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From Geology, through Geopolitics, to Security: a critical and comprehensive analysis of Rare Earth Elements, the vitamins of the modern society

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ABSTRACT

Rare Earth Elements are pivotal in the rivalry amongst leading industrial actors. The myriad of applications associated with these vitamins of the modern society has grabbed the attention of several individuals all over the world. Geopolitical realignments, environmental regulations, defence and military innovations are connected to the development of a rare earths' era, thus paving the way for hotspots of contention. As the green-tech transition accelerates, especially the one 'made in Europe', a fierce competition in order to secure access to rare earths is determining the evolutions of international relations systems. Geopolitics and security have converted these metallic elements from simple industrial inputs into critical elements of economic and strategic relevance. Nowadays, rare earths represent a top political priority both within national governments and international organisations that are fundamental in order to make ecosystems more resilient and sustainable. To certain extent, it is implausible to imagine a future without Rare Earth Elements; equally, the development of today's society cannot prescind from these goods on which the realisation of a climate-neutral, digital and secure society is dependent. Innovation, targeted strategies and adequate policy frameworks are essential to avoid scarcity and disruptions in the near future. The green-tech transition is here to stay, and Rare Earth Elements represent an added value to the latest revolution that will change the world.

Alla mia famiglia

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LIST OF ACRONYMS

- AGS Afghanistan Geological Survey
- AI Artificial Intelligence
- ASEAN Association of Southeast Asian Nations
- BRI Belt and Road Initiative
- CAGR Compound Annual Growth Rate
- CO2 Carbon Dioxide
- CRMs Critical Raw Materials
- DRC Democratic Republic of Congo
- EIT European Institute of Innovation and Technology
- EREAN European Rare Earth Magnets Recycling Network
- ERMA European Raw Materials Alliance
- EU European Union
- EVs Electric Vehicles
- FOE Future Operating Environments
- GDP Gross Domestic Product
- GECF Gas Exporting Countries Forum
- HREEs Heavy Rare Earth Elements
- IAEA International Atomic Energy Agency
- IEA International Energy Agency
- IoT Internet of Things
- IPCEI Important Project of Common European Interest
- IRENA International Renewable Energy Agency
- ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale
- LREEs Light Rare Earth Elements
- MITE Ministry of Ecological Transition
- MW Mega Watt
- NASA National Aeronautics and Space Administration
- NATO North Atlantic Treaty Organisation
- NGOs Non-Governmental Organisations
- NRPP National Recovery and Resilience Plan
- OECD Organisation for Economic Co-operation and Development

- OPEC Organisation of the Petroleum Exporting Countries
- PrNd Praseodymium-Neodymium
- PVC Polyvinyl Chloride
- QUAD Quadrilateral Security Dialogue
- REE4EU Rare Earth Recycling
- REE4EU Rare Earth Recycling for Europe
- REEs Rare Earth Elements
- SDS Sustainable Development Scenario
- SOEs State-Owned Enterprises
- UK United Kingdom
- US United States
- WEEE Waste Electrical and Electronic Equipment
- WTO World Trade Organisation

INTRODUCTION

This final dissertation investigates the utmost strategic, economic, geopolitical and military relevance of Rare Earth Elements (REEs), which are considered nowadays as the "vitamins of modern society". The aim of this master thesis is to explore the prospects of the rare-earth metal industry in the realm of the global energy transition and the defence industry. The decarbonisation of the global economy relies on critical minerals and their interconnection with the current international energy security mechanisms. One of the major future challenges is to skyrocket efforts to reduce emissions, achieving the phasing out of fossil fuels and, concurrently, safeguarding the integrity of energy systems worldwide.

The first preliminary chapter analyses the historical developments of Rare Earth Elements, the 17 metallic elements, located in the middle of the periodic table, that were discovered in the late 18th century. In the first place, a comprehensive description of each element and their industrial applications is provided, by placing the emphasis on their enigmatic terminology and codification since, from a geological perspective, rare earths are not sporadic elements. After having outlined their peculiarities and the distinction between Light and Heavy REEs, a section is dedicated to an overview of the global reserves that constitute the rare-earth mining sector. Alongside the countries with significant supplies of Rare Earth Elements, a general picture of major producers worldwide is delineated in order to forecast future trends and divert attention to supply chain issues. Subsequently, a critical analysis of the complexity that distinguishes Rare Earth Elements is carried out: after investigating the rampant demand associated to these commodities, this master dissertation sheds light on the specific sectors where they will be mostly advocated and the motives behind the expectation the demand will grow faster than in any other sector.

The first chapter then evolves in two different directions. Since domestic and industrial energy needs will increasingly deal with renewable energies and electrification processes, ergo in a world that is fighting climate change and, allegedly, running out fossil fuels in the medium-long term, a section is committed to explore the distinguishing features and similarities between non-renewable sources, primarily oil and nuclear energy, and Rare Earth Elements; in this regard, it is fundamental to come to grips with the geopolitical considerations and to the specific issue of how geographical consideration will no longer be a major driving force, thus preventing the establishment of a potential OPEC for critical minerals. Last but not least, in the forthcoming progression of the modern industrial revolution, lithium and cobalt are set to become critical minerals of extreme importance. Both commodities will be characterised by an exponential demand, similar to the Rare Earth Elements' scenario, in the realm of clean energy technology; the objective of this closing section is to compare the current and future trajectories of this mineral triad and how their paths are interconnected and essential in order to achieve climate neutrality and a global sustainable transition.

The second chapter is focused on the two side of the same coin of Rare Earth Elements: it illustrates the related thorny issues and concerns and, consequently, the solutions in the medium-long term. In the first place, attention is devoted to their geological features since, although an intense concentration in the Earth's crust, they are scarcely found into mineable ore deposits, thus pointing out at a quality rather than a quantity issue from a geological aspect. Extracting and refining those goods is not only costly and time-consuming, but it also entails enormous efforts in order to mitigate environmental impact and health effects. From the onset, despite unique fluorescent, magnetic and conductive properties, REEs have been considered as a hostile entity to the environment, triggering health concerns among people. Concrete examples are provided (i.e., Bayan Obo and Ganzhou cases in China) in order to highlight that there is even a negative connotation associated with these items, therefore paving the way for a comprehensive analysis which prompts debates and discussions, in the further chapters, about sustainable solutions and mitigating effects.

The hoped-for low-carbon economy is inevitably correlated with massive investments, scaling-up finance for sustainable objectives, reframing incentives in electricity, etc. Such an increasingly challenging scenario entails economic concerns since REEs market is considered to be imperfect: energy and the Rare Earth Elements' demand is proliferating but keeping a regular supply to meet the demand is expected to be problematic, due to several reasons highlighting a balance problem, amongst which greenflation and price volatility. The convergence of geological, environmental and economic concerns culminates in geopolitical ramifications that are analysed in order to provide a complete picture of Rare Earth Elements. The quest for these commodities is influenced by the unquestioned leadership of China; the final section of the second chapter investigates how future geopolitical entanglements develop, which actors are expected to counter this monopolistic control and how mounting geopolitical tensions may be limited by multiple initiatives that constitute the white-hot core of the subsequent chapter.

The latter part of the second chapter presents the most adequate solutions that have been adopted in modern society and the ones that will be implemented in the medium-long term in order to cope with the heterogeneous issues described in the previous part. First and foremost, an examination of the most effective processes of diversification of supply endorsed by several countries (ranging from Japan and Australia to the US and Canada, while the last chapter will be exclusively dedicated to the EU) is carried out. The objective of mitigating negative impacts and reducing associated risks from a geopolitical perspective are supposed to be integrated by rigorous assessments in order to determine the extent of environmental damage and, in this regard, promote proper regulatory measures. Alongside, the Chinese grip on the rare earths supply chain should be limited on the one hand by filing patents on an international scale, while on the other hand by new technologies that are intended to unlock additional supply. In this respect, an ample section is reserved both to innovative recycling processes and to replacement (at least) of LREEs, for instance by investigating how these commodities may be recovered from the deposits of nuclear fuel and viceversa. Finally, a succinct overview of how the REEs global market may be regulated by the most prominent actors, such as the International Energy Agency (IEA) and other less known but competent authorities, is delivered.

The third chapter is devoted to the global leader of the Green-Tech transition, the EU, whose outstanding objective is to achieve the long-awaited and discussed climate neutrality by 2050. Alongside, some insights into the connection between Rare Earth Elements and the EU defence industry are provided. Specifically, the recent Russian invasion of Ukraine has paved the way for heated discussion for boosting military and defence spending. In the second chapter, this master thesis will have already investigated the centrality of Rare Earth Elements in the development of essential military equipment in wartime, ranging from precision-guided weapons to stealth technology.

A sustainable transition depends strongly on Brussels' ability to render its industrial ecosystem more resilient to external bottlenecks and interference. The EU's high level of foreign dependency, specifically in the REEs world, has been a long-established fish to fry since those goods are a prerequisite for Brussels' green political agenda. After an historical analysis of the relationship between the EU and the REEs, starting with the development of the first list of CRMs in 2011 to modern times and some insights into the 2023 strategy, the chapter explores in depth the challenge of securing access to sustainable raw materials, by describing Brussels' connected efforts to achieve the Green Deal. Alongside, other major complementary projects are displayed and taken into account, such as the EU circular economy action plan, in order to close the loop for becoming the world leader in the Circular Economy of rare earths. In this regard, the protagonist and leading agency is the newly established European Raw Materials Alliance (ERMA), an independent forum that plays a decisive role in securing access to critical and strategic raw materials. A section is devoted to the ERMA's outstanding daily work, innovative ideas, sponsored public and private investments (14 projects throughout all Europe, the Raw Materials Investment Platform) and rare earth projects across the value chain. Lastly, in the final part, there is a discussion about a familiar concept in the Brussels' headquarters: EU's aspirations to play a global role in the coming years is strictly interrelated with the concept of strategic autonomy, that has gained strong momentum due to the EU's internal development and the erudite modifications of the global status quo. The mission to develop strategic autonomy for rare earths runs through the strengthening of trade partnerships with third countries, the ones with Canada and Australia of utmost importance, the coordination between ERMA and other relevant organs, such as the European Battery Alliance, and the opportunity of promoting a potential Important Project of Common European Interest (IPCEI) to support research and innovation in the REE's value chain. Research and Innovation are the foundation of EU's action in identifying deposits and improving extraction techniques.

The 2022 Russo-Ukrainian war is equally taken into account as a case study in order to analyse on the one hand, the extent to which the escalation of a conflict may severely affect the Rare Earth Elements market, which is inevitably connected to the military equipment deployed at scale; on the other hand, how European Member States are automatically increasing their spending on defence to come up with an effective solution. An in-depth study of the military countermeasures in the defence sector against the current and future wars is developed: this dissertation illustrates how the breakout of a conflict skyrockets proportionally the investments of EU Member States in fighter jets, anti-tank weapons and surface-to-air missiles, where production involves a considerable REEs percentage. On balance, in the realm of the EU, the aim is to clarify how Rare Earth Elements are definitively crucial for the stability on the European continent; subsequently, it sheds light on the potential global leadership in the REEs market of Europe, which has no choice but to become a vibrant knowledge economy in this sector and a serious player in this new age of great power competition, by procuring domestically the next generation of fighter jets and tanks under the guidance of Paris and Berlin.

The closing chapter is thoughtfully linked to the previous ones. In the first place, there is an introductory section opening the doors to the next frontiers of Rare Earth Elements that are analysed subsequently in details. A focus is dedicated to the Italian scenario by taking into account all the dynamics, ranging from the commercial and economic to the geopolitical and commercial ones. Concrete examples are provided after sifting through all the Italian strategies and documents, with Rome aiming to become one of the most proactive actors within the European panorama. Last but not least, a conclusive section aims to illustrate the future potential Rare Earth Elements frontiers where competition to mine will be intense, ranging from areas characterized by the world's largest deposits, such as Afghanistan and Greenland, to the least realistic but not to be discarded option of space mining and exploration. In this specific case, the final aim is to highlight how the race to mine Rare Earth Elements on these environments is not related to resource scarcity but rather to flexing the military and geopolitical muscles on a mass scale.

CHAPTER ONE

RARE EARTH ELEMENTS ARE THE 21ST CENTURY OIL

1.1 Rare Earth Elements are not exotic: the paradoxical nomenclature

The word 'exotic' has several meanings that make human minds wander. The most common one refers to the foreign character or origin of something; in the context of Rare Earth Elements, exotic can maintain this connotation that expresses the international nature of such commodities; however, it would be erroneous to define them as sporadic elements. Despite the nomenclature that is attributed to REEs due to their dissipation throughout Earth's crust, these goods are relatively abundant and discovered in a plethora of residual deposits, originating from the long-lasting erosion of igneous rocks.

Since the onset, mankind has devoted time and considerable efforts to the transformation of natural energy, coming from the sun and the wind, into mechanical energy for their purposes. Global energy development has experienced various and disparate ages: from wood and coal to oil and gas, up to renewable sources. In certain respects, experts believe a 'Rare Earth Elements era' has already begun or may impact our world in a while. This is strictly connected to a two-fold global perspective: there is not yet a straightforward and universally supported answer to what resource could thoroughly replace oil and coal, while everyone is zealous about a greener and sustainable world; on the other one, energy is traditionally essential to all basic endeavours, but neither inexhaustible nor always available. Such a dilemma implies endless security issues that affect the everyday life of each individual to the extent that REEs have been identified as a possible solution to this vicious cycle.

Presently, Rare Earth Elements are at the forefront of the global energy and security revolutions that are intertwined more than ever. Specialists are currently struggling to give meaning to the traditional semantic confusion that characterizes these goods, stemming from the geography of their extraction and production that has always resulted in significant global changes. While in the past, these energetic primary assets aroused little notice and interest at the international level, the 2010 rare earth trade dispute[1] between China and Japan, when Beijing banned the exportation of tungsten and molybdenum[2], has been a game-changer event that represents, as just hinted, the beginning of a Rare Earth Elements' age. The motto and guiding principle that is pursued by the greatest powers is "less pollution and more energy"[3] where a convergence between digital and green technologies is the *sine qua non condition* to safeguard a durable and sustainable world. Within this scenario, where are Rare Earth elements positioned themselves?

Recent developments highlight energy transition is the talk of the world in the light of a formidable growth of certain sectors: solar and wind energy are steadily increasing and will dominate the future energy panorama. The military sector is intrinsically connected to the tumultuous events that shock some vital regions of the world, not least the Russian invasion of Ukraine started in February 2022 which emphasizes the necessity to consider waging war without fossil fuels. The "rare earth frontier is vast, dynamic and plentiful"[4]: such a reference from the outstanding work of Julie Michelle Klinger encapsulates perfectly the global relevance of these commodities and the obligation of this thesis to shed some light on the future dynamics of Rare Earth Elements.

The seventeen rare earths, similarly to certain strategically valued metals such as cobalt and lithium, are pivotal to the resurgence of ethnonational feelings and communities that prompt the mobilization of resources to extract them. Their historical development embedded several phases preceding the 2010 crisis, ranging from the colonial issues to the Cold War's unbridled competition for elements. Their political and security life has simultaneously evolved with international relations since today's diplomats are increasingly using them to influence the

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[1] Bradsher, Keith. "Amid Tension, China Blocks Vital Exports to Japan." The New York Times. The New York Times, September 23, 2010. https://www.nytimes.com/2010/09/23/business/global/23rare.html.

[2] *Idem*

[3] Pitron, Guillaume, Ondina Chirizzi, and Stefano Liberti. 2019. La Guerra Dei Metalli Rari: Il Lato Oscuro Della Transizione Energetica e Digitale. Roma: Luiss University press.

[4] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

geopolitical arena. The non-fossil fuels era will reverse the global relationships between countries: geopolitical experts claim the US will progressively re-modulate their traditional connection with the Gulf oil powers; the EU will decrease its energy dependence and reliance on Russia in order to attain the long-awaited 'strategic autonomy' advocated since the 2016 European Union Global Strategy[5]; China will expand its (almost undisputed) trade monopoly in order to become the greatest power in history. Rare Earth Elements are pivotal to all these processes because their geography is permanently connected to the geography of power. Despite their paradoxical nomenclature, everyone is aware that these commodities are not rare, just expensive and difficult to extract and trade. Their historical development comes to the rescue: it is by starting from their origins that it will be possible to analyse all the aforementioned issues and understand comprehensively how Rare Earth Elements will be the 21st century oil.

1.1.1 Historical development

Ytterby in Sweden is a small village of roughly 3,000 inhabitants on Resarö island, part of the archipelago that surrounds the outskirts of the Stockholm district. Its popularity comes from the activity of a miner, the geologist Lieutenant Carl Axel Arrhenius, who, in 1788, stumbled upon an unusual but astonishing black rock that, a few years later, was discovered to be a different type of 'earth'. Since the discovery of this ore was exceptional and uncertified before, it was assumed to be sporadic and limited to Ytterby. This is the reason why Rare Earth Elements have this codification despite a different reality and narrative.

