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Resilient Rare-Earth Supply Chains: Whither Quad?

Avantika Menon

Vivekananda International Foundation

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3, San Martin Marg | Chanakyapuri | New Delhi - 110021

Tel: 011-24121764 | Fax: 011-66173415

E-mail: info@vifindia.org

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Avantika Menon is a Research Assistant at Vivekananda International Foundation, New Delhi. She has completed her M.Phil. in Security Studies at the School of National Security Studies, Central University of Gujarat. Her M.Phil. Dissertation was titled, 'The Indo-Pacific Regional Security Order: India's Perspective'. Her dissertation was an attempt towards understanding the security order in the Indo-Pacific Region (IPR), with a central focus on India's strategic interests and engagement with other major powers in the region. She is passionate about research in the maritime domain and her research interests include- geopolitics, maritime security and the regional security architecture in the IPR, the Quad and China's naval activities in the Indian Ocean Region. She has a graduate degree in Politics and International Relations and an undergraduate degree in Economics (Hons.).

Resilient Rare-Earth Supply Chains: Whither Quad?

The ubiquitous iPhone is perhaps the most commonly cited example used to showcase the globalized nature of supply chains. Starting from its design process in California, US, the complex supply chain for its production and assembly spans 43 countries across 6 continents. For instance, the chip inside the phone is designed in the US, fabricated in Taiwan, tested in Philippines and assembled into the final product in China by a Taiwanese company, Foxconn[1]. Technological advancements driven by organisations constantly vying for production efficiency and lowered costs have led to the creation of increasingly complex and interdependent supply chains. At present, even the most mundane products have an 'overseas' presence with either offshore resource procurement, manufacturing or servicing facilities. While these global supply chains have been functioning relatively smoothly for more than a decade now, concerns regarding their resilience and the dependence on China as an important node have come to fore following the onslaught of the Covid-19 pandemic.

Global Supply Chains

A 'supply chain' refers to, "a set of independent organisations that act together to control, manage and improve the flow of materials, products, services and information, from the origin point to the delivery point (the end customer) in order to satisfy the customer needs , at the lowest possible cost to all members"[2]. Simply stated, from the creation of a product/service, its manufacturing, logistics, to its eventual sale and service, are all components of its supply chain[3].

Global Supply Chains (GSC) also referred to as Global Value Chains (GVC) involve international production sharing wherein the production process is fragmented into activities across multiple countries in accordance to their comparative advantages[4]. The liberalization of trade in addition to major advancements in logistics and information and communication technology (ICT) have directly contributed to the rise of transnational companies and the correspondingly growing GVCs[5]. While one country can be the source of a product and another country the destination, there are a lot of countries in-between which while part of the process are neither the source nor the intended destination. These countries represent the 'intermediate trade' taking place within the supply chain. The astronomical rise in the amount of intermediate trade has consequently led to an increase in the levels of proliferation and complexity of global supply chains[6]. Value is added incrementally across several nodes in the supply chain. Additionally, the increasing technological sophistication of products, offshoring of processes to low-cost labour countries, and the growing number of emerging markets with concomitant suppliers of the low-cost labour have lengthened and further convoluted the nature of supply chains. This in turn, has increased the vulnerabilities of the supply chain, making them susceptible to several risks and disruptions.

Supply Chain Risks and Disruptions

Although Supply Chains (SC) are geared towards ensuring optimal benefits and minimized costs, unexpected contingencies can often lead to supply chain disruptions[7]. The complicated structures of these SCs have made disruptions inevitable and thus, they have emerged as a "key contemporary challenge"[8]. A 'disruption' can be any unexpected event that hinders movement of either materials or products within the SC[9]. Concomitantly, disruptions at one node of the SC create ripples across its length and breadth[10]. From unavailability of raw materials, changing regulations, breakdown of machinery to natural disasters, disruptions can be wide ranging and vary in the degree of their severity[11]. Cyber-security threats such as Ransomware attacks are also increasingly posing a credible risk to several SCs. Some industries are more vulnerable to disruptions in accordance to the level of complexity in their SC, for instance, the automobile industry[12]. Similarly, some types of shocks are more likely to affect certain industries. The

Aerospace and Semi-conductor industries are more susceptible to cyber-attacks and repercussions from trade disputes due to their high levels of digitization and reliance on data flows[13]. In a 2019 study, practitioners listed natural disasters (which are considered high impact-low probability events) as the least relevant disruption for SCs[14], indicative of why the Covid-19 effected SC disruptions came so far out of the left field for everyone.

