant than gold. However, in terms of individual elements, these are found in earth’s crust in different quantities, the lighter elements being generally more abundant than the heavy ones (Cotton, 2007). Additionally, despite their occurrence in as many as two hundred minerals, not all deposits can be commercially processed, owing to the costs, their geographical location and the nature of minerals themselves (Walters and Lusty, 2011). In particular, it is the complexity of processing techniques, determined by mineralogy and chemical composition, which influences the competitive advantage of individual deposits. To put this into perspective, heavy rare earths are generally claimed to be more complicated for processing than light rare earths (Cotton, 2007; Walters and Lusty, 2011). Last but not least, some of the minerals also contain radioactive elements, the disposal of which exacerbates the environmental implications of the rare earth production (U.S. Geological Survey, 2013).

International production and trade

Rare earths have often been mined as by-products of other metals, such as iron ore, titanium, or uranium (Walters and Lusty, 2011). However, with their increasing importance in modern technologies, several projects for mining specifically rare earths have been launched in recent years (Hatch, 2015). In terms of reserves, roughly 42% of global rare earth reserves are concentrated in China (as compared to 80% of heavy rare earth deposits contained in Chinese ionic clays) (U.S. Geological Survey, 2013; Walters and Lusty, 2011). Other substantial deposits can be found in Brazil, the Commonwealth of Independent Countries, Australia, India and the US, while more recent discoveries have been made in Sweden, Greenland and Canada, as well as on the seabed of the Pacific Ocean. According to the official production figures, China’s stake in global supply of...
Rare earth elements peaked in 2009 with a market share of 98% (U.S. Geological Survey, 2015). This has been gradually decreasing to 85% by 2015, due to the new supply which gradually developed in other parts of the world. The most important sources of non-Chinese light rare earth supply are Australia and the US, with global shares of 8% and 3%, respectively (U.S. Geological Survey, 2016). Production has also taken off in India, and continues in Russia which is processing rare earths from stockpiles. Nonetheless opening new mines outside China is a rather lengthy process with low rates of success, especially in the current adverse market conditions owing to long lead times, declining prices, high capital intensity, as well as higher environmental standards and lack of capabilities in terms of technically trained personnel in developed countries (Berry, 2016; Clagett, 2013; Gschneidner Jr, 2010). China is therefore foreseen to maintain its monopoly in the short to medium term.

Besides being the main producer, China is also the main consumer of rare earths, with 58% of the estimated global demand (Kingsnorth, 2011). Its consumption has been increasing rapidly during the first decade of the century by almost 300% (Zhanheng, 2010). In order to satisfy the increasing domestic demand and to assure its industrial upgrading to higher value added products (Barteková, 2014), China has been setting up various industrial policies. The rare earth production and export quotas were intended to prevent overconsumption and to keep the environmental damage under control (Information Office of the State Council, 2012). At the same time, however, these have been distorting the international trade, as illustrated in Figure 21.1. Examining the export quotas jointly with the actual exported quantities, it turns out that while during the initial years the tightening of quotas have limited the actual exports of rare earths, the majority of export quotas remained unfilled in the subsequent years. The latter is expected to reverse, driven by the recovery of the post-financial crisis global demand and with the depletion of importing countries’ stockpiled material (Kingsnorth, 2013a; Topf, 2013). Looking at the production figures, these have been exceeding the actual production quotas set by the Chinese government. This discrepancy can be explained by the competition among

![Graph showing Chinese rare earth production and exports, and respective quotas, in tonnes of rare earth oxide equivalent, 2000–2013](image)

**Figure 21.1** Chinese rare earth production and exports, and respective quotas, in tonnes of rare earth oxide equivalent, 2000–2013

*Source:* based on data collected from MOFCOM (2014); Tse (2011); U.S. Geological Survey (2013, 2014); UN Statistics Division (2013)
local governments, which derive substantial financial resources from mineral production (Tse, 2011). Taken together, the increasing wedge between export and production quotas indicates the increased Chinese domestic consumption. Though export quotas have been recently abolished further to the ruling of the World Trade Organisation, these have been replaced by resource tax and export licensing.