Nowadays, experts consider Rare Earth Elements indispensable to the digital, technological and energy infrastructures of the modern world that regulate our society. However, the first hundred years of their existence were characterized by isolated scientific progress since their industrial applications and services were minimal. Ytterby is considered a milestone in the historical development of Rare Earth Elements not only because it was the place where most of the 17 elements were discovered, but especially because Sweden is amongst those countries characterized by long winter nights in northern Europe. In the 19th century, the industrialist desire to be productive for as long as possible coincided exactly with the quest for addressing the problem of producing light in the newly urbanized industrial areas. Carl Auer von Welsbach's

[5] "A Global Strategy for the European Union's Foreign and Security Policy." A Global Strategy for the European Union's Foreign and Security Policy | EEAS Website https://www.eeas.europa.eu/eeas/global-strategy-european-unions-foreign-and-security-policy_en.

devising of gas mantles[6] was the trump card in the Rare Earth Elements' history: for the first time, their industrial usage was revealed, and rumours spread all over the world.

On the other side of the Atlantic Ocean, rare earths had been extracted from the monazite sands of the beaches of North and South Carolina[7], an activity fuelled in the subsequent years by the Welsbach Light Company of New York. The American production was soon joined by German and Austrian counterparts which exploited monazite reserves in Brazil and India[8] before the beginning of the First World War. At that time, Europe had been entirely supplied by these markets while Russia was discovering its own reserves and becoming self-sufficient. There is a pre-Second World War and a post-Second World War in the historical developments of Rare Earth Elements: research and study activities before, experimentation and industrial application after. The colonial age is considered to be a golden era in this regard: economic and political interests converged whenever the versatility and profitableness of these elements were brought to the surface.

In the current society, these commodities are primarily used in electronics, in the defence and energy sector, and in the transportation industry; nevertheless, it was only after the late 1980s that Rare Earth Elements' magnificent features were comprehensively unveiled and understood by the political leaders all over the world. 'The Middle East has its oil, China has Rare Earths': such a sentence of China's paramount leader Deng Xiaoping during a 1992 visit to the Rare Earths district of Baotou in Inner Mongolia is emblematic of the revolution around the Rare Earth Elements. In China, rare earth' mining firstly began in the 1950s, remaining an irrelevant industry until the 1970s when the chemist Xu Guangxian found a way to separate the Rare Earth elements.

In the old continent, the centrality of rare earths has gained unprecedented momentum, both from an economic and a political perspective, coincidentally with the trade crusades to grab raw materials throughout the world. British and German expeditions in remote regions were aimed at expanding knowledge and increasing awareness of Rare Earth Elements' potential: before the gas mantle and then the fuses and explosives industries increased their importance and,

[6] "Carl Auer Von Welsbach – Discoverer of Gas Mantle & Neodymium, Praseodymium Elements." worldofchemicals.com, May 20, 2015. https://www.worldofchemicals.com/484/chemistry-articles/carl-auer-von-welsbach-discoverer-of-gas-mantle-neodymium-praseodymium-elements.html

[7] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

[8] *Idem*

following the two world wars, these goods were primarily used in the manufacturing of weapons. The geopolitical context of colonialism and the Cold War skyrocketed research and application in rare earths since the political agenda of that period was structured around the nuclear arms race and, consequently, on the quest for Rare Earth Elements and their conductive, magnetic, and enhancement characteristics. To name one, promethium is predominantly found in nuclear reactors.

Rare Earths Elements are a geological concentration of atoms with outstanding properties that are described as the primary asset of the Earth's crust. Whenever they are processed industrially, even a reduced dose is able to produce a magnetic field of energy that is equal to the quantity of energy produced by oil and coal. The outstanding difference is that Rare Earth Elements do not emit the unpleasant and adverse carbon dioxide emissions that are produced by burning fossil fuels. Unquestionably, there are other divergent effects considered to be the enemy of the so-called 'green capitalism', where these metals are pivotal and connected. However, the historical development of Rare Earth Elements has been slow at the beginning but incredibly rapid whenever people realized their potential. It is expected that breathtaking discoveries and revelations in this context may pop up in future developments, given the key role these goods will hold in the energy transition and in safeguarding global security.

1.1.2 The Industrial Applications

Mankind has experienced breathtaking and sublime industrial and technological revolutions to the extent that our planet has radically modified throughout the ages. Their scale and complexity have no historical precedent: the First Industrial Revolution introduced mechanized production; the Second (the Technological Revolution) established mass production while the Third (the Digital Revolution) skyrocketed the use of information technology to automate production. In recent times, the long-awaited Fourth Industrial Revolution, well-known as Industry 4.0, characterized by remarkable and unique interconnectivity and smart automation, appeared to be a temporary destination point intended to last a few decades. Nonetheless, the heterogeneous international crises, ranging from the Covid-19 pandemic to many endless situations of war worldwide, have made a remodelling of the global supply chains indispensable.

The Fifth Industrial Revolution endorses the most impressive technological advancements of the previous one: Artificial Intelligence (AI), Internet of Things (IoT), Big Data and the rise of Robotics that, per contra, are only necessary to stay afloat. Innovation in industries is an essential daily issue on the global agenda to deal with and the REE industry will be one of the most divisive and talked-about environments due to its atypical and deviant conformation. Complex supply chains of modern technologies are hypersensitive to geopolitical turmoil and global markets turbulences associated, as in the case of REE, with soaring uncertainties and volatility. The extensive efforts to secure the balance of demand and supply in the world market of Rare Earth Metals are undoubtedly running through a comprehensive awareness of all the industrial applications of each element and their potential and current flaws in the system.

The 17 REEs hold special properties that render them indispensable in several high-growth markets, which will be singularly analysed in a subsequent dedicated sub-chapter. Rare earth elements are generally subdivided into light (LREE), Cerium (Ce), Lanthanum (La), Neodymium (Nd), Praseodymium (Pr), Samarium (Sm), and heavy elements (HREE), Dysprosium (Dy), Erbium (Er), Europium (Eu), Gadolinium (Gd), Holmium (Ho), Lutetium (Lu), Terbium (Tb), Thulium (Tm), Ytterbium (Yb), Yttrium (Y).

The modern literature on Rare Earth Elements has identified neodymium, praseodymium, and dysprosium, part of the lanthanide family, as the most critical rare earths. Neodymium, discovered by Carl Auer von Welsbach in Vienna in 1885, is pivotal to the development of powerful permanent magnets used in several electronic devices, including mobile phones, and in high-efficiency electric motors for hybrid cars and generators for aircraft and wind turbines. The development of commercially available neodymium-based equipment, that are central to the current global transition, highlights how influential the industrial applications of this Rare Earth Element are in the relevant market.

Alongside, Praseodymium, a soft and silvery metal with prominent electrical, magnetic and chemical properties, is used in an assortment of alloys. Discovered simultaneously with Neodymium by Carl Auer von Welsbach, it is a fundamental component of aircraft engines and, combined with other lanthanides, a prerequisite to fostering high-power magnets. The praseodymium-neodymium (PrNd) duo accommodates the electric vehicle sector[9] rampant growth and will be amongst the highly sought-after commodities geopolitically disputed in the coming years. Dysprosium, whose Greek name means "hard to get"[10], was excavated by Paul-Émile Lecoq de Boisbaudran in Paris in 1886; it is a pure metal that integrates the praseodymium-neodymium combination concerning magnets in motors, wind turbines and electrical vehicles. Additionally, this Rare Earth Element is a semiconductor used in the production of laser materials.

There are two elements that are not lanthanides but are equally critical considering their chemical properties: scandium and yttrium. The former was discovered by Lars Frederik Nilson in 1879 through a complex extraction from euxenite. The first transition metal, extremely difficult to obtain, is an integral part of the alloy used in Russian MIG fighter planes: it was firstly processed by the Soviet Union during the Cold War and its production and demand, despite being relatively small, have always been associated with Russian military programs. The latest devastating attack on Ukraine by the Kremlin, if long-lasting, will turn the tables concerning scandium production because Moscow will not be able to afford a disruption in its aerospace sector. Conversely, Yttrium has lost its commercial momentum by a twofold difficulty: this element is rarely found in nature and is classified as the most dangerous in working environments; people dealing with Yttrium may run into serious health consequences, namely lung and hepatic cancer. Future sustainable mobility goes in parallel with certain Rare Earth Elements, amongst which lanthanum, discovered in 1885 by Carl Gustav Mosander, that does not have any commercial use, but it is necessary to store hydrogen gas for use in hydrogen-powered vehicles as well to develop batteries in hybrid cars.

Developments in the defence industry, that rely on increasing military expenditure and technology all over the world in the light of a global rat race, will inevitably need more openness to the REEs market, considering the importance of various elements to grab the most advanced missiles as well as laser devices. Certainly, in this regard, it is fundamental to keep in mind that defence budgets are ephemeral and averse to moving up and down as a reaction to unforeseeable dynamics in global politics and security. However, for this purpose, promethium and terbium are

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[9] Crossley, Gabriel, and Min Zhang. "China Says Domestic Competition Hurting Rare Earth Prices." Reuters. Thomson Reuters, March 1, 2021. https://www.reuters.com/article/us-china-rareearths-industry-idUKKCN2AT13G.

[10] "Dysprosium - Element Information, Properties and Uses: Periodic Table." Dysprosium - Element information, properties and uses | Periodic Table, n.d. https://www.rsc.org/periodic-table/element/66/dysprosium.

extremely desired by every national department of defence due to their use in military equipment; along with europium, which is not only used in European banknotes, such REEs are also considered to be major elements of a nation's economy that, now more urgent than ever, should realise how aerospace and defence industries are the key sectors to survival.

Last but not least, it is worthwhile to mention the remaining REEs that are least known from a geopolitical and security perspective. Cerium is the most abundant element that holds several practical applications, amongst which petroleum cracking catalysts; Samarium is deployed in order to create powerful magnets, but its function has been gradually replaced by Neodymium in this context. Gadolinium, Holmium and Erbium have two primary commercial applications, as a medical laser and in fibre optic cables; whereas Thulium, Ytterbium and Lutetium, being the rarest and most expensive to be processed elements, are predominantly delimited to research purposes.

1.1.3 The major reserves and deposits worldwide

Ytterby in Sweden has been 'the most important village in chemistry'[11] for a while. Nowadays, this small town close to Stockholm is depicted as the source of a trade spiral that encompasses Rare Earth Elements and their reserves throughout the planet.

According to the most recent estimates, 'the total worldwide reserves of rare earths amount to approximately 120 million metric tons[12]. In the new millennium, the overall volume has remained flat, with an abundance of commodities in the Earth's crust. However, problems and thorny issues arise when it comes to determining the amounts of mineable concentrations. REEs are largely accumulated in China: the latter is at the forefront of both the list for reserves, with 44 million tons[13], and of annual mine production in 2021, with 168,000 tons[14]. In order to understand the noteworthiness of these data, the other countries' statistics are illustrative: Vietnam and Brazil have respectively the second and third global reserves, whose collective sum is still lower than China's stocks; but what is astonishing are the Vietnamese and Brazilian mine productions, amongst the lowest on Earth. Conversely, actors such as the US and Australia have

[11] Kit Chapman, Kristy Turner. "The Most Important Village in Chemistry." RSC Education, October 29, 2018. https://edu.rsc.org/feature/the-most-important-village-in-chemistry/3009670.article.
[12] U.S. Geological Survey. 2022. "Mineral commodity summaries 2022". United States: U.S. Geological Survey.
[13] *Idem*
[14] *Idem*

a notable mine production, but they are characterized by a structural dependency on imports, predominantly from Beijing. This scenario is precisely explicative of the current global trend in the REEs market: certain actors have massive reserves whereas others are capable producers of rare earth from mines. There is only one of these players that benefits from both: the Red Dragon.

Since the 1990s, Beijing is driving international demand and all roads led to this path. China has produced almost 2/3 of the world's refined rare earths in 2021 through six state-run companies[15] and is expected to broaden its horizons if the other superpowers, the European Union primarily, would remain inactive to some extent. There is immense potential in certain regions: not only Vietnam and Brazil but also Russia and India, with respectively 12 and 6.9 million tons may play a valuable role. There are also the future 'rare-earth frontiers' that should be taken on board: Greenland, for instance, has "some of the world's richest untapped mineral seams"[16] near the Kvanefjeld site; Australia has a substantial reserve, equal to 4,1 million tons[17], that is expected to reduce China's supply dominance in the Eastern Hemisphere; Africa is home to a myriad of several unexploited rare earth deposits, ranging from South Africa, Mozambique and Namibia to Kenya, Burundi and Tanzania.

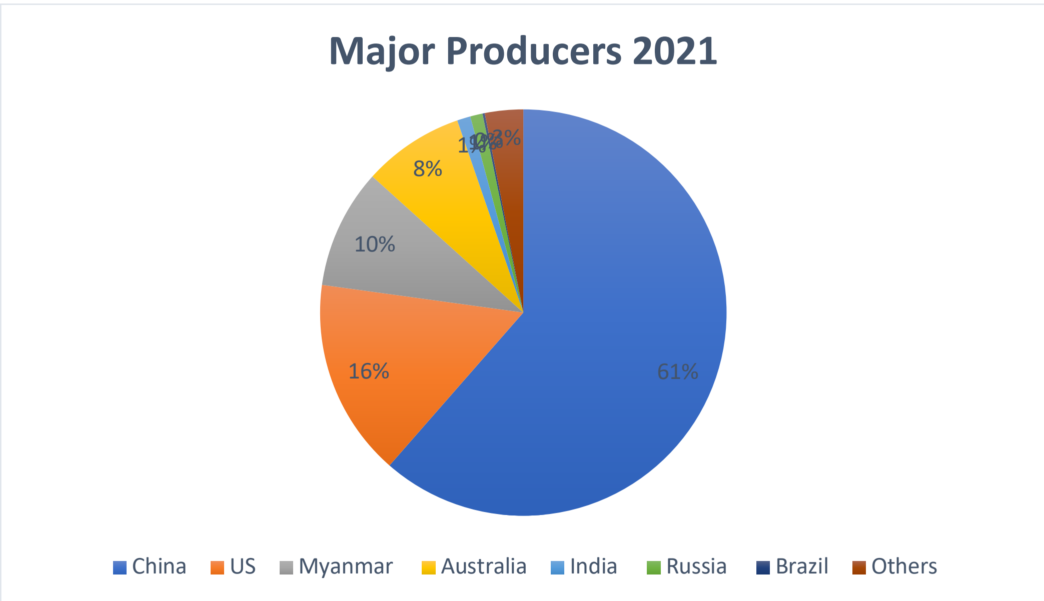

Table 1: The biggest producers of Rare Earth Elements in 2021. *Source:* U.S. Geological Survey. 2022. "Mineral commodity summaries 2022". United States: U.S. Geological Survey.

[15] Daly, Tom. "China Hikes 2021 Rare Earth Quotas by 20% to Record Highs." Reuters. Thomson Reuters, September 30, 2021. https://www.reuters.com/business/energy/china-hikes-2021-rare-earth-quotas-by-20-record-highs-2021-09-30/.

[16] Meyer, Robinson. "Greenland's Rare-Earth Election." The Atlantic. Atlantic Media Company, May 3, 2021. https://www.theatlantic.com/science/archive/2021/05/greenlands-rare-earth-election/618785/.

[17] U.S. Geological Survey. 2022. "Mineral commodity summaries 2022". United States: U.S. Geological Survey.

As can be deduced from *Table 1*, China has been the biggest producer of Rare Earth Elements in 2021. Such unquestioned domination has been even strengthened following the reopening of the China-Myanmar border gates which has facilitated the commercial exchange between those two nations that are at the forefront of this industry. Countries like Brazil, India and Russia are expected in the near future to improve their share of production, a bit since they have massive reserves, but also because their economies are intertwined and expected to dominate global growth by 2050, together with China and South Africa.

1.2 Rare Earth Elements & transition: a skyrocketing demand for clean energy technologies

Climate change has been defined as the "biggest threat modern humans have ever faced"[18] by the United Nations. This phenomenon is expected to trigger serious complications for international peace, stability and security. Both the highest authorities and common people are struggling to come up with an effective and long-lasting solution in order to preserve the future of the next generations, some more than others. By identifying climate change amongst the major crisis multipliers and threats to our society, several governments and institutions have implemented long-term programs and agreements, starting with the iconic United Nations Paris Agreement in 2015 to the more challenging and aspirational Green Deal by the European Union, whose final objective is to attain carbon neutrality by 2050. Such ambitiousness necessarily passes through the reduction of energy-related CO2 emissions and the decarbonization of the energy sector.