Supply Chain Resilience

Although academics and practitioners have been interested in understanding the resilience of organisations and their supply chains for over a large part of the previous decade[15], the Covid-19 pandemic has brought this issue to the forefront as the gaping vulnerabilities of the GSCs have been exposed to all and the sundry. Supply chain resilience refers to the system's ability to revert back to its original state after experiencing a shock or disturbance[16]. Some minor or major setbacks to the smooth functioning of a supply chain are inevitable, thus it is pertinent for them to be resilient. Accordingly, a resilient supply chain has the ability to recover quickly from any and all unexpected events[17]. For the purpose of building a resilient SC, a five-step process has been proposed which begins with the identification of risks, conducting a risk analysis, developing continuity strategies followed by a periodic review of plans and strategies[18].

Adoption of technologies such as Artificial Intelligence and Internet of Things, increased digitalization and enhanced analytics significantly contribute towards building resilience. These technologies enable companies to efficiently review different scenarios, assess trade-offs and increase transparency along all segments of the SC[19]. But increasing digitalization has its own caveats, it increases the vulnerability to cyber-security threats by several fold. Employing suitable mitigation strategies is crucial for minimizing the magnitude of the aftermath from exposure to shocks. Another critical aspect for building resilience is diversification. Diversification within SCs, particularly for critical raw material and components is essential during times of crisis. Other recommended approaches for enhancing resilience of GSCs are near-shoring and vertical integration. Near-shoring as opposed to offshoring can reduce excessive dependence on global logistical networks. Similarly, a shift towards vertical integration, which refers to creating in-house manufacturing units for critical components can also increase adaptability to shocks and create resilient SCs.

The Changing Nature of Global Supply Chains

China has dominated global manufacturing for quite some time now. Loosened state control coupled with cheap, efficient labour provided the ideal location for the outsourcing of manufacturing and thus, in no time China emerged as the 'world's factory'[20]. It is important to note that the global supply chains were in a state of flux well before the onset of the pandemic. Several geo-economic and geo-political forces had led to a renewed vigour for arguments against globalization and a subsequent rise in protectionist tendencies[21]. In addition to this, China's exponential economic growth driven by its manufacturing industry gave way to a subsequent increase in labour rates and cast a harsh light on its lax environmental regulations. The brewing US-China trade war added fuel to the fire and "dealt a fatal blow towards Chinese manufacturing"[22]. The supply chain disruption caused by the pandemic was the cherry on the cake, as the consensus regarding rethinking traditional supply chains grew by leaps and bounds. The pandemic exposed the flaws of outsourcing critical supplies and the excessive dependence on countries (like China) for both essential raw materials and vital finished goods. The supply chain disruption further heightened simmering geopolitical tensions and paved the way for the emergence of more nationalist policies that promote regionalization of supply chains and a shift in focus towards developing domestic manufacturing[23].

Rare-Earth Elements

Rare-earth elements (REE) subsume a group of 17 chemically and physically similar elements which are used as critical components for the production of various high technology goods ranging from mobile phones, computers, energy efficient lights to hybrid vehicles. Apart from consumer items they are also used in the manufacture of critical defence equipment and hence have gained increasing strategic importance.

Unlike what the name suggests, rare-earths are not that rare, in fact they are even more abundant than gold[24]. The 17 REE comprise of 15 lanthanoids in addition to scandium and yttrium. Although REE share several similarities, they have individually unique characteristics and thus cannot be substituted for one another. Due to this, REE such as neodymium, europium, terbium, dysprosium and yttrium with significantly vital applications, have been accorded a 'critical' status[25]. REEs are further grouped into Light REE, Heavy REE and Medium REE. In accordance to this classification, Cerium (Ce), Lanthanum (La) and Neodymium (Nd) are Light REE. Europim (Eu), Samarium (Sm) and Gadolinium (Gd) are Medium REE. Holmium (Ho), Erbium (Er), Terbium (Tb), Ytterbium (Yb), Dysprosium (Dy), Thulium (Tm), Yttrium (Y) and Lutetium (Lu) are Heavy REE. HREEs are significantly rarer than both LREEs and MREEs and are found in small quantities within LREE rich minerals like monazite and bastanasite[26].