The other main consuming countries of rare earth oxides are Japan and the North East Asian countries with 22%, followed by the US with 12% and rest of the world with 8% of estimated global demand (Kingsnorth, 2011). Due to the rare earth market inefficiencies described above, virtually all countries are import dependent from China (especially on heavy rare earths). Moreover, the rare earth import dependence by developed countries comes with high environmental costs and geopolitical uncertainties. The former comes in form of pollution export by developed countries relocating dirty industrial production to countries with less stringent environmental policies. The latter can be illustrated by the recent diplomatic dispute between Japan and China, which resulted in temporary suspension of the rare earth trade. The environmental and geopolitical perspectives arising from lack of systemic approach to policymaking are discussed within the following two sections, respectively.

**From dirty mining and processing to low-carbon technologies manufacturing**

*Environmental hazards of rare earth production*

Historically, rare earths have been mined from monazite, xenotime, bastnasite and ionic clays. While the former two contain impurities of radioactive thorium and uranium, the ionic clays of China contain no radioactive elements and are also easier and more cost efficient to process (U.S. Geological Survey, 2013; Walters and Lusty, 2011). It has been estimated that for each tonne of rare earths produced, there are up to 12'000 cubic meters of waste gas, 75 cubic meters of acidic wastewater, 1 tonne of radioactive residue as well as 2'000 tonnes of mine tailings containing thorium emitted to the environment (Hurst, 2010). Worse even, due to the lax environmental policies in most of the producing countries, these are discharged into rivers without any prior treatment, causing water and soil contamination, with adverse effects on lives of local residents and biodiversity. Besides the emissions of pollutants, surface mining and in-situ leaching techniques used for the extraction of rare earths from ionic clays have led to destruction of forests and severe landslides in mining areas (Packey and Kingsnorth, 2016).

The severity of rare earth production emissions on environment and people’s health has now also been recognised by the Chinese government (Information Office of the State Council, 2003, 2012). Yet, the implementation and enforcement of environmental protection and sustainable resource management remains weak (Liu and Maughan, 2012). This is further exacerbated by the rise of illegal mining activity in China, driven by increased global demand which cannot be satisfied by official supply, and facilitated by favourable conditions for extracting rare earths from ionic clays (Packey and Kingsnorth, 2016). Of a particular concern is mine sterilisation, whereby illegal miners extract high-grade ore and leave behind the medium- and low-grade ores. This not only causes environmental damage, it also has adverse implications for the sustainability and economic viability of rare earth deposits over time (Packey and Kingsnorth, 2016). It is also for this reason that China has started to actively combat illegal mining, having closed down 110 mines in southeastern provinces during the past years (Information Office of the State Council, 2012).
Rare earth elements

Evidence from other parts of the world underpins further the severity of societal and environmental costs of rare earth mining and processing: the La Rochelle plant switched the feed materials from monazite to thorium-free rare earth chloride, after the debate on radioactive thorium has intensified in France in the 1990s (Hedrick, 1994); the only American rare earth mine in Mountain Pass, California was forced to shut down in 2002, after a series of wastewater leakages containing heavy metals and radioactive material (Nystrom, 2003); and the Australian rare earth producer in the Mount Weld deposit outsourced the processing of rare earth concentrates to Malaysia, where also the waste is disposed of (Lynas Corporation, 2016). Regarding the latter, the Malaysian government granted the operating licence for the refinery, despite the large opposition by local civil societies (Stop Lynas, 2015), and the earlier experience of Malaysia with severe negative externalities from rare earth processing on local people’s health (Consumers Association of Penang, 1993).²

In spite of this evidence, the consumer countries continue neglecting China’s environmental motivations in setting up rare earth industrial policies. Undeniably, China has been using some of them to keep back rare earth supply for its domestic uses, so as to fuel the country’s industrial upgrading. At the same time though, these also aim at internalising the externalities to people’s health and environment. Disregarding these externalities by importing countries further propagates the implications of environmental consequences across the global supply chain. In this respect, rather than devising industrial policies, which ultimately distort international markets, producing countries should be developing eco-innovations in terms of cleaner production processes and more sustainable pathways to resource management. These would not only help minimising the externalities in producing countries, but once adopted internationally they would also allow establishing supply in countries with more stringent environmental policies, and thus contribute to decreasing import dependence and threat of supply disruptions. From a resource nexus perspective, this would significantly contribute to minimising pollution export, and ultimately contribute to greening the entire supply chain.