Urgent action is required on an international scale and several countries are already implementing far-reaching plans toward the usage of renewables and zero-emission mobility since, according to the International Renewable Energy Agency (IRENA), renewable energy and energy efficiency measures can potentially achieve 90% of the required carbon reductions. The most influential governments have devised green strategies and pledged to skyrocket the deployment of clean energy technologies. This intricated scenario has inevitably increased the demand for materials that are key components of such technologies, Rare Earth Elements on top. The latter ones are fundamental for low-carbon devices and, as had been widely predicted, these elements are frequently referred to as new geopolitical leverages in the global energy transition.

[18] "Climate Change 'Biggest Threat Modern Humans Have Ever Faced', World-Renowned Naturalist Tells Security Council, Calls for Greater Global Cooperation | Meetings Coverage and Press Releases." United Nations. United Nations. https://www.un.org/press/en/2021/sc14445.doc.htm.

Geopolitical competition is a renowned concept when it comes to analyse access to critical minerals that are vulnerable to disruption and highly geographically concentrated. With specific reference to Rare Earth Elements, these elements are predominantly supplied from China which has already been involved in geopolitical disputes, such as the 2010 crisis with Tokyo and the recent frictions with the US. This complex scenario is determined by a geographical collocation of these minerals in nations characterized by high measures of fragility and corruption and by their essentiality to the production of high-tech, renewable energies and defence applications.

These 17 arcane elements are an integral part of more than 200 products[19], ranging from cellphones and wind turbines to lasers and sonar systems. In the subsequent sections, the industrial applications of Rare Earth Elements will be investigated given the indispensable character of these elements in the production of renewable resources (such as solar panels and wind turbines), in the transportation sector with a specific focus on the Electric Vehicles (EVs), in high-tech applications (such as computers and smartphones), and finally in the defence industry (such as missile guidance system, submarines and smart bombs).

The transition towards a zero-emission world and a green future is universally recognised but not without contradictory implications; the mining sector is struggling because, although it is a crucial and decisive component with its innovative technologies, the extraction and processing of these elements encompass environmental concerns, for instance by contaminating water and soil or by encroaching on natural habitats. On balance, it will be fundamental to find an equilibrium that involves all the driving factors and determinants at stake, because a sustainable international energy system goes hand in hand with global lasting security where Rare Earth Elements should not be a subject of disputes but rather an added value for humanity.

1.2.1 Solar and wind energy markets

Rare Earth Elements are a vital component for clean energy technology products. There are two specific types of rare earth magnet materials whose demand is schizophrenic: Neodymium (Nd-Fe-B) and Samarium Cobalt (SmCo). Their different physical and magnetic properties are considered pure gold since rare earth magnets are the strongest permanent magnets

[19] "What Are Rare Earth Elements, and Why Are They Important?" American Geosciences Institute, February 1, 2018. https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important.

on the market. Specifically, neodymium magnets are characterized by a high coercive force and an unprecedented resistance to demagnetization. They are composed of Neodymium and Praseodymium (two "light" rare earths) and Dysprosium and Terbium (two "heavy" rare earths). In 1984, the two independent companies General Motors and Sumitomo Corporation devised two different magnets that were respectively bonded and sintered permanent magnets. The light rare earths are essential to their magnetic strength while the two heavy ones allow a substantial degree of resistance to demagnetization at high temperatures.

The global energy transition requires, without question, massive investments in clean energy apparatus because natural wind and solar energy are considered to be the future of our planet's energy needs. The Covid-19 lockdowns have skyrocketed the growth of the wind and solar energy sectors that have attained unprecedented economic levels and sales records: according to the Global Wind Report 2021 provided by the Global Wind Energy Council, "2020 was the best year in history for the global wind industry with 93 GW of new capacity installed"[20]. Once again, China and the US, followed by the European Union, are the world's largest wind power markets that, by force of circumstance, are the antagonists when it comes to exploring the Rare Earth Elements scenario. This is primarily associated with the permanent magnet generators that have gained traction specifically in offshore turbines. The Lynas Rare Earth company clarifies the connection between Rare Earth Elements and the wind market because "a 3MW direct drive turbine consumes close to 2 tons of rare earths permanent magnets"[21]. The latter ones have been used in nearly offshore wind turbines in Europe and in roughly 76% of offshore wind turbines all over the world[22].

Such figures are therefore emblematic of the noteworthiness of Neodymium (Nd-Fe-B) permanent magnets to the extent that the demand for this rare earth is expected to grow by more than 600% from 4,900 tons in 2020 to 37,700 tons in 2040 and its share in clean energy technologies would rise from 16% to 41% over that period[23]. Wind offshore turbines, which are typically composed of 360 kg of neodymium and 60 kg of dysprosium, offer an annual production

[20] "Global Wind Report 2021." Global Wind Energy Council, January 10, 2022. https://gwec.net/global-wind-report-2021/.
[21] LynasCorp. "How Are Rare Earths Used - Wind Turbines." Lynas Rare Earths, January 28, 2022. https://lynasrareearths.com/products/how-are-rare-earths-used/wind-turbines/.
[22] Alves Dias, Patricia, Silvia, Bobba, Samuel Carrara, and Beatrice Plazzotta. 2020. "The role of rare earth elements in wind energy and electric mobility." Luxembourg: Publications Office of the European Union.
[23] IEA (2021), World Energy Model, IEA, Paris https://www.iea.org/reports/world-energy-model

of clean energy that is associated with a low lifetime cost and are used in a plethora of technologies in this sector.

Alongside, the relationship between solar energy and Rare Earth Elements deserves attention. The development of solar panels, which are another indispensable device in order to reduce CO2 emissions, is somehow based on the supply of indium and tellurium, whose demand is rapidly growing. Tellurium, one of the least common elements on Earth, is primarily deployed in the development of photovoltaic solar cells, particularly in the emerging thin-film solar panel sector. Its scarce concentration has determined its production as a byproduct of refining copper concentrates, demonstrating therefore how the solar sector is connected but not totally reliant on Rare Earth Elements.

Actually, the environmental damage and the possibility to use recycled materials have abated the commercial hysteria around Rare Earth Elements in the solar market. Certainly, there is room for manoeuvre in this regard, as demonstrated by the $2.9 million investment by the Rio Tinto company in Utah aimed at recovering tellurium as a byproduct of copper smelting in order to provide enhanced electrical conductivity[24]. The US are at the forefront of the growing market for solar energy generation with 23 gigawatts of solar PV capacity installed in 2021[25] and are intensively working in order to extend a clean-energy approach that embeds the extraction of Rare Earth Elements through a benign energy process.

On balance, these minerals are definitively associated with all the dynamics in the wind and solar markets given their definition as 'vital ingredients' for certain products. Nevertheless, this is not the end of the story because Rare Earth Elements' ways are infinite.

1.2.2 Transportation industry and the Electric Vehicles

In the first decade of the new millennium, the EVs panorama was minimal but the opportunities related to it were grandstanding. The advent of climate change issues on a global scale has dramatically changed our perception and nowadays EVs are a major component of the

[24] O'Donoghue, Amy Joi. "It's Rarer than Gold and Critical for Green Energy - and It's about to Be Mined in Utah." Deseret News. Deseret News, March 27, 2021. https://www.deseret.com/utah/2021/3/26/22344673/utah-green-energy-rare-element-for-solar-panels-mined-in-salt-lake-tellurium-rio-tinto.

[25] "U.S. Solar Market Insight." SEIA, https://www.seia.org/us-solar-market-insight.

transportation industry. The vehicle marketplace is currently considered the most fruitful landscape when it comes to discussing the countermeasures against climate change. As a result, in 2020 electric car sales worldwide reached their peak with a market share of over 4% and 3 million new vehicles on the roads[26]. It is estimated that 10 million EVs are spread across the world and their sales are expected to attain unprecedented levels by 2030, especially within the European Union.

In the past, the transportation industry had the highest level of reliance on fossil fuels, being responsible for 37% of CO2 emissions from end-use sectors[27]. Several initiatives have been therefore implemented in order to minimize the damage in this regard: Brussels has recently activated its Fit for 55 package which aims at banning internal combustion engine car sales from 2035 onwards; the United Kingdom and Canada have set a similar target that includes even hybrids while China has developed a targeted strategy in order to become the leader of the EVs transition. Notably, the last statement is representative because EVs are totally reliant on permanent magnets composed of Rare Earth Elements and therefore the related motors are expected to stay for good.

From an economical perspective, the rare earth value chain is evidently beneficial and worthwhile when it is connected to the electric vehicle market: the latest technological evolutions highlight that 95% of EVs use rare earth permanent magnet motors[28], considering their high energy efficiency which results into the longer driving range. These magnets offer superior efficiency and power density; this is the reason why, despite chronological attempts to decrease their utilization, experts in the sector have realized they are indispensable. According to IDTechEX, the neodymium volume demand in 2032 from batter-electric vehicles is expected to be 11 times the demand experienced in 2021[29]. Contemporary, the International Energy Agency (IEA) expects that, in order to attain the Paris targets by 2040, the annual global sales of electric cars and trucks will need to overcome more than 70 million[30] new vehicles on the roads, in other words, a thirty-fold production greater than the current one.

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[26] IEA (2021), Electric Vehicles, IEA, Paris https://www.iea.org/reports/electric-vehicles

[27] IEA (2021), Transport, IEA, Paris https://www.iea.org/topics/transport

[28] Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

[29] Edmondson, Dr James. "Rare Earths in Evs: Problems, Solutions and What Is Actually Happening." IDTechEx. October 28, 2021. https://www.idtechex.com/en/research-article/rare-earths-in-evs-problems-solutions-and-what-is-actually-happening/25071.

[30] IEA (2021), Global EV Outlook 2021, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021

As expected, the relationship between Rare Earth Elements, specifically neodymium and dysprosium, and the transportation industry is the most critical one and extremely vulnerable to price volatility and fluctuations. Following the 2010 crisis, China has skyrocketed their price by 2000% and since 2017 prices have experienced a constant 1.5-fold increase, with ups and downs on the order of the day. However, since the electrification of the transportation industry is a once in a lifetime opportunity, the application of Rare Earth Elements has gained unprecedented traction to the extent that their demand, which has been growing rapidly in recent times due to their wider deployment in innovative technologies, will be key to many political strategies.

1.1.3 Defence Sector

Some people may wonder why there is an imperative association between the Rare Earth Elements and the defence sector, apparently two opposite poles in the popular imagination. Nonetheless, the ramifications that intersect these clusters are woven more than ever. Several modern defence equipment relies on specific sections that are made of Rare Earth Elements. Besides green energy and EVs, these commodities are fundamental in creating weapons. To mention a few, aircraft drop the so-called ‘smart bombs’, whose peculiarity is the controlled direction, that are composed of neodymium-iron-boron magnets; the creation of long-range lasers in order to identify enemy targets rely on neodymium, yttrium-aluminium-garnet while sound system components have within neodymium-iron-boron permanent magnets.

The defence sector is a heterogeneous environment that includes a multitude of dimensions; the military is the most important one, but it is noteworthy to analyse even outer space and, anew, the connection with Rare Earth Elements that are used in space shuttle components, jet engine turbines and state-of-the-art drones used in search and rescue operations. A striking example is cerium, the most abundant element, that is essential to NASA’s Space Shuttle Programme. On balance, Rare Earth Elements are strategically relevant at the national and international levels when security and defence issues are discussed.

Defence uses of Rare Earth Elements

Lanthanum	Night-vision goggles
Neodymium	Missile guidance system, communications
Praseodymium	Aircraft engines, satellite components
Promethium	Long-lived batteries for missiles
Samarium	Precision-guided weapons, nuclear reactor control roads, lasers
Gallium	Light-emitting diodes

These vitamins of modern society allow the development of more efficient, intelligent and agile military capabilities and combat systems that are in the headlines following the most recent Russian invasion of Ukraine. Communication satellites, stealth technology and precision-guided weapon systems are deployed in the contemporary battlefield and therefore, without Rare Earth Elements, it is notoriously difficult to emerge as the most prepared. But the specifics do not stop here: the most modern frigates encompass more than 1.5 tons of rare earths[31] while, following a US Congressional Research Service report, it is claimed the famous F-35 aircrafts require 417 kg of rare-earth materials in order to be successfully manufactured. These fighter jets have gained momentum following their purchase by Germany[32] (but also Switzerland and Finland) in recent months as a defensive countermeasure against any potential imperialist design in Europe.

Innovations in the defence and military sectors are not possible if Rare Earth Elements are not available. However, precisely those metals are used as weapons by Beijing in international political trade negotiations. Therefore, technological advancements need to be integrated by structured partnerships between the other superpowers and those regions where these elements are abundant. Latest developments indicate the discovery of massive deposits in Japan's far eastern territorial waters[33], a proactive Australian government intended to halt the Chinese monopoly, emerging international companies that are expected to provide alternative supply

[31] Chomon, Juan Manuel, and Ganser, Andreas. "How Relevant Are Rare Earths to Europe's Security and Defence?" European Security Defence, October 7, 2021. https://euro-sd.com/2021/10/articles/exclusive/23989/how-relevant-are-rare-earths-to-europes-security-and-defence/.

[32] "Germany to Buy 35 Lockheed F-35 Fighter Jets from U.S. amid Ukraine Crisis." Reuters. Thomson Reuters, March 14, 2022. https://www.reuters.com/world/europe/germany-decides-principle-buy-f-35-fighter-jet-government-source-2022-03-14/.

[33] "Japan Just Found Enough Rare Minerals for 780 Years of Local Demand." South China Morning Post, July 11, 2018. https://www.scmp.com/news/asia/east-asia/article/2141445/discovery-rare-earth-minerals-japan-coast-secures-780-years.

sources and, last but not least, unexplored deposits such as Kvanefjeld in Greenland[34] that may turn the tables.

On the whole, the military and defence sectors are predominantly dependent on access to rare earths. In this context, the problem of dependence on China and the vulnerability of supply chains is to the greatest extent. This is the reason why advancements in these sectors are expected, discussed and hopefully developed and agreed on the global agenda. The utmost objective is to secure the supply of such critical minerals which is the most challenging issue when it comes to analyse the Rare Earth Elements panorama. Before discussing in-depth such a framework, some insights into the differences between them, fossil fuels and other minerals (i.e., cobalt and lithium) will be drawn by taking, from a wider perspective, Rare Earth Elements as the protagonists of the diversification of the fossil fuel industry's portfolio.

1.3 Rare Earth Elements and their contraposition to fossil fuels

The reduction of emissions worldwide entails the establishment of a secure and resilient energy system that gradually wanders off fossil fuels. The current global warming is primarily driven by the pollution that is generated by oil, coal and gas processes: when burned, these resources produce massive quantities of carbon dioxide that trap heat in the atmosphere and lead to climate change. According to a 2022 report by the United States Environmental Protection Agency, the global carbon emissions produced by hydrocarbons have skyrocketed since the 20th century, surging by 90% since 1970. Amongst the top CO2 emitters there is China that, as in the Rare Earth Elements' panorama, is the undisputed protagonist and, for all the other countries, the main antagonist.

Starting from the basics, the most relevant difference that catches the eye is that there are different types of fossil fuels, for instance petroleum and oil shales, but when it comes to analyse rare earths, there are 17 elements on the periodic table to deal with. Furthermore, their features are hardly known and are typically embroiled in high school chemistry class rather than in a high-level policy debate. Certainly, both are found within Earth's crust and have environmental implications but the dynamics that have developed over the centuries, especially concerning

[34] Meyer, Robinson. "Greenland's Rare-Earth Election." The Atlantic. Atlantic Media Company, May 3, 2021. https://www.theatlantic.com/science/archive/2021/05/greenlands-rare-earth-election/618785/.

security issues, are totally different, this is the reason why it is possible to claim that the collective trend is changing.

The current society has implemented international energy security mechanisms that protect the most advanced systems and infrastructures against disruptions and economic shocks in supplies of fossil fuels. The decarbonization of the energy system, inextricably connected to Rare Earth Elements and other minerals, implies the advent of a distinct set of challenges that point out peculiar vulnerabilities and international trepidation on the matter. While the security issue of supply is a common ground, if not a greater problem, considering that production of Rare Earth Elements is more concentrated than that of oil, concerns about price spikes are expected to disappear in a renewable-rich energy system. History, in the guise of the 2010 rare earth crisis between China and Japan, has taught us that price fluctuations and blackmail are always possible, but it has been a localized episode that hopefully will be a drop of water in the desert.

The security of oil and Rare Earth Elements entails heterogeneous aspects and dynamics in case of a crisis and its repercussions. The historical oil shocks of 1973 and 1979 have triggered an unprecedented level of costs that affected all consumers worldwide driving cars and trucks; conversely, a potential price spike in the supply of neodymium and praseodymium would only engrave the supply of new EVs or solar plants. Such a statement is not intended to minimize the potential risks arising from the rare earths' market but is presumed to highlight where the actual critical problem is. Consumers of EVs or using solar-powered electricity are not immediately affected because minerals shocks and side effects will be more devastating in the longer term, for instance by missing the global objectives and therefore failing to ensure a safe future for younger generations.