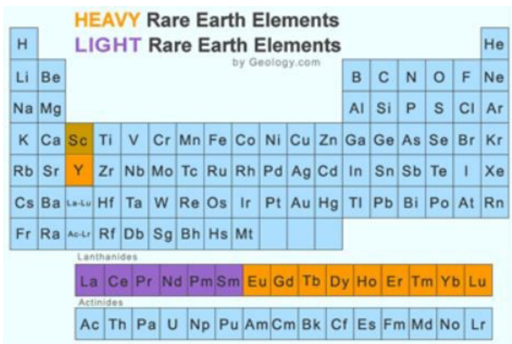

Figure 1: Heavy REE and Light REE, Source: Geology.com[27]

Applications of REE

Their largely varied characteristics allow for a wide range of applications for REE. Gareth Hatch divides REE applications into two categories- use of REEs as 'process enablers' and as 'technology building blocks'. Within the first category, REEs are used as fluid cracking catalysts in the petroleum refining industry, as catalytic converters in modern vehicles and as a polishing medium for glass mirrors, TV screens, computer displays and in the wafers used in silicon chips[28]. Within the second category, REE are used in collusion with other compounds to manufacture sophisticated products and devices. In this regard, REE are used to manufacture permanent magnets which are used in high performance electric motors and generators. Applications for these motors can range from use in electric or hybrid cars to wind turbines. These magnets are also used in the manufacturing of several consumer electronics such as speakers and hard drives. Another major application of REE is in the production of 'phosphors' which are then used for the manufacturing of all kinds of screens, ranging from LCD screens, LED screens to plasma screen displays. Lastly, REE like lanthanum in a compound with nickel are used to produce battery cells[29]. Rechargeable batteries made with REEs are increasingly replacing traditional cadmium or lead batteries due to their relatively low levels of toxicity and the provision of greater energy density[30].

The emerging wave of switching to greener technological alternatives has further solidified the significance of critical materials like REE in multiple intersecting global supply chains. Revisiting the iPhone example, within a single device, REE are used to manufacture the display screen, the phone circuitry, the glass polish of the exterior body, the speakers and the vibration unit[31]. And this range of applications for even a single element has widened over time with ever increasing technological innovation. For instance, Neodymium while initially used for colouring glass, today is majorly used for manufacturing permanent magnets[32]. Apart from their wide use in energy efficiency products and digital technology, REE have important medical and military applications as well. Militaries require the use of permanent magnets for use in both weapons systems and the manufacturing of rockets and bombs[33]. With constant innovation, the ambit of use for REE has widened even further with emerging uses in the production of lasers, super conductors, magnetic refrigeration and signal amplifiers[34]. This impressively wide array of applications portends the rising significance of securing supply chains of these rightfully deemed, critical minerals.

Rare-Earth Supply Chains

Akin to other GSCs, various stages of the REE supply chain are also carried out by a motley of companies across different countries[35]. The supply chain in divided into six stages– starting with mineral exploration and mine development, moving on to mining and concentration, after which the mixed rare-earth concentrate is put through a process of separation, followed by a conversion to metals and alloys, after which, the rare-earths are ready for use in further product development and manufacturing. But this is not the end of the life-cycle for these minerals, the sixth and final stage is the recycling and disposal[36].

Although REEs are available fairly abundantly in the earth's crust, their minable concentrations are scarce[37]. Thus, while several major deposits can be found all across the world, with the most substantial ones located in China, Vietnam, Brazil and Russia, not all of these are economically feasible for use and exploitation[38]. The United States held the position of the leading producer of REE till about the mid-90s. It was around this time that China emerged as a producer and quickly replaced the US with its share in global production crossing over a whopping 95 percent in 2010[39]. There are three major mining areas in China located at Baotou, Sichuan and Jiangxi which collectively make up 80 percent of its deposits[40]. The world's largest source for rare-earths is also located in China at the Bayan Obo Ore[41]. China is also home to unique ion-adsorption clay deposits in its southern regions which are believed to be one of the most "economic source of REEs"[42]. Bastnaesite, Monazite and Xenotine are the most prolific sources of REE as they constitute 95 percent of the world's known resources[43]. Out of this, monazite, most commonly found in beach sands, has been historically processed for REE in both India and Australia[44]. In India, the production of REEs is undertaken by Indian Rare Earths Limited (IREL), with monazite continuing to be the main source of rare-earths. In case of Australia, however, the carbonatite rich Mount Weld mine under the ownership of Lynas Corp. has emerged as its main source of REE[45]. The United States also initially depended upon monazite mining for rare-earths but the discovery of bastnaesite in the Mountain Pass district shifted the production focus and in the early 1950s open-pit mining for REE was started under a company called Molycorp. China's emergence as a strong competitor in the market in addition to the environmental and production concerns with the Mountain Pass facility, eventually nudged the US out from its prime position in the REE supply chain[46].