Rare earths as bottlenecks to low-carbon energy transition

Besides the negative externalities from the production of rare earths, the latter also create bottlenecks on the downstream side of the supply chain, due to their uses in various technologies. In fact, rare earths are used in various forms across an unusually wide spectrum of applications: ranging from mischmetal in metallurgic applications, through phosphors in medical applications (MRIs, X-rays, lasers) and in electronics (energy-efficient fluorescent lamps), to highly purified forms in high-tech products (cell phones, hard disk drives, microphones) and in defence applications (radars, sonars). At present, the largest pressure on the demand for rare earths is driven by low-carbon energy technologies. Their accelerated deployment is driven by industrialisation and energy poverty eradication in developing countries on the one hand (Miroux et al., 2011), and by decarbonising electricity generation and transport on the other (UNFCCC, 2015). The key technologies to achieving these objectives are wind turbines and electric vehicles. Their dependence on rare earths mainly comes from the use of rare earth permanent magnets in generators of some of the wind turbine technologies, as well as in electric motors, batteries and other parts of electric vehicles. For example, permanent magnet excitation generators within offshore wind turbines contain up to 250 kg of rare earths per megawatt (MW) of power range, or 2.5 tonnes of rare earths for a typical 10 MW wind turbine. In case of electric vehicles, a typical mid-size hybrid-electric vehicle with a permanent magnet electric motor and a nickel metal-hydride (NiMH) battery contains up to 4.1 kg of rare earths. An additional amount of up to 0.44 kg
has been estimated to be scattered across various parts of vehicles, such as in small magnets in sun roofs and automatic door locks, and in catalytic converters (Barteková, 2015). Note that the latter are contained in both internal combustion engine and advanced technology vehicles (i.e. hybrid-electric and all-electric vehicles).

Considering the tighter supply of some of the rare earths (Kingsnorth, 2013b) and the increased adoption rate of these technologies, concerns prevail that the deployment of the automotive market and its electrification could be severely disrupted by sourcing volatility of rare earths (Barteková, 2015). In terms of pricing volatility, the general increase in dimensions of offshore wind turbines, and the higher relative material cost in production of rare earth-intensive batteries, are the main concerns to keeping the offshore wind and electric vehicles competitive with other technologies on the market. Manufacturers hedge against pricing and sourcing volatilities by optimising the design of technologies towards less rare earth-intensive technologies. Currently, several rare earth-free alternatives to permanent magnets in wind turbine drivetrains and electric motor and batteries co-exist on the market. Some provide potentially viable future alternatives still waiting to be marketed (e.g. high temperature superconductors which make use of more abundant rare earths), some others have already been deployed yet have been found inferior in terms of their performance, efficiency and reliability (e.g. less efficient induction motors and generators due to excitation losses, or less reliable Li-ion batteries due to security issues and lower drive ranges, as well as geared drivetrains and hybrid drivetrains due to moving parts), as compared to rare earth-intensive technologies (Barteková, 2015).

The above discussion demonstrates how increasing reliance on low-carbon technologies within the energy mix, without considering the availability of rare earths (in terms of capacities to increase the supply in short to medium term), creates bottlenecks to a sustainable and equitable low-carbon energy transition. From a resource nexus perspective, a stovepiped approach to climate change policymaking creates bottlenecks in other parts of the system. Though individual manufacturers strive to develop strategies in response to pricing volatilities and availability risk, they aim at innovating in less rare earth-intensive technologies, which however often tend to be inferior in terms of their performance. Should sourcing of minerals for low-carbon technologies be left to distorted global markets only, these might cause manufacturers to get locked in myopic investment decisions leading to inefficient uses of materials and technologies. Instead, a more systemic approach to policymaking beyond the sector (i.e. considering the interlinkages across supply chains) and a better coordination across supply chains (rare earth strategies within and across rare earth consuming countries) is required. This translates into a need for a more active involvement by governments of consumer countries through comprehensive rare earth strategies and international collaboration.