Lessons and experience from fossil fuels markets are thus fundamental in order to structure a comprehensive approach against the disruption that encompasses innovative supply-side measures and countermeasures. On balance, it is possible to define Rare Earth Elements as an integral part of the antithesis of oil because they will be fundamental in order to promote the optimal functioning of an innovative energy system. The striking issue is that the approach to oil security has evolved through overall efforts in order to improve efficiency, define critical areas of demand restraint and strengthen countries' preparedness against potential disruption. Rare Earth Elements' security is not yet extremely developed because there is an overabundance of possibilities and strategies that appear to be viable. At present, there is only one important common knowledge that is Rare Earth Elements market could never be characterized by an extended leadership as the Organization of Petroleum Exporting Countries (OPEC) did in the oil market.

1.3.1. Why it is not possible to replicate a Rare Earth Elements' OPEC

Rare earths' international demand has steadily grown since 1990s following their renowned popularity in selected sectors and impetus given to a greener future. Today's energy security is connected to their market while in the past its nuances were different. Previously, the abundance of oil supplies and less stringent environmental constraints led oil to be the world's leading transportation resource, desired by all countries and stakeholders. Oil has traditionally been a tool of coercion with several famous disputes throughout history. The critical point has always been the price fluctuations that concerned this energy market, excessively subject to vulnerabilities and appetite for power. To come up with an effective solution, the Organization of Petroleum Exporting Countries was created at a conference held in Baghdad in September 1960 and was formally established in January 1961 by five countries: Saudi Arabia, Iran, Iraq, Kuwait, and Venezuela.

The primary objective was to regulate such a core market with a two-fold strategy: on the one hand, to limit the lowering of prices, on the other one, to coordinate production and export policies thus monopolizing the industry. Such a futuristic scenario could count on the OPEC members' collective contingent: those countries held about four-fifths of the world's proven petroleum reserves while accounting for two-fifths of world oil production[35]. Nowadays, OPEC is composed of 13 of the world's major oil-exporting nations committed to the stabilization of oil prices in the international market.

Some experts have wondered whether a similar scenario could be replicated within the Rare Earth Elements market. In this regard, the common view is that the current society will not be characterized by a structured organization of Rare Earth Elements but rather by a 'one-nation OPEC' that is China. In December 2021, the Chinese government has approved the establishment

[35] "OPEC." Encyclopædia Britannica. Encyclopædia Britannica, inc., n.d. https://www.britannica.com/topic/OPEC.

of a leviathan society in this scenario: the China Rare Earth Group[36], created by the merger of three of China's biggest rare earth metals state-owned enterprises (SOEs)—China Minmetals Rare Earth, Chinalco Rare Earth & Metals, and China Southern Rare Earth Group—along with two other companies—Ganzhou Zhonglan Rare Earth New Material Technology and Jiangxi Ganzhou Rare Metal Exchange.

Such a pioneering move by Beijing could be a decisive checkmate to consolidate China's rare earths industry and therefore control the physical production of rare earth metals worldwide. This will consequently entail the ability to influence their prices, as OPEC tries to manage the price of oil. Nevertheless, if the latter sees the convergence of several sovereign actors, the former one is entirely dominated by a single country because the others have neither the strategic means nor the raw materials to counterbalance such a monopolistic seizure of power. In 2020, OPEC members accounted for 36% of total world crude oil production[37] while China controls more than 60% of the market share of the global rare earth supply, more than OPEC ever held in the global oil market.

On the whole, it is claimed that no country can control the entire critical mineral value chain because every commodity has its own market dynamics and peculiarities. Nonetheless, it is implausible to imagine a scenario where an international organization may control the Rare Earth Elements industry to the detriment of China because it would require a diminished level of authority and power by Beijing, traditionally reluctant to take a back seat.

1.4 Similarities and differences between Rare Earth Elements and other strategic metals: cobalt and lithium

Minerals essential for green energy technologies have gained substantial impetus since a considerable percentage of them are located in countries characterized by high levels of fragility, corruption and external interferences and influences. This ultimate section will investigate the commonalities and the discrepancies between Rare Earth Elements and two other critical minerals, cobalt and lithium, where geopolitical dynamics and industrial applications converge.

[36] "China Set to Create New State-Owned Rare-Earths Giant." The Wall Street Journal. Dow Jones Company, December 3, 2021. https://www.wsj.com/articles/china-set-to-create-new-state-owned-rare-earths-giant-11638545586.
[37] "Oil and Petroleum Products Explained." U.S. Energy Information Administration (EIA), https://www.eia.gov/energyexplained/oil-and-petroleum-products/prices-and-outlook.php.

In the first place, despite the hype surrounding their supplies, all these three elements are not particularly rare: cobalt can be extracted from most rocks on our planet while lithium, one of the three elements that emerged in the primordial era, is the first metal in the periodic table and the 33rd most common element on Earth. These two critical elements intercept the scenario and industrial applications of Rare Earth Elements since they are employed not only in the development of wind and solar energy but also in that of batteries for mobile phones and laptops as well as in EVs. Their magnificent effect is the considerable degree of performance, energy density and longevity they ascribe to the green technological apparatus.

The cobalt market has been traditionally monopolized by the Democratic Republic of Congo (DRC) which produces currently 70% of it as a by-product of its copper mines[38]. Therefore, the bulk of its supply comes from a traditionally corrupted and politically unstable country that has become a (common) breeding ground for the international strategy of China. Alongside, lithium market sees the participation of the largest producer, Australia, followed by the second one, Chile with 32% of the global market[39], and the Red Dragon itself. A recent agreement between the last two countries, which awarded Chinese companies a lithium extraction contract in South America worth $121 million[40], is emblematic of Beijing's control over the world's lithium market. Therefore, the first common factor that associates all these three elements is China's dominance and surveillance of the respective markets, due to production, geopolitical and economic reasons.

These minerals are hence characterized by an oligopolistic market and supply chain. The DRC and China are responsible for 70% and 60% of the global production of cobalt and Rare Earth Elements in 2021[41] while 60% production of global lithium chemicals is in the hands of the Red Dragon. If processing operations are taken into account, this supremacy is even more evident: China's share of refining is roughly 50-70% for lithium and cobalt and around 90% for Rare Earth Elements[42]. Alongside, the Chinese government is strengthening its economic power by investing massively in overseas assets both in partnership countries, DRC and Chile, and in

[38] IEA. 2021. "The Role of Critical Minerals in Clean Energy Transitions." Paris, OECD Publishing.
[39] "China's BYD Wins Chile Lithium Extraction Contract." Asia Financial, January 13, 2022. https://www.asiafinancial.com/chinas-byd-wins-chile-lithium-extraction-contract.
[40] *Idem*
[41] IEA. 2021. "The Role of Critical Minerals in Clean Energy Transitions." Paris, OECD Publishing.
[42] *Idem*

competing countries, Australia and Indonesia. For instance, half of the DRC's cobalt output is regulated by Chinese companies that "have snapped up cobalt mines abroad in recent years"[43].

Such an extensive level of concentration rises automatically the possibility of physical disruption and trade restrictions. There have already been some examples: the 1978 cobalt crisis in the province of Katanga resulted in a global shortage of cobalt, which skyrocketed the mineral's prices all over the world and caused several vicissitudes similar to those of the two oil shocks in 1973 and 1979. Nowadays, with the increasing substantial production of electric cars where cobalt is a crucial component, a similar geopolitical and economic turbulence may have far-reaching and dire repercussions on the international arena that is 100% focused on realizing the energy transition. This is the reason why potential bottlenecks and value chains' dominance concerning these three minerals is to be taken with a grain of salt in order not to trigger global shocks, just as oil and natural gas, especially with the 2022 Russo-Ukrainian conflict, have theirs.

Whether the cobalt demand could be anything in the coming years depending on the technological evolution of batteries as well as on restrictive climate policies, lithium and Rare Earth Elements are supposed to deal with tight supplies, with a specific reference to chemical products and neodymium and dysprosium respectively. The dramatic increase in EVs market requires constantly high-quality materials whose refining is hegemonized by China. There are several alternative projects intended to keep up the demand and satisfy the diversification of the sources of supply but the environmental standards, for instance in the EU or in the US, are slowing down all the processes because finding a balance between all these issues is a can of worms. Therefore, as in the case of Rare Earth Elements to which a section will be dedicated, minimising waste and promoting resource efficiency is the desired solution.

Recycling and reuse are only one of the hundreds of potential solutions that serve for a more circular economy and for reducing emissions to zero by 2050. For instance, the battery compositions of vehicles currently in use may be recycled through innovative chemical and biological techniques. The UK is at the forefront of such a revolution concerning lithium batteries and is on the verge of finalizing certain measures: in the first place, it is essential to establish functional battery recycling facilities in order to strengthen the security of supply and improve

[43] Farchy, Jack, and Warren, Hayley. "China Has a Secret Weapon in the Race to Dominate Electric Cars." Bloomberg.com. Bloomberg, December 2, 2018. https://www.bloomberg.com/graphics/2018-china-cobalt/.

the circular economy; subsequently, in these structures, batteries will be tested in order to determine whether or not a 2^{nd} life battery may guarantee the same performance; lastly, the governments are expected to intervene concretely by allocating targeted funds environmentally benign practices in order to establish a green and market-oriented system. Currently, the awareness in the field of cobalt and especially lithium has already been raised to a notable extent, even if much remains to be done. In the Rare Earth Elements scenario, there have been less heated discussions and debates about these possibilities but, particularly within the EU, the tide about recycling and reuse is turning.

The most effective procedure in order to identify the most suitable solutions is to investigate firstly all the concerns and controversies that characterize the Rare Earth Element universe and then the potential answers that may be provided by all stakeholders. This will be the objective of the second chapter that will open up with an analysis of the geological and economic issues of Rare Earth Elements which have been the traditional problems to cope with since those commodities have impacted the Earth's surface.

CHAPTER TWO

RECONCILING THE END WITH THE MEAN: ACHIEVING CLIMATE NEUTRALITY THROUGH A SUSTAINABLE TRANSITION

2.1 Geological concerns: emphasis on quality rather than quantity

Geology is the study of the Earth and its materials, a science that deals with rocks and their peculiarities. The discovery of Rare Earth Elements in 1787 in a Swedish quarry allowed geologists to study a different and atypical mineral, characterized by outstanding properties but even the maddening characteristics of being extremely difficult to exploit and collect. These 17 elements are relatively common in the Earth's crustal rocks, this is the reason why they are often referred to as enigmatic elements. Their rarity lies rather in the adversities, both geological and environmental, during the extraction, separation and refining processes from the surrounding rocks.

Despite occurring between twenty and thirty parts per million on our planet, Rare Earth Elements are problematic to be mined in deposits because their formation and geological features coincide with hazardous minerals. From a geological perspective, rare earths are unconventional because they have been consolidated into deposits through complex geological processes in Earth's mantle. The most intricate issue concerns the difficulty to extract and purify these elements given their low concentration in ores. Furthermore, such complicated processes require several chemical compounds which generate a massive volume of solid waste, incompatible with the global current living.

There is a multitude of steps in the processing of Rare Earth Elements ores, ranging from mining and chemical treatment to separation, refining and purifying. Since these 17 elements are distinct from one another, the actual wrath is that there are heterogeneous compositions of deposits to the extent that no two deposits are identical; the consequence is that no two extraction, separation or purifying processes are alike, thus increasing the uncertainty from a geological outlook. It is possible to distinguish between primary potential deposits and secondary potential deposits[44] of Rare Earth Elements: the formers are those crafted by magmatic, hydrothermal and metamorphic processes while the latter are those created by erosion, which include bauxites and placers. However, precisely classifying them is a utopia since a deposit is characterized by a complexity of geological environments and may be further subdivided on the basis of mineralogy and form of occurrences.

The most capacious Rare Earth Elements deposits are the primary type established by the partial melting of deep mantle rocks, such as Bayan Obo (Inner Mongolia), the largest deposit that is home to 80% of the world's LREE[45]. Alongside, a noteworthy source for these elements is bauxite, the principal ore of aluminium used in the Bayer process for its production; similarly, monazite ore deposits are economically viable resources where Cerium is abundantly present. Despite numerous possibilities, the critical issue is that economic deposits are rare and therefore these 17 elements are mined as a co- or a by-product to another material: Bayan Obo itself is an iron ore even if it has become hugely popular for Rare Earth Elements.

Property name	Country	Development stage	Contained reserves and resources (000 tonnes)
Bayan Obo	China	Operating	56,940
St-Honore	Canada	Late stage	18,382
Minami Tori Shima	Japan	Early stage	16,000
Kvanefjeld	Greenland	Preproduction	11,120
Ashram	Canada	Late stage	4,686
Ngualla	Tanzania	Feasibility	4,620
Ozango	Angola	Feasibility	4,470
Strange Lake	Canada	Late stage	4,406
Montviel	Canada	Late stage	3,877
Mt Weld	Australia	Operating	3,368

Table 1: the 10 largest Rare Earth Elements reserves. *Source:* S&P Global Market Intelligence

[44] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.
[45] *Idem*

On balance, there is only a tiny portion of REE deposits that are sufficiently voluminous and concentrated to be exploited economically throughout the world. The so-called 'reserves' have several repercussions on the REE market because they entail both fixed factors, such as concentration and distribution, and variable driving forces, like environmental regulations, technology for extraction and refining, and commodity prices. Therefore, when analysing the geological concerns related to Rare Earth Elements, experts have to deal with a scarce and heterogenous concentration of REE in deposits that are economically unviable; subsequently, the processes that constitute the REE lifecycle are time-consuming, expensive and environmentally problematic; last but not least, certain deposits contain these commodities as a by-product of other minerals but if it is not possible to extract and separate the latter, there is no life for any Rare Earth Element.

At first glance, the geological concerns may appear to be less stringent and imperative to cope with because economic, environmental and geopolitical issues are the most heatedly discussed. However, the geological origin of Rare Earth Elements is the fundamental starting point in order to find the actual problem and devise long-term solutions that may address the other concerns. The exploitation of new REE deposits or the adaptation of the already existing ones would have a positive impact on the rare earths market; simultaneously, the investigation of alternative solutions, namely the secondary supply of these elements through recycling and reuse, would help relieve the geopolitical anxiety around their demand and to adapt their lifecycle to the demanding and strict environmental standards all over the world.

2.2 Environmental concerns: the dark side of Rare Earth Elements

The relationship between geology and the environment is perhaps not always noticeable at first sight, but the increased levels of industrialization have created fertile ground for an analysis of such liaison. 'Environmental geology' may be defined as the interactions of humans with their environments[46]. The core of this environmental science is represented by the sustainable management theory, meaning the interaction with natural systems to support development but not at an acceptable environmental cost[47]. This concept ideally intersects with the Rare Earth Elements world: it is universally recognized that sustainable development cannot

[46] Bennett, Matthew R., and Peter Doyle. 1999. Environmental Geology: Geology and the Human Environment. Chichester: Wiley.
[47] *Idem*

prescind from these commodities, however, their mining may cause certain environmental damage to the extent that Rare Earth Elements are intermittently defined 'a not so green technology'.

The complex legacy of their geological processes of extraction and refining has been a heated topic of debate within specific countries, US, China and Malaysia on top. Rare Earth Elements mining relies on two popular methods that release toxic chemicals into the environment. The chemical erosion applied to the extracted earth in order to separate metals and thus dissolve rare earths is the most common method[48], but also the least environmentally sustainable since it may affect whole waterways; the second one consists of drilling holes into the ground using Polyvinyl Chloride (PVC) pipes and rubber hoses that trigger similar environmental damage[49]. The pollution that has resulted from rare earths mining has rendered soil incapable of supporting crops and has deeply contaminated water supplies[50].

Alongside, scientists have emphasized certain environmental and health problems caused by the toxic and radioactive waste generated by the processing plants. Rare Earth Elements deposits are contaminated by thorium and uranium, radioactive elements which increase the exposure to certain serious illnesses such as pancreatic, lung and other cancers. Considering that over 2,000 tons of toxic waste[51] are produced throughout these processes, it is not surprising that some negative calamities have occurred all over the world. Well-known and extreme examples include a toxic lake located in a remote area of Inner Mongolia, defined as "a dumping ground for waste byproducts"[52], as well as Chinese small town in the same region, Baotou, where people living in farms and villages have been forced to abandon the zone in order to avoid death.