China's Dominance in the Rare-earths Industry

The oft-repeated quote, "The Middle-east has its oil, China has rare earths" is perhaps the most fitting summation of China's role in the rare-earths industry[47]. China's rare-earths production is primarily dependant on two sources, the Bayan

Obo deposit in Inner Mongolia and the ion-adsorption ores in South China[48]. China's displacement of the US from the top of an industry built on technology developed and commercialized by the latter has been the focus of several studies and research papers. It has been theorized that China followed a deliberate and carefully calculated strategy driven towards cementing a dominant position in an industry that has gradually gained immense strategic relevance[49]. An interesting paper by Brig. V. Mahalingam adeptly traces this strategy. According to him, China's REE strategy had a two-fold objective which while expanding the research and production within its domestic REE industry, simultaneously worked towards retarding the growth of REE industries both in the US and in other parts of the world. He states that, "China's larger aim of its REE strategy therefore was to become the leading high-tech power in the world overtaking the position held by the US"[50]. China was able to successfully push out competitors from the market by developing refining capacities fuelled by its large deposits. Additionally, the prevalent low labour costs and looser environmental regulations allowed it to offer unmatched competitive prices[51]. The processing of rare-earths from their mined deposits is a complex affair. The downstream segment of the REE processing chain is extremely capital and energy intensive[52]. Only a small handful of states possess the relevant technology, thus further squeezing the available market space. Fortuitously for China, ion-adsorption clays don't require any physical beneficiation[53], thus allowing it to supply high quality REE at significantly lower costs.

Even after the opening of newer mines and production centres outside of China, it continues to uphold its dominant position in the industry as separation and refining operations are still largely concentrated within its territory. In this segment, China continues to hold a daunting market share of 90 percent as of 2019[54]. Concerns regarding China's controlling position in the REE industry first emerged in 2010-2011 when rare-earth supply chains were jolted following Beijing's decision to reduce its export quotas by 40 percent[55]. This cap on exports was unexpected and the corresponding fears of a severe supply shock drove up the demand, resulting in high export prices for China. While the prices of REE have since stabilized to their pre-2011 levels,[56]the call for developing robust supply chains outside of China has only grown stronger, even more so after the supply chain crisis that occurred in the wake of the pandemic.

Supply Chain Resilience Initiative

The renewed Quad has so far shown greater vigour towards deepening their partnership and cooperation across multiple avenues, from maritime security, infrastructure development, ensuring vaccine supplies to climate action and securing vital supply chains across the region. While the commitment towards a free and open Indo-Pacific continues to be the core of their partnership, across the span of the two formal meetings in this year, the Quad has displayed a greater commitment towards creating resilient and secure supply chains in the region.

The Australia-India-Japan trilateral announced the Supply Chain Resilience Initiative (SCRI) in April 2021, during a ministerial video conference. Acknowledging the supply chain vulnerabilities exposed due to the pandemic, the Ministers agreed that there is a pressing need to address these disruptions and adopt relevant policy measures to enhance resilience. In a bid towards affirming their shared commitments towards strengthening supply chains, the trilateral announced the launch of the SCRI. Under the ambit of this initiative, two initial projects were launched with yearly meetings in place so as to provide requisite guidance to the implementation, as well as to regularly consult on further development of the initiative[57]. In his address at a special plenary with trade ministers in the Indo-Pacific Region in June 2021, Piyush Goyal, the Indian Minister of Commerce and Industry described the Indo-Pacific region as the "new economic centre of gravity of the globalized world". He also said that, "when the world looks at resilient supply chains it looks east to the Indo-Pacific Region" and reiterated India's commitment towards "ensuring a transparent, trustworthy, dependable and reliable supply chain"[58]. Diversifying supply sources and increasing competitiveness in various sectors have been earmarked as key features of the SCRI. There will also be an added focus towards attracting Foreign Direct Investment (FDI) in the region and the initiative will actively work towards strengthening their partnership[59].