**Rare earth strategies in the international context**

Concerns about volatilities in pricing and availability of rare earths for the manufacturing and innovation in rare earth-intensive low-carbon technologies have resulted in countries developing individual mineral strategies. However, despite their common objective, different countries responded differently to the global problem of securing stable supply of rare earths over time. This can be largely attributed to the fact that policy responses have been shaped by individual countries’ historical courses of action in terms of their national interests, resource endowment and experience in tackling earlier events of supply risk, as well as their respective policy styles (Barteková and Kemp, 2016).
The Chinese hegemony across the entire supply chain

China started to mine rare earths in the 1950s, and has gradually been increasing its monopoly position ever since (U.S. Geological Survey, 2015). It has often been claimed that this success owes to China’s cheap labour force and less stringent environmental regulations, as well as to the rare earth deposits which are easier and more economic to mine (Haxel et al., 2002). While this is generally true, there is more to China becoming the global leader in the rare earth industry. In particular, China’s early mineral policy encompassed strengthening of geological work, strategic prospecting and enactment of mineral laws and regulations (Information Office of the State Council, 2003). Moreover, China has also started to build up the rare earth innovation system in the 1960s. It established the first rare earth research institutes and state key laboratories, which were involved in R&D on industrial uses of rare earths, and basic and applied research on rare earth chemistry and physics, respectively (Barteková and Kemp, 2016).

Later on, the strategy of moving up the rare earths value chain has become an explicit part of the Chinese vision for industrial upgrading (Baotou National Rare Earth Hi-Tech Industrial Development Zone, 2015). After the classification of rare earths as “protected and strategic materials” (Information Office of the State Council, 2012), China started actively introducing industrial policies to limit the access of foreign enterprises to its supply chain, to restrict export and production of rare earths, to consolidate the upstream supply chain through merging rare earth producers into six state-owned industrial groups, to eliminate smuggling and to establish strategic stockpiles (Barteková, 2014). Recently, China has also attempted to assure upgrading through technology transfer. An example of such foreign direct investment is the purchase of an American permanent magnet producer, which has been holding patents on bonded permanent magnets (Robison and Ratnam, 2010). This acquisition has clearly helped China to establish production of permanent magnets, and ultimately also contributed to setting up production of higher valued added technologies which make use of these magnets. From its more recent policies, China has introduced the “go global policy” whereby it targets acquisition of resources abroad. Evidence shows successful acquisition of projects in Australia, forming joint ventures in Canada, and considering new untapped sources of rare earths in North Korea (InvestorIntel, 2015; Schearf, 2014; The Sydney Morning Herald, 2009).

Taken together, China has well-integrated activities across the entire supply chain, both in terms of extraction and processing, but also in terms of manufacturing of component parts like magnets, motors and generators, as well as of end-use technologies like wind turbines and alternative technology vehicles.

Weak rare earth strategies in the US, Europe and Japan

As opposed to the well-developed mineral, innovation and industrial policies targeting the rare earth industry in China, policies in other countries involved in the rare earth supply chain are far less advanced. While the downstream parts of supply chains tend to be well established across Europe, Japan and the US, these countries suffer a general lack of well-integrated upstream supply chain activities.

In the US, rare earth extraction was established in first half of the 20th century, the country subsequently becoming the major global producer of rare earths between 1965 and 1995. The early development of rare earth supply chain has been facilitated by a well-established regulatory environment rooted in early national legislations, in materials and minerals policies, as well as in the early establishment of institutions to manage potential supply disruption of minerals.
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(Barteková and Kemp, 2016). Besides the upstream activities, the US was also known for its permanent magnet industry, which was first established in the 1970s. Over time, however, its strategic perception of rare earths and their security of supply considerations have weakened, owing to the change in geopolitics (Humphreys, 1995). These have in turn been reflected in the decline of the American rare earth industry: the operations of Molycorp were suspended in 2002 (the production has resumed some years later, but the company filed for bankruptcy proceedings in 2015); and the permanent magnet production facilities of Magnequench have been closed down and relocated to China (Robison and Ratnam, 2010). Moreover, the US has also suffered a loss of know-how and expertise in all areas of rare earth mining, processing, chemistry and manufacturing of higher value added products (Gscheidner Jr, 2010). Thus, as opposed to China, which has comprehensive policymaking with long-term vision, the American rare earth supply chain faced disruption due to the discontinuity of political interests.