Beijing's lenient environmental standards have enabled producers to commercialize Rare Earth Elements at roughly a third the price of other countries. The most critical problem is the development of independent auditing services that are traditionally regulated by the industry

[48] Smith, S.E. "Dirty, Dangerous and Destructive – the Elements of a Technology Boom." The Guardian. Guardian News and Media, September 26, 2011. https://www.theguardian.com/commentisfree/2011/sep/26/rare-earth-metals-technology-boom.

[49] "How Rare-Earth Mining Has Devastated China's Environment: Earth.org - Past: Present: Future." Earth.Org - Past | Present | Future, July 14, 2020. https://earth.org/rare-earth-mining-has-devastated-chinas-environment/.

[50] Pitron, Guillaume, Ondina Chirizzi, and Stefano Liberti. 2019. La Guerra Dei Metalli Rari: Il Lato Oscuro Della Transizione Energetica e Digitale. Roma: Luiss University press.

[51] *Idem*

[52] Maughan, Tim. "The Dystopian Lake Filled by the World's Tech Lust." BBC Future. BBC, April 2, 2015. https://www.bbc.com/future/article/20150402-the-worst-place-on-earth.

or by the government in countries such as China and Malaysia. Such a dark scenario has led to the creation of the "cancer village"[53], Dalahai in China, where people deal every day with cancer, strokes and high blood pressure[54]. The life expectancy there is apocalyptic because a rural area populated by farmers, forced to relocate by the provincial authorities, has been transformed into a closed universe consisting of a succession of rare-earth refineries that, paradoxically, are the beating heart of the energy and digital transition.

China is the emblematic example of a spectacular economic boom where little attention has been paid to the environmental impact. Considering that the world's top five polluters were responsible for 60% of global emissions and only Beijing produced roughly the same amount of CO2 as the other four countries combined[55], a change of direction is mandatory in order to attain the hoped-for results. However, it would be simplistic and reductive to consider only China as the enemy of the environment in the Rare Earth Elements' panorama. In Australia, South Africa, Malaysia and Taiwan, the electricity used in the extraction of those elements and in the production of EVs comes primarily from coal-fired plants, this is the reason why it is almost impossible to talk about a completely environmentally sustainable production.

Scientists have placed the emphasis on the compelling regulatory nature of rare earths projects. Market pressures have traditionally prompted producers and project managers not to conform to certain environmental protections. In the past, the global community has somehow tolerated such default and non-compliance, but multiple examples of soil erosion, acidification or high concentration of radioactive residues have reversed the general outline. The economy can no longer be considered more important than the environment; rather, the economy and the environment need to be the two complementary sides of the same coin where there is no room for shortcomings. The natural consequence is wondering whether it is possible to moderate rare earths' consumption on a large scale in order to relieve the environmental impact of their extraction and refining.

[53] Pitron, Guillaume, Ondina Chirizzi, and Stefano Liberti. 2019. La Guerra Dei Metalli Rari: Il Lato Oscuro Della Transizione Energetica e Digitale. Roma: Luiss University press.
[54] *Idem*
[55] Bloomberg.com. Bloomberg, October 24, 2021. https://www.bloomberg.com/graphics/2021-china-climate-change-biggest-carbon-polluters/.

Daily discussions and dialogue have focused on the possibility to recycle rare metals. This activity has been traditionally considered at the heart of a greener world, but it is not as eco-friendly and cost-effective as anyone may think. Certainly, it is one of the arrows in the Rare Earth Elements' quiver of solutions that will be analysed in the next sections. However, the world is confronted with a loop that is predominantly nurtured by an economic desire to stand out. On balance, the most effective solutions should encompass both the environmental and the economic dimensions where the environmental concerns are caused by the profit motive inherent in the economic systems to a certain extent. Before discussing such an intersection, it is fundamental to analyse the economic concerns that beset the rare earths' universe.

2.3 Economic concerns: geography and price volatility, greenflation and other critical inputs

The global objective of preserving our planet is fashioned on the basis of a more sustainable economy that clashes with the rare earths' industry in certain respects. The latter is a highly volatile industry, fundamental in order to produce some of the world's most advanced technologies. As a matter of fact, rare earths are expected to be the prime growth market over the next decades, with neodymium, praseodymium and dysprosium on top. This is because the relative permanent magnets industry is expected to increase its share by 12% to 14% and to grow at a compound annual growth rate (CAGR) of 5.9% from 2020 to 2027[56]. However, when the economic dimension of Rare Earth Elements is taken into account, criticalities and concerns are on the order of the day.

Differently from other metals and commodities, the Rare Earth Elements' universe is composed of 17 distinct elements and, therefore, heterogeneous market dynamics and peculiarities. There is no singular rare earth market to study but rather multiple scenarios and, in some cases, combinations that render market predictions almost inconclusive. From an economic perspective, the fragmentation of the market has never been a good feature; in this specific case, combined with the global recession of 2008-09 and the 2010 rare earth crisis, it has led to an alarming instability when it comes to analysing prices and costs. Trade disputes, disruptions in

[56] "Permanent Magnets Market Size Report, 2022-2030." Permanent Magnets Market Size Report, 2022-2030, April 2022. https://www.grandviewresearch.com/industry-analysis/permanent-magnets-industry

supply and demand and geopolitical decisions are the most relevant driving forces in this regard that have impacted the market value.

The 2010 rare-earth crisis, the first on the global stage, where China imposed an embargo on exports to Japan, triggered a significant disruption in the global supply of these elements and prompted market panic. The consequent and immediate reaction was an unprecedented price spike: *Table 2* is emblematic of the fragmentation of the Rare Earth Elements market, where not all rare earths have been affected equally because their respective markets are diverse and responsive to distinctive dynamics. In the aftermath of the crisis, samarium prices skyrocketed to the greatest extent with cerium and lanthanum; whereas, in the long-term, those elements involved in the permanent magnet sector, i.e. neodymium, praseodymium, europium, terbium and dysprosium, have started to soar gradually.

	Q3 2010	Q4 2010	Q1 2011	Q2 2011	Q3 2011	Q4 2011	Q1 2012	Q2 2012
Lanthanum	16.37%	**374.47%**	**366.10%**	**348.22%**	**348.71%**	143.07%	140.42%	59.82%
Cerium	20.36%	**439.84%**	**425.33%**	**410.26%**	**412.68%**	139.05%	135.20%	65.63%
Praseodymium	46.15%	61.51%	59.72%	88.99%	94.00%	**108.49%**	**120.27%**	43.22%
Neodymium	37.13%	63.97%	64.58%	97.58%	84.79%	**122.07%**	**138.34%**	73.88%
Samarium	1.47%	**865.67%**	**840.27%**	**808.42%**	**803.10%**	122.45%	117.11%	45.00%
Europium	7.62%	5.85%	3.60%	77.71%	**285.42%**	**296.18%**	**303.59%**	**322.21%**
Terbium	48.30%	44.48%	45.35%	84.52%	**191.66%**	**204.88%**	**211.99%**	**222.02%**
Dysprosium	44.82%	48.99%	45.72%	76.68%	**199.73%**	**199.38%**	**218.60%**	**242.57%**

Table 2: Rare Earth Elements' economic reactions to the 2010 Chinese embargo on Japan. *Source:* Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

On the whole, it is unclear how the Rare Earth Elements' markets will respond to geopolitical shocks and trade disputes in terms of supply and demand. Conversely, what is certain are the price fluctuations that materialise in all the market facets. This is primarily due to the price to be paid for going green. The global fight against climate change has triggered a paradoxical circumstance: shifting to a greener economy in the least possible time and, simultaneously, maintaining considerable profits and the highest living standards have paved the way for a new age of energy inflation. In the short run, such a process is extremely expensive because, as demand rises, supply is constrained, and the development of new mines and reserves would take between five to ten years. This imbalance has skyrocketed the prices of many critical commodities to the extent that it is possible to talk about 'greenflation'[57], meaning a considerable increase in the price of Rare Earth Elements used in the creation of renewable technologies.

A striking example is neodymium: its market is amongst the most vulnerable to externalities and geopolitical disputes considering its magnetic properties used in the development of extremely powerful magnets. Neodymium changes everything about electric cars, guided missiles, smartphones and producers are fully aware of this. As it can be seen in *Table 3*, Neodymium's price is constantly soaring, with a three and a half times increase from May 2020 to March 2022. Even in this case, the strong imbalance between supply and demand is the most relevant driving force where governments incessantly push the energy transition without taking into account the lack of balance in specific markets.

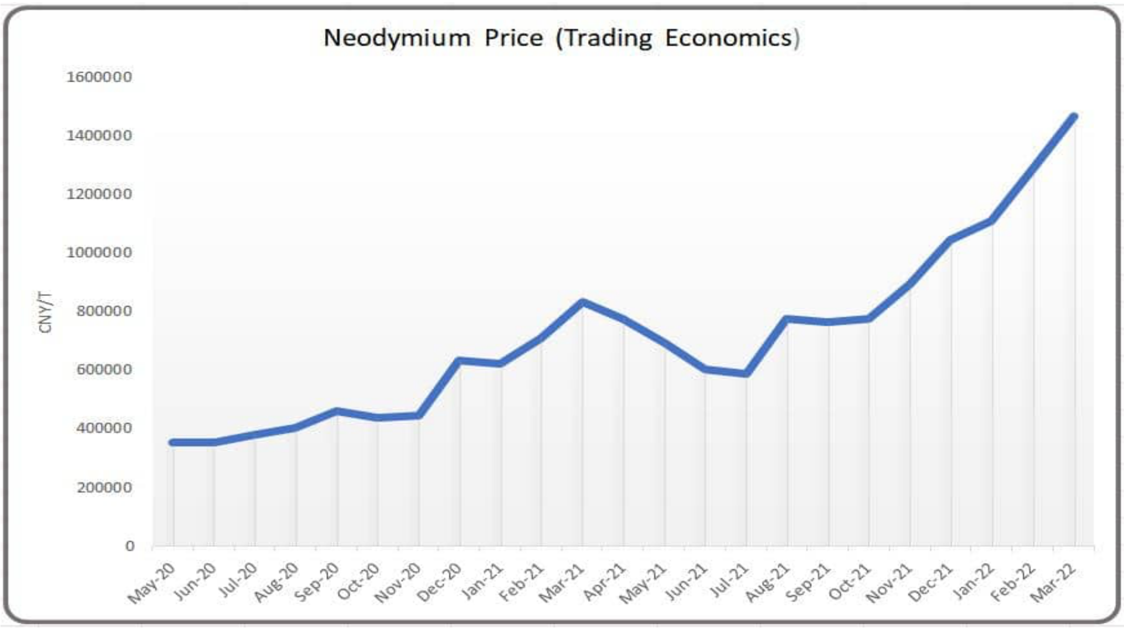

Table 3: The critical price fluctuations of Neodymium and the uncertain price projections. *Source:* Trading Economics

These price variations, coupled with current rising energy costs due to certain global events, amongst which the human tragedy in Ukraine[58], are determining the highest levels of inflation in over 40 years. The critical repercussion is the rare earths' supply chain instability

[57] Sharma, Ruchir. "'Greenflation' Threatens to Derail Climate Change Action." Financial Times. Financial Times, August 2, 2021. https://www.ft.com/content/49c19d8f-c3c3-4450-b869-50c7126076ee.
[58] Harrison, Alex. "Ukraine Crisis Drives Rush to Secure Supply in Global Metal Markets." Fastmarkets. Fastmarkets, April 11, 2022. https://www.fastmarkets.com/insights/ukraine-crisis-drives-rush-to-secure-supply-in-global-metal-markets.

where manufacturers are struggling to deliver quality products at a profit. Since the demand for rare-earth metals is two-fold dependent, on the request for applications and on the end-user industries, it is almost impossible to predict future economic scenarios in this regard. This matter is further complicated by the fact that Rare Earth Elements are primarily sold in the private market, which makes their prices difficult to monitor and track.

The economic dimension is of utmost importance in the Rare Earth Elements' panorama because controlling the relative market allows the development of a strengthened economy of scale difficult to compete with. In this respect, China has already demonstrated that its monopolistic oversight of rare earths' supply may be used as strategic geopolitical leverage amongst contending superpowers. On specific occasions, Beijing has tested the use of these commodities as a bargaining chip for its ultimate economic and geopolitical objectives, emphasizing how interrelated these two dimensions concerning are international security and peace all over the world.

2.4 Geopolitical concerns: the security risk for Western supply-chain resilience

The perception of security within the current society is undergoing a process of redefining where the national and international dimensions have been gradually joined by specific types of security, namely economic security, energy security, environmental security, military security and trade security. The Rare Earth Elements' saga incorporates all these aspects that are connected to each other: a disruption in the supply chain has repercussions not only on the economic side but equally on the energy and trade security; a geopolitical crisis may reshape the international relations and trigger the implementation of national security measures as well. Rare Earth Elements deserve to be approached holistically, otherwise, the related security impacts may be destructive and hardly remediable.

Today, stock depletion is not a critical issue for the rare earths' markets; conversely, flow disruption is intermittently taking place because of conflicts, trade wars, embargoes and the resulting geopolitical competition. The latter one is becoming more feverish all over the world since the schizophrenia behind the access to critical minerals essential to the energy transition is attaining unprecedented peaks. The geographical concentration and the vulnerability to disruption have always been systemic challenges in the Rare Earth Elements' panorama that have been exacerbated by unfeasible economic extraction and refining processes and environmental issues.

These are the most discussed topics when it comes to getting into arguments about rare earths but, behind the scenes, everything is manoeuvred by geopolitical patterns and their security implications.

Contrary to the current narrative where the undisputed control of China is evident to everyone, the world's dominant producer of rare earths has not always been the Red Dragon. Until the 1980s, the United States controlled the entire supply chain[59] thanks to the activity of the Mountain Pass mine in California where Molycorp, the only major rare earth producer nationally, supplied rare earths for the electronic needs of the Cold War economy[60]. However, due to tight environmental regulations and increasing costs, the American government decided to relocate the extraction of minerals that started to be exported to other countries where environmental damage was out of sight. Brick by brick, Beijing managed to become the most productive country and the sole market controller able to handle the commercial relations at its leisure.

China's leadership in the Rare Earth Elements' universe has been materialized following the convergence of multiple driving factors. In the first place, the effects of globalization have allowed the liberalization of cross-border trade and investment. Alongside, the Chinese policy initiatives and internal market conditions, complemented by an environmental security less stringent than in other countries; last but not least, the policy changes in other producing regions where rare earths exist but are not economically workable. The focal point is not the Chinese ample resources and large mines that are present worldwide, but rather the processing steps to obtain rare earth elements where Beijing has not yet encountered a worthy opponent. The acquisition of technological know-how in the rare earth sector from abroad has been the Chinese play of the century in order to become the dominant upstream producer of rare earth oxides and to control certain market segments such as NdFeB magnets[61].

The structural problems that characterize the world of these commodities, amongst which the global dependence on China, have been underestimated until the first decade of the 21st century. Media discourse or international policy have not devoted great attention to the matters until Rare Earth Elements became a subject of a trade dispute between China and Japan in 2010,

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59 Areddy, James. "Rare-Earth Miner in U.S. Tackles China, Its Own Past." The Wall Street Journal. Dow Jones Company, December 20, 2010. https://www.wsj.com/articles/SB10001424052748704476045760072909280 49906.

60 Smyth, Jamie. "US-China: Washington Revives Plans for Its Rare Earths Industry," September 14, 2020. https://www.ft.com/content/5104d84d-a78f-4648-b695-bd7e14c135d6.

61 Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

which awakened the two sleeping giants, meaning the US and the EU. The Senkaku islands[62], eight inhabited remote places of about seven square kilometers, have been the geographical epicentre of the Sino-Japanese controversy. Their geostrategic position, north of Taiwan and southwest of Okinawa in Japan, is contested by China, Japan and Taiwan since the discovery of oil deposits in the 1970s and the proximity to fundamental shipping lanes. In 2010, following an incident in the disputed waters between a Chinese fisherman and two Japan Coast Guard ships, China halted rare earth exports to Japan, starting the first global rare-earth crisis. This event has been only a recent example of the economic coercion that is a recurring countermeasure of Beijing's foreign policy[63].

Since then, a hostile trade policy for rare earths has become an effective geopolitical tool whenever China finds itself in political and economic disputes, or when it aims at strengthening its negotiating position around diplomatic tables, especially if the antagonists are the US or Japan. In this specific scenario, China is unchallenged because of its leading processing capabilities. Despite frequent discoveries of potential reserves where rare earths might be found in abundance, grandstanding projects and renewed enthusiasm are almost immediately toned down by structural impediments such as high-cost financing, infinite lead times and stringent environmental regulations. The impasse of the other countries leaves automatically room for manoeuvre for China which is consolidating its growing global power.