The SCRI comes in the backdrop of a simmering supply chain crisis with investors increasingly seeking alternatives to China in an attempt towards securing their vulnerable supply chains. With Chinese manufacturing in decline, countries in Southeast Asia and South Asia have emerged as potential candidates for businesses looking for new locations to outsource their manufacturing to. In a bid towards occupying the apparel manufacturing niche, Vietnam has so far been successful in attracting Nike and Adidas to reallocate a large portion of its manufacturing and footwear base from China to Vietnam[60]. Similarly, Thailand has also seen an increase in its export volumes and is also gradually emerging as a potential competitor to China in terms of electronic manufacturing[61]. Regionalizing supply chains has also emerged as a suitable avenue towards enhancing resilience. With manufacturing centres in close proximity, the effects of supply shocks and disruptions can be minimized, thus making them more resilient[62]. It has been suggested that South Asia has immense potential for building robust and resilient regional value chains, a potential which so far remains largely untapped[63]. In this context, the SCRI provides a lucrative platform to partner with countries in the region in the pursuit towards diversifying supply chains, facilitating economic growth and eroding the Chinese position as a manufacturing giant.

Quad Collaboration on Critical Technology Supply Chains

In their first virtual meeting on 12 March 2021, the Quad announced the creation of a Quad Critical and Emerging Technology Working Group. As a part of their quest towards ensuring a free, open, inclusive and resilient Indo-Pacific, they have emphasised upon the key role played by emerging technology. One of the focal points within the agenda of the working group was to facilitate and convene regular dialogue on critical technology supply chains[64]. During the follow up landmark Quad leaders' summit, securing technology supply chains was identified as one of the four core efforts of the previously established working group. The Quad also launched a semi-conductor supply chain initiative which will essentially be a joint initiative towards mapping capacity, identifying vulnerabilities and bolstering supply chain security for both semi-conductors and their vital components[65]. These announcements are reflective of the Quad partners' strengthened commitment towards restructuring critical mineral supply chains and loosening China's stranglehold on the industry.

Hinging on its strategic position in the REE supply chain, China has often wielded this dominant position as a diplomatic bargaining chip. In a similar vein to its export curbs to Japan in 2010, following the nationalization of the disputed

Senkaku islands[66], China has indicated that it is not averse to weaponising its rare earths in response to further escalation in its trade war with the United States[67]. The events of 2020 have significantly soured China's relationship with each one of the Quad partners, thus further galvanizing their efforts towards creating reliable and resilient supply chains for critical minerals.

In this regard, the US president Joe Biden signed an executive order mandating a 100 day review of critical supply chains, largely focusing on semi-conductors, large capacity batteries, critical minerals and materials, and pharmaceuticals and Active Pharmaceutical Ingredients (API)[68]. Following the order, a report was released by the White House in June, 2021. In addition to increasing the domestic production of critical minerals in the US, the report recommended that Washington must work with allies and partners towards building collective resilience[69]. The report suggests that the US should, "engage with like-minded foreign producers of strategic and critical materials to promote value-based approach as they consider approaches to sustainability– rather than one focused on cost imposition"[70]. US Geological Survey, 2020 data indicates that at present the US accounts for 16 percent global REE production, with Australia accounting for seven percent and India trailing in with one percent[71]. The graph below shows the Quad's production metrics in comparison with China for 2019 and 2020.

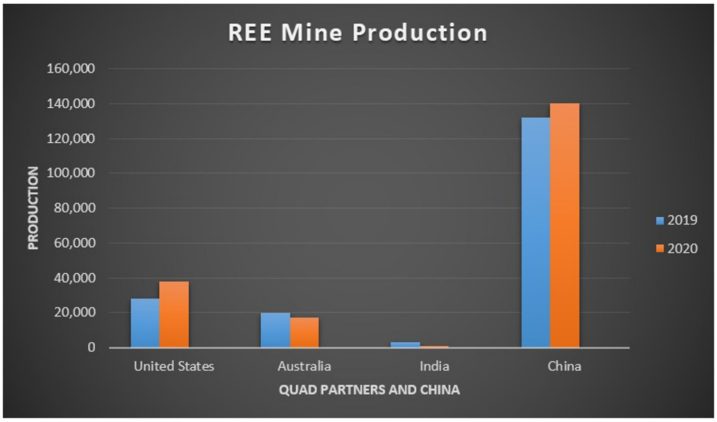

Figure 2: REE Mine Production of Quad Partners and China. Production in metric tonnes. Data from US Geological Survey, Mineral Commodities Survey, January 2021.