The case of Europe is different in that it has been historically a resource-poor country in metallic minerals. And while the debate of security of raw material supply dates back to the late 1970s (European Commission, 1975), building largely on raw material diplomacy, an integrated approach to securing minerals has been missing from the European agenda until recently. Moreover, on the country level substantial differences exist, some of them having an established track record in domestic rare earth policymaking (Sweden and Finland), while some others pursuing resource diplomacy to secure resources from abroad (France and Germany) (DEFRA, 2012). Yet, mineral strategies by most other European countries are still in their infancy (EUROMINES, 2016). As a result, extraction and processing activities are practically inexistent across Europe. In terms of mining, only two advanced projects exist in Greenland and Sweden (the actual start of their production depending on environmental permitting and financing), along with two separation plants located in Estonia and France. Some production of polishing powders, compounds and alloys occurs in the UK, Germany and Slovenia (ERECON, 2015). The main hurdles in establishing the European rare earth supply chain have been the missing EU-wide knowledge base on mineral deposits, as well as the lack of access to land, of streamlined permitting processes and of public funding of exploration (Barteková and Kemp, 2016). In terms of downstream activities, while production of electric vehicles and wind turbines is well established in Europe, manufacturing of component parts, such as permanent magnets, is practically inexistent. Taken together, the lack of accomplishment in establishing a European rare earth supply chain has been largely owing to the uncoordinated non-energy mineral policies across countries, and to Europe’s reliance on resource diplomacy in sourcing mineral resources from abroad.

Similar to Europe, Japan has also been a historically resource-poor country dependent on foreign imports. However, as opposed to Europe, it has had a more hands-on approach when it comes to stockpiling of minerals (dating back to its experience during the Second World War), and in securing these through long-term supply agreements via public–private partnerships, but also through pioneering seabed exploration within its exclusive economic zones (Deep Ocean Resources Development, 2015; JOGMEC, 2015; Sojitz, 2013). This diversification strategy has been driven mainly by the industrial lobby and the government’s active engagement in securing alternative sources of rare earths (Barteková and Kemp, 2016). Japan’s economy is significantly dependent on rare earths: the imported oxides are processed domestically into metals and alloys, and used as input materials for manufacturing of component parts and high value added products. In terms of the former, the production of neodymium–iron–boron permanent magnets dates back to the 1980s. Japan is also the market leader in production and export of home appliances, robotics and electric motors of electric vehicles. Taken together, the well-established rare earth industry in Japan is driven by national interests, by its active policy style in securing
access to new sources of rare earths, and by the existence of well-functioning institutions and public–private partnerships.

**Rare earth supply chain development from a nexus perspective**

Following from the above analysis, China appears to be the only country with a well-integrated rare earth supply chain. On the contrary, the upstream rare earth supply chains remain largely underdeveloped across the other countries. The US has seen its mining operations disrupted yet again, while in Europe further development of mines heavily depends on future permitting and public financing. Japan, which does not have mineable deposits of rare earths on land, attempts to establish seabed mining of rare earths, which however is more of a long-term project. In terms of separation and refining, besides China, facilities also exist in Japan, but are rather scarce in Europe and the US. With regard to downstream supply chain, the production of components and of end-use technologies is well established in all the four countries (though to some extent less in Europe, which has been historically lacking capabilities in the magnet industry).

Yet, in order to secure stable and equitable supply of rare earths, a more active involvement by governments of individual countries is required. These have now started formulating their respective rare earth strategies: the Raw Materials Initiative in Europe (European Commission, 2008, 2011), the Critical Materials Strategy in the US (Bauer et al., 2010) and the Strategy for Ensuring Stable Supplies of Rare Metals in Japan (Advisory Committee on Energy and Natural Resources, 2009). In general these strategies focus on: establishing stable access to raw materials on global markets through strategic resource diplomacy, supply diversification, and actions to removing distortionary measures by producing countries; establishing domestic supply by setting up framework conditions to facilitate exploration and extraction of minerals; decreasing primary consumption of minerals through increasing resource efficiency, establishing recycling and promoting use of alternative materials; stockpiling; and financing basic research programs carried out through public–private partnerships on minimisation and replacement of rare earth uses, and improvement of performance of rare earth–free technologies. While some developments have already been accomplished, establishing domestic supply of rare earths requires more active industrial, mineral and innovation policies across individual countries. These include devising mineral policies to streamline permitting, grant land access, and facilitate prospecting and industrial policies to (re-)establish knowledge infrastructure, pioneer mining from new deposits of rare earths and establish secondary sources of rare earths (recycling), and last but not least innovation policies to develop environmentally responsible mining and production techniques.