In 2013, China's president Xi Jinping devised the 'One Belt One Road' strategy, subsequently well-known as Belt and Road Initiative (BRI), which is a transcontinental long-term policy and investment program aimed at increasing trade and economic growth by connecting Asia with Europe and Africa via land and maritime networks. Such a magnificent plan, worth between 1 and 8 trillion Dollars, has energy and transport projects as milestones where railways, airports, ports, dams and pipelines are interconnected to the greatest extent. Beijing is the largest stakeholder whose final objective is to establish functional and long-lasting partnership characterized by an alternative vision of development to the traditional one of the Western partners.

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[62] They are referred to as the Senkaku Islands in Japan, as the Diaoyu Islands in the PRC and as the Diaoyutai Islands in Taiwan and have become a proxy battlefield in the growing Sino-US great power competition in the Indo-Pacific. Source: "Sino-Japanese Controversy over the Senkaku/Diaoyu/Diaoyutai Islands." July 2021. https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/696183/EPRS_BRI(2021)696183_EN.pdf.

[63] *Idem*

This Chinese reinvigorated geopolitical and economic stance is threatening the Western leadership, in the guise of the US, the EU and Japan, which has dominated the postwar world international relations, technology, industry and defence. As it is displayed in *Table 4*, China has created a magnificent network system that is empowering Beijing to control the Rare Earth resources all over the world. The quest for the technological command in a decarbonized world economy passes through the race for Critical Materials; the strategy of developing partnerships with those countries that are resource-rich is straightforward in the corridors of Beijing. Alongside, certain countries such as the Democratic Republic of Congo (DRC), Argentina, Bolivia, Russia, South Africa, Kazakhstan, and Brazil are not members of the Organisation for Economic Co-operation and Development (OECD), thus representing a critical issue in the governance of Rare Earth Elements to cope with in the coming years.

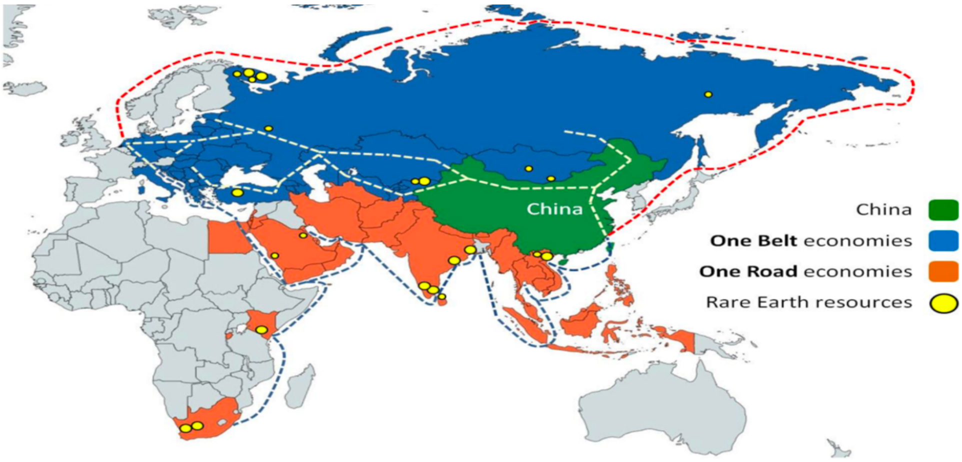

Table 4: The Belt and Road Initiative and its connection with the most important Rare Earth Elements' reserves worldwide. *Source:* Barakos, George, and Helmut Mischo. 2018. "The potentials of scientific and industrial collaborations in the field of REE through China's Belt and Road initiative." International Journal of Georesources and Environment, Vol. 4, n°3 (July): 86-91.

The other global superpowers cannot sit by and watch. The EU, the US and Japan have started a cycle of tripartite collaboration in order to decrease their dependence on China and find alternative and innovative technologies to recycle and reuse Rare Earth Elements. The possibility that China would reply a commercial embargo as in 2010 to Japan cannot be discarded; there are already worrying red flags that reverberate in the Western world that may come true suddenly in no time. The global transition is running at an unheard speed to the extent that it is mandatory to avoid being caught unprepared. Beijing's success has been driven by a model of government relying on a long game, strongly opposed to the Western decisions traditionally guided by the 'all at one' principle.

Nowadays, the emerging countries are looking to the Chinese development model where a solid economic growth is associated with political stability; Rare Earth Elements have significantly contributed to this scenario and are expected to be the game-changer of the future, especially in the renewal of international relations and security dynamics. All over the world, there is a broad array of solutions that will be investigated carefully in the subsequent sections in order to come up with solutions to the traditional shortcomings and bottlenecks from the geological and environmental perspective to the economic and geopolitical outlook.

2.5 Geological solutions: improving the utmost importance of secondary supply

Rare Earth Elements are increasingly more referred to as critical minerals, whose most relevant definition is the one provided by the 2020 US Energy Act: "a non-fuel mineral or mineral material essential to the economic or national security of the US, as well as the supply chain, which is vulnerable to disruption"[64]. Nowadays, there is a tendency of updating a list of critical minerals every three to five years: there is the list of critical minerals[65] provided by the US Department of Interior in partnership with the US Geological Survey; the list of Critical Raw Materials[66], now in its fourth edition, devised by the European Commission; there is the most recent Australia's 2022 Critical Minerals Strategy[67] which is expected to provide eventually a universal knowledge of the critical minerals' growing demand, even considering that Canberra is at the forefront of the supply diversification in this sector.

The essential early step is therefore to increase the awareness of the crucial issues, ranging from the actual shortcoming and deficiencies from a geological perspective to the environmental, economic and geopolitical repercussions that are expected to exacerbate the international panorama in the coming years. The Covid-19 pandemic has paved the way for an unprecedented momentum in the quest for resilient and secure supplies of critical minerals and

[64] "The Energy Act of 2020." The Committe On Science Space and Technology, December 21, 2020. https://science.house.gov/bills/the-energy-act-of-2020.
[65] "U.S. Geological Survey Releases 2022 List of Critical Minerals: U.S. Geological Survey." U.S. Geological Survey. February 22, 2022. https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals.
[66] "Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability." European Commission, September 3, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474.
[67] Department of Industry, Science, Energy and Resources. "2022 Critical Minerals Strategy." Australian Government, March 7, 2022. https://www.industry.gov.au/data-and-publications/2022-critical-minerals-strategy.

Rare Earth Elements. The most relevant stakeholders have realized a two-fold tipping point: on the one hand, it is of utmost importance to investigate the possibility of exploiting new reserves all over the world; the already existing ones are not sufficient to meet future global demand. Improving access to rare earths' reserves is an unquestionable solution and represents a magnificent opportunity in order to develop new processing and recycling capabilities, the latter being the second solution to be investigated to its greatest extent.

Currently, the largest rare earths reserves are located in China, Vietnam, Brazil, Russia, Australia and United States. According to the recent estimates and findings of a paper[68] published in the journal Geology, Rare Earth Elements are distributed on an equal basis all over the world; the critical point is to identify the deposits that are economically viable through innovative indicators and massive investments. Certainly, major steps forward have been made in various countries; however, it is fundamental to analyse to whom these discoveries will bring benefits. For instance, Myanmar is full of Rare Earth Elements to the extent that its total compound stocks are still unknown. Nevertheless, they are already exploited by China, especially in Myanmar's Kachin state, therefore contributing to the Chinese dominance[69] of the market.

Brazil, with its second-largest reserve of rare earths worldwide, is a mysterious giant. In 1972, the Brazilian Geological Survey identified deposits in São Gabriel da Cachoeira[70], claimed to be the largest in the world. In 2011, Brazil's Mines and Energy Ministry included rare earths as strategic minerals of the 2030 National Plan[71] while an outstanding paper[72] illustrated the country's potential to be the world's biggest producer of these materials. However, its ascent has always been limited by national legislation precluding mining in the area and by the reluctance of indigenous movements to large mining company projects[73]. Recently, both Canada and the EU have laid their eyes upon Brazilian reserves; the Canada Rare Earth Corporation is developing operations in the Rondônia national state[74] in order to extract minerals and meet the

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[68] Brandt, Sönke, Marc Lorin Fassbender, Reiner Klemd, Chandra Macauley, Peter Felfer, and Karsten M. Haase. 2020. "Cumulate olivine: A novel host for heavy rare earth element mineralization." Geology, Vol. 49, no. 4 (December): 457–462.

[69] Name. "Illegal Rare Earth Mining Harms Environment in Myanmar's Kachin State." Radio Free Asia, March 10, 2022. https://www.rfa.org/english/news/myanmar/mining-03102022184456.html.

[70] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

[71] Alves, Renato. "Bolsonaro Wants Brazil to Cash in on the World's Rare-Earth Obsession." The Brazilian Report, August 23, 2021. https://brazilian.report/business/2021/08/23/rare-earth-obsession/.

[72] "Usos e Aplicações De Terras Raras No Brasil - CGEE," https://www.cgee.org.br/documents/10182/734063/Terras_Raras_Web_9532.pdf.

[73] Maisonnave, Fabiano. "The Amazon Home of Bolsonaro's Mineral Fantasy." Climate Home News. Climate Home, October 23, 2020. https://www.climatechangenews.com/2020/07/05/amazon-home-bolsonaros-mineral-fantasy/.

[74] http://www.canadarareearth.com/12-april-2022

rising demand in the Americas while the EU is strengthening its raw materials dialogue and bilateral partnership with Brasília.

Australia is amongst the proactive superpowers in the investigation of emerging market opportunities and in the modernization of local and global infrastructures in order to maximize the sector's opportunities. They have implemented the Critical Minerals Accelerator Initiative to support strategically significant projects with an investment of $200 million[75]; Canberra has also leveraged Australia's existing Free Trade Agreements in South East Asia and the Indo-Pacific to develop businesses and gain access to these markets[76]; the government has even established the $2 billion Critical Minerals Facility[77] in order to develop processing facilities throughout the territory, like the one in South Australia by Renascor Resources; last but not least, one of the biggest players in the rare earths universe, Lynas Rare Earths, has received $14.8 million to skyrocket its production while Arafura Resources Limited has been allocated $30 million to construct the Nolans Project Rare Earth Separation Plant in the Northern Territory[78].

The Chinese monopoly on the market has been facilitated by the progressive withdrawal of the United States following the total inactivity of the Mountain Pass mine in 2012. The latter has been for decades, since its opening in 1952, the world's foremost supplier of valuable rare earth minerals. However, the increasingly stringent environmental regulations nationwide have forced the Pentagon to relocate rare earths' production to China, thus contributing to Beijing's dominance. Recently, the United States and its Department of Defence have awarded three rare earth-related grants in order to resume domestic production of these elements used to make weapons, electronics and permanent magnets[79]. Washington has definitively realized that boosting local production is fundamental in order to mark a turning point in securing these elements.

Such a change of direction has been dictated by the fact that, despite a fundamental contribution, recycling and reuse are not sufficient in order to mitigate the effects of potential

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[75] Department of Industry, Science, Energy and Resources. "2022 Critical Minerals Strategy." Australian Government, March 7, 2022. https://www.industry.gov.au/data-and-publications/2022-critical-minerals-strategy.

[76] *Idem*

[77] *Idem*

[78] *Idem*

[79] Scheyder, Ernest. "Pentagon Awards $13 Million in Rare Earths Funding to U.S. Projects." Reuters. Thomson Reuters, November 18, 2020. https://www.reuters.com/article/usa-rareearths/pentagon-awards-13-million-in-rare-earths-funding-to-u-s-projects-idINKBN27Y2F0.

disruptions: according to the Pentagon's Office of Industrial Policy, Danielle Miller, "domestic production of strategic and critical materials is the ultimate hedge against the risk of deliberate non-market interference in extended overseas supply chains"[80]. The United States, Europe and the other major stakeholders need more mines in order to go electric, increase national security and strengthen the integrity of supply chains all over the world. In the subsequent chapters, ample space will be devoted to the analysis of the European Union's leading position in the discovery of unlocated mines and to the new geological frontiers of rare earths, Afghanistan, Greenland and the Outer Space on top of the list. However, such an analysis cannot prescind from a preliminary discussion on how recycling and reuse are considered fundamental in order to integrate these efforts and eventually identify the keystone of the Rare Earth Elements' world.

2.6 Environmental solutions: coping with the Rare Earth Elements' dark side through recycling and reuse

The global transition to a clean energy economy should encompass an unprecedented degree of environmental justice across all the aspects of the global supply chain. Energy provision, on which national and international peace and security are always more dependent, should be affordable, reliable and safe; to this end, the environmental dimension perspective has drawn most of the attention especially in the framework of Rare Earth Elements, due to their 'not so green technology' side. Nowadays, an environmentally ethical approach is mandatory and requested in order to perform in such a market, even if this has not been the golden rule. The Chinese empire has been erected on poor environmental safety requirements in the past, to the extent that several inhabitants have been forced to abandon their homes and to be cured of various diseases. Alongside, even the West has chosen to relocate its pollution, just to mention Mountain Pass in the US and La Rochelle in France whose rare metals production and refining have been transferred within the Chinese borders.

From an economic perspective, everyone has walked out with a gain; however, Beijing has effectively laundered dirty minerals at the end of the day. Such a scenario is unacceptable today, with mankind striving for a net-zero emission economy and planet. It is true that having the lowest price possible has been traditionally a preponderant condition, but it is no longer tolerable to put the environmental considerations apart when discussing rare earths. This is the

[80] Scheyder, Ernest. "U.S. Needs More Mines to Boost Rare Earths Supply Chain, Pentagon Says." Reuters. Thomson Reuters, October 19, 2021. https://www.reuters.com/business/us-needs-more-mines-boost-rare-earths-supply-chain-pentagon-says-2021-10-19/.

reason why the environmental prospect of these elements is expected to be comprehensively taken into account. In the past, experts and governments did not have sufficient information on the subject because technologies were not impressive as today and the public opinion often ignored such a critical issue. With the passing of time and the emergence of unexpected (or only unknown) problems, ensuring that the rare earths' processes are environmentally acceptable has become a prerogative to comply with.

The radiation caused by rare earth mining activities is rising severe concerns all over the world to the extent that industrialists have given special consideration to rendering the processes of extraction and refining more sustainable and compliant with environmental regulations. Amongst the techniques reviewed, the cheapest and easiest to be deployed is selective precipitation, used to remove and separate contaminants in an aqueous solution[81]; however, the most important companies are opting for a combination of multiple separation techniques based on solvent extraction in order to separate the undesired thorium and uranium in the rare earths that have caused critical problems on a global scale. There is more interdependency and exchange of techniques and ideas between the stakeholders of the sectors. Alongside, there is evidence that the average concentrations of radioactive matter are lower in the secondary sources than those of the primary sources, this is the reason why when it comes to analysing potential environmental solutions, there is ample room for manoeuvre concerning recycling and reuse.

Innovative plans and strategies, further incentives and capabilities on how to handle end-of-life materials are on the everyday critical materials' agenda. Recycling energy is directly connected with a reduction in the demand for fossil fuels; but recycling Rare Earth Elements is equally important in order to close the loopholes on the demand and supply side. For instance, the US army, which is amongst the largest consumers of rare metals for their military equipment, has ample storage of rare-earth metals to be recycled and reused. Despite the ambition looks good on paper, experts have realized how complex such a process is to implement. In this sector, not all that glitters is gold because Rare Earth Elements are not used in their pure state in green technologies.

[81] Silva, Ruberlan G., Carlos A. Morais, and Éder D. Oliveira. 2019. "Selective precipitation of rare earth from non-purified and purified sulfate liquors using sodium sulfate and disodium hydrogen phosphate." Minerals Engineering, Vol. 134 (March): 402-416.

The most critical problem that is expected to be dealt with is the prohibitive cost of recovering rare metals, a sum that currently exceeds their value. Alongside, recycling companies are obliged to process these activities in the countries of the collection; the 1989 United Nations Basel Convention specifies that it is prohibited to move waste that is considered hazardous, on account of its potentially toxic heavy metal content, to countries with lower environmental standards[82]. Therefore, it is ascertained that working both on innovative technologies in order to reduce the prohibitive costs of recycling and more appropriate and shared environmental standards on a global level are now the two ways to go.

In this regard, the European Union has been a pioneer and aims at becoming the leader in recycling activities and in raising the environmental bar. In the realm of permanent magnets, the REE4EU project and technology[83] are an outstanding advancement, with several tons of in-process wastes and end-of-life products containing rare earth elements treated successfully. Alongside, in 2019 the implementation of Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SUSMAGPRO)[84] is allowing to recover recycled neodymium magnets in Europe, which is assiduously looking for a strategic autonomy in this regard and a progressive distancing from the Chinese supply and economy.

At the industrial level, the most active magnet producers in Japan are reprocessing industrial waste and recovering as much as 30% of the rare earths used in the preliminary production phases, thus demonstrating that with important expertise and knowledge, recycling and reuse can bring major benefits and show visible results. It is true that the cost of recycling may remain greater than intended, but the goods full of rare earths, such as full-electric and hybrid vehicles and wind turbines, generally complete their life cycles; if governments devise public policies intended to regulate their recycling, such as the EU's Circular Economy Action Plan[85], the supply of recyclable material will grow and their supply will have positive effects on the total demand of these technology metals.