As the United States and Australia have moved towards boosting REE production, China's share within global production has shrunk to just over 60 percent in 2019[72]. In an effort towards diversifying production, several new projects have been launched outside China, particularly in Australia, Canada and the US. Out of the 20 projects announced, five will be ready to operationalize in the early 2020s[73]. Taking advantage of their ample deposits both the US and Australia have embarked upon a series of joint initiatives to boost production at both upstream and downstream levels. The Australian firm Lynas has announced the signing of a first phase contract with its American partner, Blue Line for building a facility for processing HREE such as dyprosium[74]. At present, China continues to dominate the processing of HREE, with HREE composition outside China only amounting to five percent[75]. While the US has significantly expanded its REE production it lacks domestic processing capabilities. Mined American ore is exported to China for further processing after which it is imported back to the US[76]. The proposed Lynas plant at Texas thus is a bold step away from the present dependence on China for processing needs. However, it is believed that this pivot away from China is easier said than done as the Lynas mines have much lower REE content than the ones in China. Thus, more ore will have to be mined to extract the requisite material[77]. Similarly to the US, Australia also lacks processing capabilities, "which is where most of the profit in rare-earths lies"[78].

Although lacking in resources, Japan plays a vital role in the REE supply chain. As a leading manufacturer of high technology products, Japan occupies vital space in the supply chain as an import destination, a source of finance for overseas mining projects, a node for providing downstream processing services and a hub for constant research and development[79]. Japan has a well-established partnership with Australia in the REE domain and has significantly invested in Australian mines. With the backing of the Japanese government, a Japanese firm, Sojitz signed a USD 250 million supply deal at Mount Weld, Western Australia[80]. Additionally, with the aid of Japanese loans, Lynas will be moving its processing facilities from Malaysia to Western Australia, in closer proximity to the mine[81]. Outside of China, Japan has emerged as the largest consumer of REE and several Japanese companies such as Toyota, Mitsubishi and Hitachi are increasingly announcing REE recycling initiatives with a goal of covering ten percent of their needs via recycling in the near future[82].

With REE reserves approximating 6.9 million tonnes, India has immense potential to emerge as a vital supplier in the REE supply chain, but this potential remains seemingly untapped[83]. As mentioned previously, India's reserves of LREE are contained in monazite deposits which can be found in the beach sands of coastal states like Odisha, Andhra Pradesh, West Bengal, Kerala and Tamil Nadu[84]. India is a net-importer of REE in finished form and at present continues to hold its position as a "low cost ore, concentrate and oxide provider to the rest of the world"[85]. Australia has shown increasing interest in partnering with India on critical mineral supplies, looking to propel India's goal of transitioning to Electric Vehicles (EVs) by 2030[86]. In this regard, Canberra signed a preliminary agreement in June, 2020 for supplying critical minerals to India[87]. While India has substantial LREE deposits, what it lacks are economically viable HREE reserves and domestic downstream processing facilities. India can secure its HREE needs by collaborating with strategic partners such as Australia, US and Japan. India can leverage its large reserves and work with the Quad partners towards securing capital and technology needed for developing domestic refining and processing facilities. It has been recommended that India could barter its LREE concentrates in exchange for processed lanthanum or neodymium from a proposed decentralized Quad reserve[88].

With both large reserves for production and even larger markets for consumption, the Quad has immense scope and potential for developing robust and reliable critical mineral supply chains. They need to work together and collaborate on developing requisite processing facilities outside of China and focus on more sustainable, recycling initiatives as a source for rare-earths. As climate action, sustainability and decarbonisation efforts have emerged as important facets of Quad cooperation, the four states can emphasise their shared commitments towards the same by developing and expanding the recycling of critical minerals as an alternative source. The processing of rare-earths has high environmental costs and negative externalities. The entire process is characterised with high water usage, energy input and the use of harmful chemicals[89]. In this context, recycling has emerged as a viable addition to the primary REE supply and can help in offsetting the high environmental cost of traditional REE production while simultaneously diversifying and strengthening the supply chain.

With the rising demand for green technology amidst a shared consensus towards expediting decarbonisation efforts, there have been speculations regarding whether the supply of minerals for these technologies can keep up with the growing demand[90]. It is no secret that this increasing demand will require an expansion of production facilities and supply sources outside of China while correspondingly minimizing environmental externalities. The Quad will have to navigate this tight-rope on its quest towards securing reliable critical mineral supply chains.

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VIVEKANANDA INTERNATIONAL FOUNDATION

3, San Martin Marg, Chanakyapuri, New Delhi – 110021

Phone: +91-11-24121764, 24106698

Email: info@vifindia.org,

Website: https://www.vifindia.org

Follow us on twitter@vifindia