Yet, given the global nature of supply chains, and the system-wide implications of individual strategies, coordination should not only be pursued across sectoral stovepipes within countries, but also internationally across them. From a resource nexus perspective, coordination of strategies on global level is required for securing a stable access to minerals at fair prices within distorted global markets. Therefore, a need arises for global governance, with the overall aim of regulating the equitable access to supply chains and overseeing sustainability issues related to this, as well as reducing barriers to diffusion of technologies and moving into better coordinated innovation and market development processes on both ends of the supply chain. This in turn calls for establishing an international multi-stakeholder forum or board, composed of representatives from across the entire supply chain. This could examine the pressing nexus issues and could facilitate the international discourse, as well as the strategic short- and medium-term decision-making, for a smooth transition to low-carbon energy systems globally. Moreover, in order to
Conclusions

The aim of this chapter is to discuss the challenges of the rare earth market from a broader resource nexus perspective. In particular, this chapter aims at introducing the debate on how ambitious climate change policies devised without considering their impact beyond the sector, transcend into import dependence on rare earths, leading to high environmental costs and geopolitical uncertainties. These occur when extraction and production are carried out in an environmentally unsound fashion, concentrated in few developing countries such as China. The chapter also illustrates how individual investors might take myopic investment decisions leading to inefficient uses of materials and technologies. Therefore, in order to solve the rare earth dilemma, which arises from sourcing minerals gained through environmentally dirty processes for the manufacturing of low-carbon technologies, an active involvement of individual countries’ governments is required. Besides diversifying foreign supply, establishing recycling, and minimising the consumption of rare earths through efficiency improvements, a need emerges for setting up respective domestic upstream supply chains. Currently, the lack of rare earth mining and processing in developed countries is driven by environmental considerations and economic viability. This ultimately leads to pollution export to countries with laxer environmental regulation. Therefore, in order to avoid increasing further the externalities to environment and human health from accelerated deployment of low-carbon technologies, rather than imposing industrial policies which distort the internal market, there is an urgent need to develop eco-innovations for sustainable mining and processing techniques. These could on the one hand solve the problem of externalities in producing countries, and thus minimise their exposure to pollution export. On the other hand, they could enable establishing supply in countries with more stringent environmental policies, and thus tackle the issue of import dependence and threat of supply disruptions. A contrasting force here could be the “not in my backyard attitude” (NIMBY) which has been on increase in Europe and in the US, and relates to the citizens’ resistance towards development projects which are believed to have negative impacts on environment. Nonetheless, taken together, eco-innovations in mining and processing rare earths could contribute to continued industrialisation and green growth of both producing and import-dependent countries, as well as to greening of the global supply chain, and to a better coordinated climate change policy.

In a more general perspective, a stovepiped and territorial approach to climate change policymaking has been shown to create bottlenecks in other parts of the supply chain. In contrast, the resource nexus approach looks at critical interlinkages within socio-economic systems across scales, and allows thus identifying potential negative externalities and system-wide implications of using of specific resources. Therefore, policymakers should aim at devising policies beyond their sectoral reach, and accounting for the impacts internationally; that is, rather than adopting a silo-thinking to resource management, they should seek to establish international innovation alliances which could contribute to faster deployment of low-carbon technologies. What is more, it is important to involve various actors at multiple scales in the process of policymaking, so as to accommodate their distinct and often competing interests (e.g. the contrasting environmental concerns by civil societies with the profit-oriented industry). Such integrated approach to low-carbon energy transition concludes on the need for a multilevel polycentric governance mechanism, which could facilitate further the coordination in a world of interconnected
systems, heterogeneous national policies and priorities, and distorted markets. Ultimately, since rare earths are not so rare, a proper application of nexus thinking might help to deliver the Paris Agreement on climate change for multiple parties, and at the same time pave the way for integrated thinking in other areas where critical raw materials are required for a sustainable resource management.

Notes

1 It has been estimated that as much as 40% of China's total output was coming from the illegal mining. To put it into perspective, the illegal mining in China alone has been larger than the entire non-Chinese supply of rare earths (Packey and Kingsnorth, 2016).

2 An earlier example of pollution export in the Malaysian context is the case of Asia Rare Earth, the main shareholder of which (Mitsubishi Chemicals) despite of its established know-how in handling radioactive materials, has relocated the rare earth processing from Japan to Malaysia. While products were shipped back to Japan, the radioactive waste remained in Malaysia.

3 Assuming the variation of prices in permanent magnets of up to 420 USD/kg, the cost of electricity production by a permanent magnet excited direct drive wind turbine has been estimated to increase by 50% relative to a competing rare earth-free gearbox driven wind turbine with the same parameters (Barteková, 2015).

References


Rare earth elements