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[82] UNEP. 1989. "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, 1989. International Documents on Corporate Responsibility." Basel.
[83] REE4EU, September 4, 2020. https://www.ree4eu.eu/.
[84] "Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SUSMAGPRO)," https://cordis.europa.eu/project/id/821114.
[85] "A New Circular Economy Action Plan - For a Cleaner and More Competitive Europe." European Commission , March 11, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM%3A2020%3A98%3AFIN.

Recycling rare earths does not entail developing new technologies; rather, it paves the way for economies of scale and the establishment of an effective supply chain no longer characterized by the existing gaps. At the highest levels, it is fundamental to work on the implementation of integrated systems that will include the collection, disassembly and sorting of useful waste containing Rare Earth Elements based on a series of refining centres where people may even have the possibility to share ideas and insights. Nowadays, the most important contributions come from specific electronic components, such as recycled neodymium from computer hard disks or cerium from car catalytic converters. The final objective should be to recover (at least partially) all the 17 elements from already existing devices in order to relieve the quest for new reserves and deposits for instance.

It would be an outstanding solution and outcome to create a rare earth recycling industry on a large scale, led by actors such as the European Union or Japan, where companies would collaborate on an integrated pyramidal structure. In the permanent magnets sector, recycled rare earths magnets account for less than 5%[86], but in the current decade, such a percentage is expected to increase at least five-fold[87]. As the use of rare earths in products will increase, the amount contained in items reaching end-of-life will also increase.

On balance, research into greater, more efficient processing techniques and the establishment of related and specific environmental regulations could make a big difference. Breathtaking discoveries have been recently made concerning chemical methods to split rare earths element by element and then recover them. Once again, the EU is at the forefront of such a revolution because its Waste of Electrical and Electronic Equipment laws require manufacturers to finance or perform the recycling. Other regulations are about to be adopted, especially most specific governance about requiring vehicle batteries and electric motors within the United States. There is still much work to do but the current path that has been adopted worldwide seems to be the most appropriate one. Anyway, if geological and environmental solutions are correctly implemented and generate outstanding results, it will also depend on how stakeholders will deal with the geopolitical and economic dimensions because, as already anticipated in the previous sections, all these aspects underlie long-lasting international security.

[86] Kinch, Diana. "Recycling Could Account for 25% of Rare Earths Market in 10 Years: Mkango CEO." S&P Global Commodity Insights, November 3, 2021. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/110321-recycling-could-account-for-25-of-rare-earths-market-in-10-years-mkango-ceo.
[87] *Idem*

2.7 Economic solutions: global sustainable investments in diversified supply source

Mining and mineral explorations have traditionally been associated with economic growth and prosperity. In the past, there was copper, gold, zinc and diamonds while nowadays the pivotal elements are the 17 rare earth metals that have definitively attracted international attention. In the pursuit of the 2050 net-zero emission scenario, in line with the 2015 Paris agreement on climate change, governments are seeking to decrease and (hopefully) take out any carbon emissions. The decarbonization of energy generation and transport passes inevitably through the Rare Earth Elements' market. China has long dominated the supply chain of these 17 elements, particularly the magnet metals neodymium, praseodymium, terbium and dysprosium. For instance, according to Australia's biggest rare earths miner, Lynas corporation, in the three months ended March 31, 2022, the average price of Neodymium magnets lifted to $64.70 a kilogram, almost double the $35.50 a kilogram received a year ago.

The potential disruption and shortage of these key elements is stimulating governments to adopt a targeted and remarkable diversification of the sources of supply as a top political priority. The Australian Lynas Corporation, the unique non-Chinese company with significant refining experience, has been selling rare earth oxide from its plant in Malaysia since 2012[88] and has entered into agreements with the United States to allow light and heavy rare earth capacity throughout their borders[89]; Pensana is establishing the world's first Rare Earth processing hub at Saltend Chemicals Park in the United Kingdom, the first separation facility to be built in more than a decade in a Freeport[90]; the American Energy Fuels is an emergent local producer in the commercial rare earth elements business whose objective is to support and boost a fully integrated US supply chain[91].

In *Table 5* it is possible to analyse the rare earths' non-Chinese companies that are working in their respective countries and markets in order to cope with the strength and capacity Chinese counterparts. Australia and the United States are striving for counterbalancing China's

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88 LynasCorp. "Kuantan, Malaysia." Lynas Rare Earths, January 28, 2022. https://lynasrareearths.com/about-us/locations/kuantan-malaysia

89 "Australia's Lynas Wins Funding for U.S. Heavy Rare Earths Facility." Reuters. Thomson Reuters, April 22, 2020. https://www.reuters.com/article/us-usa-rareearths-lynas-corp-idUSKCN2240UL.

90 "Diversifying Rare Earths: Inside Pensana's Angolan and Yorkshire Projects - Mine." Mine, May 10, 2022. https://mine.nridigital.com/mine_mar22/pensana_angola_yorkshire.

91 Hering, Garrett. "Infographic: Q4'21 US Wind Power by the Numbers." Infographic: Q4'21 US Wind Power by the Numbers | S&P Global Market Intelligence, April 22, 2022. https://www.spglobal.com/marketintelligence/en/news-insights/blog/infographic-q421-us-wind-power-by-the-numbers.

monopoly by focusing primarily on Neodymium and Praseodymium, together with other LREEs, whose demand is expected to skyrocket in these years. It is not surprising that both the Trump and the Biden administrations are working on economic partnerships with Australia and Canada in order to secure the supply of Rare Earth Elements.

Company	Relevant jurisdiction	Specialisation
MP Materials Corporation	United States	Samarium, Europium, Gadolinium, Terbium, and Dysprosium
Lynas Rare Earth	Australia	Neodymium & Praseodymium
Iluka Resources	Australia	Neodymium & Praseodymium
Australian Strategic Materials	Australia	Neodymium & Praseodymium
Energy Fuels	United States	LREE (Cerium and Lanthanum)
Neo Performance Materials Inc.	Canada	Gallium & Indium
Greenland Minerals	Australia	Neodymium & Praseodymium

Table 5: author's independent data collection. *Source*: companies' websites.

The economic solutions are consequently based on the geopolitical arrangements and strategies that will be discussed in the forthcoming section. It is commonly accepted that there is the existence of 17 different rare-earth markets and phenomena like greenflation that have negative impacts on them; therefore, governments should work on the development of a circular economy model for REEs in order to strengthen eventually energy efficiency and material flow in diversified sectors. This economic adjustment might be possible only if the just mentioned companies share their knowledge and expertise, while governments are expected to support such advancements. Recent discussions within the US have emphasised the possibility to exempt rare earth minerals from severance taxes and providing tax breaks for rare earth material.

The establishment of a circular economy approach in the REEs markets is expected to contribute to supply chain resilience, climate change adaptation and job creation and help foster social acceptance of the risks and benefits of sustainable technological development[92]. From an economic perspective, heated debates about replacing Rare Earth Elements with substitutes have taken place. In critical applications, experts have suggested substituting rare earth metals with

[92] Dang, Duc Huy, Karen A. Thompson, Lan Ma, Hong Quan Nguyen, Son Tung Luu, Minh Thao Nguyen Duong, and Ashlyn Kernaghan. 2021. "Toward the Circular Economy of Rare Earth Elements: A Review of Abundance, Extraction, Applications, and Environmental Impacts." Archives of Environmental Contamination and Toxicology, Vol. 81, (November): 521–530.

other materials and developing products that require less or no rare earths. However, considering the outstanding properties that characterize these elements, the potential substitutes are less promising and do not represent a viable alternative in the short-medium term, otherwise, the tricky issues that proliferate in the rare earths' universe would have been immediately addressed.

On balance, the global economic approach should be the pursuit of a circular economy model that incorporates high-tech manufacturing, economic geology and social inclusion. Further studies, socioeconomic planning and regulations are on the verge of being developed in order to assess comprehensively the economic impacts of the rare earths. Hopefully, the horizontal integration of the various markets could be no longer a utopia if complex geopolitical issues that determine the international price and supply of these elements are worked out. The intensive geological exploration programs that have been implemented worldwide and that have led to the discovery of new, economically viable reserves is a major step forward that is expected to be fuelled. The momentum in both Rare Earth Elements mining and recycling is expected to boost global production and therefore to affect positively the supply and the price of these elements.

2.8 Geopolitical solutions: working toward a homogeneous approach

All the global superpowers are heavily dependent on imports of specific mineral commodities from certain countries: the cobalt supply chain is controlled by the Democratic Republic of Congo; the lithium business is dominated by Chile while rare earths are an almost exclusive Chinese affair. These mineral commodities are essential to the national security and economic prosperity of several countries, the US and the EU on top. In the realm of rare earths, experts have often emphasised how dependency on foreign sources represents a decisive factor in the strategic vulnerability that grips the economy and military sectors. Miners and producers in the American and European continents have encountered various constraints such as permitting delays, stringent environmental regulations, price fluctuations and scarce geological and geophysical data.

Such an intricated set of dynamics has paved the way for a 21st-century Chinese dominance of the market, holding more than one-third of the world's total metric tons of Rare Earth Elements. Beijing has never concealed its ambition to absorb everything possible, ranging from the elements themselves to the most innovative and effective techniques and refining processes. Chinese President Xi Jinping has never been satisfied with such an accumulation of power and business to the extent that the efforts in order to secure supply outside the country have been multiplying all over the world. Several superpowers have engaged in geological exploration programs, in-depth environmental studies and related solutions and targeted economic investments, especially after the trade conflicts between Japan and China in 2010 and the US and China in 2018.

Both the US and the EU have guided such revolutionary processes in order to become less reliant on the imported raw materials. They have devised lists of critical minerals, raised investments, digitalized their economies and look for improving their national security and balance of trade. Specifically, the US under the Trump administration has realized how the technological superiority and readiness of their Armed Forces, amongst the most significant consumers of rare earths, are almost totally reliant on these commodities. The latter have been the epicentre of the 2018 trade war between the US and China, whose desire to keep its undisputed leadership in production and supply has prompted Beijing to covertly threaten Washington.

Executive order 13817[93] of December 20, 2017, adopted by the United States, should represent a milestone in the global counterstrategy against Chinese domination. Great emphasis has been placed on identifying new sources of rare earth elements and, since then, several new projects have been implemented outside China, especially within the US, Canada, Japan and Australia; the strengthening of critical infrastructure data and facilities is intended to raise the standards within those sectors that are crucial to national security; structured partnerships, notably with all these countries and the EU, have been signed in order to access and develop critical minerals. The United States has realized that prevention is better than having to react and are not willing to engage in a second Cold War, this time commercial and against China because they are aware that the chances of coming out as winners (or simply not losers) are extremely high.

This is the reason why the Biden administration has followed such a route and, following the 2021 Executive Order on America's Supply Chains[94], it has awarded, for instance, MP Materials $35 million to process heavy rare earth elements at Mountain Pass facility in

[93] "A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals." Executive Order 13817, December 26, 2017. https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals.

[94] "Executive Order on America's Supply Chains." The White House. The United States Government, February 24, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/.

California[95]. The United States has set the path and the other actors have not stood by and watched. While the EU deserves a dedicated section, Australia and Japan have achieved substantial results. Canberra has developed long-term strategic investments to internationalise the Rare Earth Elements supply and modernised its production in order to mitigate China's influence in this sector[96]. Rare earths have been identified as a strategic industry even in Japan which has introduced a comprehensive policy package to end the dependence on Chinese rare earths. As it can be deduced from *Table 6*, the measures to secure diversified supply sources, such as the 2011 loan to Lynas Rare Earths and investments in other territories, integrated by a strong recycling activity, have allowed Tokyo to halve its rare earth dependence on China.

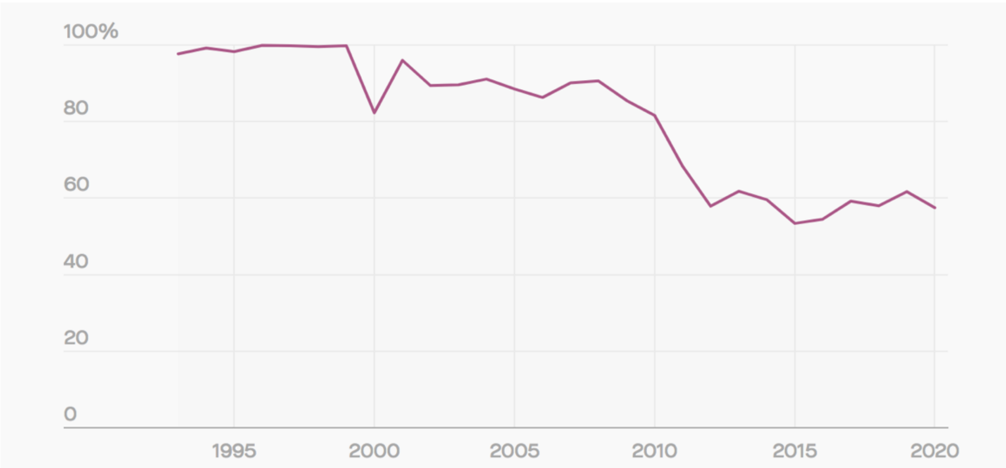

Table 6: Japan's rare earths dependency on China. *Source*: Hui, Mary. "Japan's Global Rare Earths Quest Holds Lessons for the US and Europe." Quartz. Quartz, April 23, 2021. https://qz.com/1998773/japans-rare-earths-strategy-has-lessons-for-us-europe/.

All these countries strongly believe that the most relevant geopolitical solution and adjustments are the adoptions of common approaches where each actor is an integral part and backbone of the initiatives taken together. The Quadrilateral Security Dialogue (QUAD) deal between leaders of Australia, the US, India and Japan[97] is probably the most relevant agreement in this regard which aims at securing supply chains outside China through subsidies, incentives and regulatory congruence. The development of rare earths extraction and refinement, even in territories and countries that are not parties to the agreement such as the EU Member States and

[95] Sink, Justin, and Leonard, Jenny. "Biden Seeks to Boost Rare Earth Element Extraction in U.S." Bloomberg.com. Bloomberg, February 22, 2022. https://www.bloomberg.com/news/articles/2022-02-22/biden-seeks-to-boost-extraction-of-rare-earth-elements-in-u-s.

[96] "Australia Gives Rare Earths US$360 Million Boost to Counter China Dominance." South China Morning Post, March 16, 2022. https://www.scmp.com/news/asia/australasia/article/3170630/australias-rare-earths-projects-get-us360-million-funding.

[97] "Joint Statement from Quad Leaders." The White House. The United States Government, September 25, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/24/joint-statement-from-quad-leaders/.

South Korea, is increasingly gaining ground; the consequence is that, in the Beijing's corridors, speculations about commercial threats to its undisputed throne are more and more insistent.

In the next five years, the market for Rare Earth Elements is expected to grow heterogeneously all over the world. The race for these elements will be vehement in those countries that are full of resources, especially in South-East Asia and Oceania. Within the Old Continent, some EU Member States have a relevant metal refining and manufacturing base; this is the reason why Brussels expects to unearth untapped reserves for sourcing critical minerals domestically; the Americas, Africa and the new frontiers such as Greenland, represent currently an open issue to be addressed in the coming months. Certainly, the 2022 Russo-Ukrainian war may be a massive earthquake in the market and redesign all the global dynamics and prices of Rare Earth Elements, especially within the EU whose only commercial rare earth separation plant, Silmet in Estonia, imports its raw materials from Russia.

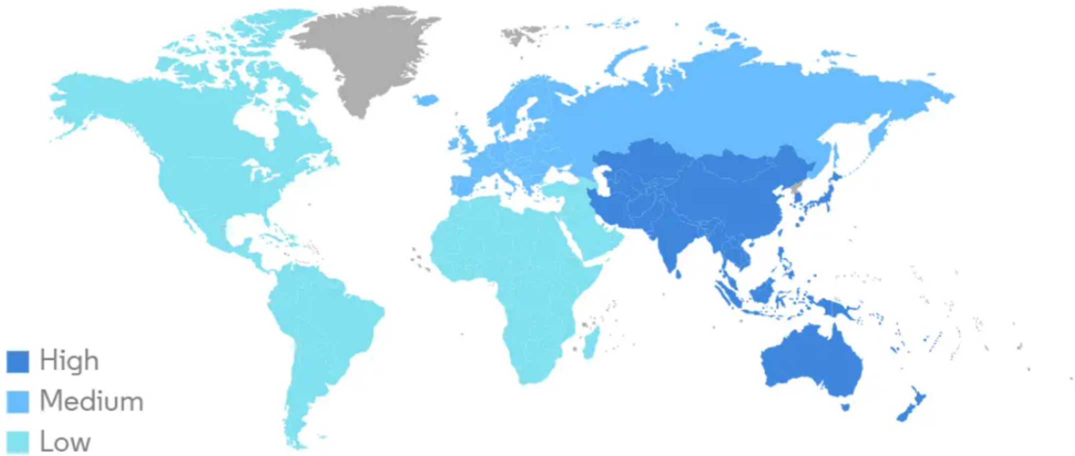

Table 7: Rare Earth Elements market – Growth Rate by Region, 2022-2027. *Source*: Rare Earth Elements Market - Growth, Trends, Covid-19 Impact, and Forecasts (2022 - 2027), Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/rare-earth-elements-market

On balance, most of the superpowers have activated themselves in order to break China's hold on the market. There are still several measures, financial and environmental, to be taken in the forthcoming years. The global equilibrium is on a knife-edge because unexpected calamities are next door and current governments have demonstrated to struggle for maintaining the reins of the situation under control. This is the reason why it would be extremely valuable and constructive if, besides those nations, international agencies and private sector entities had a concrete role in the regulation of the Rare Earth Elements market. To safeguard national security, it is of utmost importance that every entity is engaged in collective measures and joint actions in order to fill the others' gaps.

2.9 Global Governance: IEA's (and beyond) long-standing experience in balancing energy markets

There is no common definition of global energy governance; however, it can be referred to as the act of managing the stability and sustainability of the global energy order. Traditionally, extreme price fluctuations, supply and demand disruption and environmental issues represent the externalities of the international energy market to the extent that discussions about energy security are on the order of the day. Since the 19th century, the international energy market has been associated with the developments of fossil fuels; specifically, the instability of supply, demand and prices in the international oil market has been a real head-scratcher for the international community. To come up with effective solutions in order to minimize the adverse economic effects of such calamities, global energy governance has emerged through several initiatives: the preliminary oil market regulation by the Standard Oil company at the beginning of the 20th century[98]; the oil standards set out by the "Seven Sisters"[99]; the emergence of the OPEC and its output adjustments in the 1980s.

These mechanisms and systems have been successful and, in certain regards, fruitless at the same time. This is because the competition for oil resources, vital for national security in the past and still today, has been hysteric and zealous over the decades. Only when an effective global energy governance has managed to prevail, the market has enjoyed stability and prosperity characterized by cooperation and prices in check. The sustainability of the system relies on surplus supply capacity that allows coping with prices fluctuations and disruption in the supply and demand sides. In the case of oil, such a scenario has been materialized throughout the decades while in the case of Rare Earth Elements, this is the most relevant flaw in the system which rocks the global boat. It has already been discussed why an OPEC of rare earths would be almost impossible to establish; however, a mechanism of international energy security management in the realm of these commodities could be the most effective initiative in ensuring the stability of the market.

[98] Burclaff, Natalie. "Standard Oil Established." Research Guides, January 14, 2020. https://guides.loc.gov/this-month-in-business-history/january/standard-oil-established.
[99] Colgan, Jeff D. 2021. Partial Hegemony: Oil Politics and International Order. Oxford University Press Inc.

Certainly, structural changes in geopolitics and in the global economy lead to diverse and thorny issues. In the past, international energy security was all about oil while nowadays the world is heading towards a global energy governance increasingly more focused on renewable energies and critical minerals. Remote regions have become the epicentre of the energy markets, especially those territories that are managed by non-OECD countries such as China, India and the ASEAN countries[100]. All these countries are and will be at the forefront of the future Rare Earth Elements' market to the extent that an effective and efficient global energy governance is mandatory.

At present, several stakeholders have enacted legislation in order to curb the flow of conflict minerals and advocate for transparent and efficient minerals supply chains. For instance, the OECD had adopted its Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas[101] in order to provide companies operating in contexts of fragility with effective guiding principles. The EU has implemented its Conflict Minerals Regulation[102], which came into force on January 1, 2021, in order to stop the exportation of conflict minerals and metals, to be reviewed in 2024.

In the energy security realm, focused and tailored governance mechanisms are fundamental in order to pursue the global objectives set up by the 2015 Paris Agreement. For each energy source there is a traditional organization which provides a platform for cooperation and dialogue, such as the OPEC, the Gas Exporting Countries Forum (GECF) or the International Atomic Energy Agency (IAEA). Following the first oil crisis of 1973-1974, the OECD countries have established the International Energy Agency (IEA), which has dealt with different energy sources ever since. This transnational entity is a world-class example of crisis management and prevention; however, its membership-limited structure to the OECD countries makes it ineffective when it comes to dealing with specific sectors, such as the one of Rare Earth Elements, where the most important countries, China, India or Myanmar, are nor parties to it.

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[100] ASEAN is an organization composed of ten Southeast Asian states – Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam. *Source*: "Member States - ASEAN." https://asean.org/about-asean/member-states/.

[101] OECD. 2016. OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. Third Edition. Paris: OECD Publishing.

[102] "Conflict Minerals Regulation." Trade. https://policy.trade.ec.europa.eu/development-and-sustainability/conflict-minerals-regulation_en.

A stunning initiative in this regard has already been undertaken with the creation in 2009 of the International Renewable Energy Agency (IRENA), a multilateral intergovernmental organization whose primary objective is to be the global voice for the use of renewable energy[103]. Since IRENA is actively engaged in looking into the geopolitical implications of an energy transition and all the rare earths' stakeholders are parties to it, experts claim that the development of common global approach and strategy in this sector should be entrusted to this cross-border authority. Improvements in the global trading system, extremely liberal in the case of Rare Earth Elements, should be the top priority of the global energy governance in order to regulate the market and avoid further distortions by Beijing. Even because the dispute settlement mechanism within the WTO system, invoked in the aftermath of the 2010 rare-earth crisis, has demonstrated to be ineffective.

Beijing has erected its empire through the allocation of economic subsidies to the most important industrial actors; the US and Europe are trying to follow the path in order to redress the current exposure, but they probably lack the expertise and knowledge to be effective in this regard. Offering targeted financial support to non-China producers in order to rebalance the market could be a mission assigned to a transnational body such as IRENA given its widespread activity in the sector and its good relationship with its members.

On the whole, geological, environmental, economic and geopolitical issues of the Rare Earth Elements' saga have been analysed in most of their facets. Presumably, energy security is currently one of the most relevant pillars of international security and stability, with foreign policies of every nation considering it a top political priority. The convergence of disparate and heterogeneous issues in the rare earths' universe is a serious concern that is possible to address only through the involvement of all stakeholders. The Rare Earth Elements' world is complex, vulnerable to externalities, still relatively unknown; however, it will be probably the most crucial sector in order to achieve the global energy transformation and thus strengthen the national security of all the 195 countries in the world today. In the subsequent chapter, ample space will be devoted to the global leader of the Green-Tech Transition, the European Union; its objective to minimize the high level of foreign dependency in the rare earths' panorama will be the amongst

[103] With 167 Members, IRENA plays a leading role in the energy transformation as a centre of excellence for knowledge and innovation, a global voice for renewables, a network hub and a source of advice and support for countries. Source: "International Renewable Energy Agency (IRENA)." IRENA International Renewable Energy Agency. https://www.irena.org/.

the biggest security challenges of the 2020s that may represent an example to be followed in order to render this market as profitable as possible for the sake of everyone.

CHAPTER THREE

DIGGING DEEP THE PILLARS OF THE EUROPEAN GREEN-TECH TRANSITION AND THE EUROPEAN STRATEGIC AUTONOMY IN THE DEFENCE INDUSTRY

3.1 The race for Critical Raw Materials: a heated decade

For decades, Critical Raw Materials have been the economic and strategic cross and delight of Europe. These commodities are used in the EU's mega sectors such as defence and aviation, space exploration, health and environmental technology, transportation and services. Critical Raw Materials, and more specifically Rare Earth Elements, are characterised by a traditional dilemma: despite their name may evoke scarcity in the collective imaginary, their actual problems are the severe risks associated with their supply and the lack of viable substitutes that may replace properly their unique features. The modern technologies cannot prescind from an everyday supply of these goods to the extent that access to Critical Raw Materials has become a greatest and growing concern within the EU and throughout the planet.

In the last decade, Brussels has actively got engaged in the race for Rare Earth Elements, fundamental for a broad range of modern technologies and for its role as a bold climate leader aiming at achieving net-zero emissions by 2050. Such an objective lies at the heart of the European Green Deal[104], whose primary and non-negotiable target is to emit no more greenhouse

[104] "The roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all". Source: "The European Green Deal Sets out How to Make Europe

gas emissions than can be absorbed. The access to these resources is a strategic security question for Brussels' ambition to accomplish the Green Deal; replacing today's reliance on fossil fuels with one on Critical Raw Materials is an ambitious but affordable challenge despite global frenetic competition. The industrial revolution of the EU is based on an innovative way to build and renovate that is influencing energy supply, mobility and infrastructures.

Since 2007, metals and minerals markets have been altered by a series of events, calamities and dynamics on an international scale. In 2008, the global financial crisis triggered the EU's worst economic recession in its six-decade history. That economic collapse influenced prices in all major commodity markets which peaked in 2008 and increased steadily since 2009. Within the Old Continent, consumer prices skyrocketed, and social deprivation and unrest were common issues in all the 27 EU Member States. As is customary, to alleviate the negative repercussions and effects of such fluctuations, especially on the most vulnerable consumers and producers, the European Union implemented compelling and successful policy responses that laid the groundwork for future developments and outcomes.

The global attention attracted by Critical Raw Materials led the European Commission to adopt a series of targeted initiatives in order to streamline sustainable access to these commodities, both within and outside its borders and boundaries. The major response to these market shocks was an array of measures to regulate energy markets and render them more resilient and transparent. In the realm of Rare Earth Elements, following the 2008 Raw Materials Initiative[105] devised by the European Commission, the tipping point was the development of the First List of CRMs[106], composed of 14 elements. On the eve of the first rare-earth crisis in 2010, the European Commission already emphasized how rare earths were crucial for high-performance magnets, wind turbines and catalytic converters as well as its quasi-total dependence on China and the non-existence of substitutes and recycling processes.

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the First Climate-Neutral Continent by 2050, Boosting the Economy, Improving People's Health and Quality of Life, Caring for Nature, and Leaving No One Behind." European Commission - European Commission, December 19, 2019. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691.

105 "The Raw Materials Initiative — Meeting Our Critical Needs for Growth and Jobs in Europe." European Commission, November 4, 2008. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0699:FIN:en:PDF.

106 "Tackling The Challenges In Commodity Markets And On Raw Materials." European Commission, February 2, 2011. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52011DC0025.

The EU paved the way for the definition of 'criticality' by predicting how these commodities would have been characterised by an unprecedented risk of supply shortage in the coming decade. There was no more truthful prediction in this sector. Such a criticality is traditionally connected to the concentration of the production in a handful of emergent countries, some of them associated with low political and economic stability. Since a stable supply is indispensable for a value chain as well as for technological innovation and climate policy objectives, the EU started to work intensively on improving its knowledge and multiplying targeted initiatives to strengthen the industry. For instance, in 2009, to provide a comprehensive picture of actual and future deposits within the continent, the EU launched the ProMine project[107], a pioneer activity in the stimulation of the extractive industry geared to reduce the minerals' foreign dependency.

Such a refreshing change enticed the development and implementation of a number of research projects in order to investigate comprehensively the Rare Earth Elements supply chain. On the one hand, the EURARE project[108] was the European Commission's pilot and cornerstone project in order to set the basis for the development of a European Rare Earth Element industry. On the other hand, the Systemic Analysis of Rare Earth Elements (ASTER) project[109], benefiting from the French National Research Agency funding, defined the most pressing-related challenges and prompted the importance of recycling within the European Union after a thorough analysis of the flows and stocks of these precious commodities.

Despite intensive efforts and massive investments, the EU found itself in a disadvantageous situation in its infancy. This is the reason why, even on the side of the list, a substantial update in 2014 was carried out. In comparison with the first one, a net distinction between Heavy and Light Rare Earth Elements was provided, thus demonstrating how these elements gained momentum in the European panorama. Alongside, the European Rare Earth Competency Network (ERECON) project represented a superb showcase to deliver sector papers and policy recommendations. Three years later, given the strategic importance of Critical Raw Materials, another significant update was delivered to ensure a secure and sustainable supply.

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[107] "A four years long EC project in the area of exploration and efficient use of mineral resources within Europe". Source: "Promine," June 16, 2020. https://www.eurogeosurveys.org/projects/promine/.

[108] "EURARE - Development of a Sustainable Exploitation Scheme for Europe's Rare Earth Ore Deposits," https://cordis.europa.eu/project/id/309373/reporting.

[109] "The Aster Project Shines a Light on Rare Earths." Agence nationale de la recherche, September 2, 2015. https://anr.fr/en/latest-news/read/news/the-aster-project-shines-a-light-on-rare-earths/.

From 14 entities in 2011, passing through 20 elements in 2014, the European Commission introduced 7 new Critical Raw Materials in 2017[110], giving emphasis to its initiatives and its role as a future leader in the sector.

Alongside, experts wondered whether such a list of Critical Raw Materials was compiled and drafted. Any potential reasonable criticism was wiped out by the introduction of the Methodology for establishing the EU list of Critical Raw Materials[111] in 2017. The European Commission managed to shed light on guidelines and recommendations concerning the identification and classification of those commodities, increasingly more pivotal in the international arena. On the basis of such prerogatives, the latest review, which dates back to 2020, used "the average for the most recent complete 5-year period for the EU without the United Kingdom (EU-27)"[112]. The most relevant innovations were the chronological evolutions of how criticality had evolved since the publication of the first list and the threshold of 30 materials[113], with the integration of bauxite, lithium, titanium and strontium, two-fold with respect to its native outline.

Antimony	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements	Scandium
Beryllium	Light Rare Earth Elements	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural Graphite	Vanadium
Coking Coal	Natural Rubber	Bauxite
Fluorspar	Niobium	Lithium
Gallium	Platinum Group Metals	Titanium
Germanium	Phosphate rock	Strontium

Table 1: 2020 EU list of Critical Raw Materials. *Source*: Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability

110 "List of Critical Raw Materials" Raw Materials Information System. https://rmis.jrc.ec.europa.eu/?page=crm-list-2017-09abb4.

111 "A prescriptive document containing the guidelines and the 'ready-to-apply' methodology for the EU criticality assessment and the revision of the list of critical raw materials (CRM) for the EU". *Source*: European Commission. 2017. Methodology for Establishing the EU List of Critical Raw Materials: Guidelines. Luxembourg: Publications Office of the European Union.

112 "Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability." European Commission, September 3, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474.

113 *Idem*

In the last decade, the EU has laid the groundwork for its mission to build out its domestic rare earths' capacity. The crux of the matter was never in doubt because, according to European Commission's Vice-President Šefčovič, "the question is not whether we should mine in the EU but under what conditions?"[114] Brussels has all the credentials to wrest back control of the Rare Earth Elements supply chain from China, on the one hand, because it can rely on a structured network of governments, industry and academia, all determined to cope with the problematics of the sector; on the other one, its mutual partnership with the other important players such as Japan, Canada, US and Australia, are fundamental to combine forces and work together against the monopoly of the market. Even the emergent players are approaching the EU and its recognized leadership in the future dynamics of rare earths.

It is a political mission, characterized by the complicated relationship between China and both the US and Europe; it is a commercial mission because demand for these Rare Earth Elements used in permanent magnets is expected to increase tenfold by 2050[115]. Specifically, Brussels cannot afford to rest easy because the EU27 mobility and automotive sector are expected to grow to around 400 billion euros by 2030, a period of time that leaves no room for hesitation. As it stands, the EU is dependent on third countries for roughly 100 products[116], this is unacceptable, in some ways, considering the traditional commercial nature of this supranational entity. This is the reason why reducing dependencies and vulnerabilities has become the top political priority in Brussels' headquarters because Europe's supply chain security is essential to deliver the Green Deal and the related digital ambitions.

The economic and geopolitical complexities, that have been discussed in the previous chapter, have prompted the European Commission to adopt its Action Plan on Critical Raw Materials[117]. This innovative strategy is based on 10 concrete actions in order to build the resilience of Critical Raw Materials' supply chain as well as to identify definitively those Member States and regions where mining, processing and waste valorisation projects can be actually

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[114] "Speech by Vice-President Šefčovič at the Press Conference on Critical Raw Materials Resilience in the EU." European Commission, September 3, 2020. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1558.
[115] *Idem*
[116] *Idem*
[117] Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

implemented by 2025. The establishment of the European Raw Materials Alliance (ERMA) is the major initiative in order to deal with those value chains where rare earths are vital, ranging from magnets and motors sectors to renewable energy, e-mobility, space and defence.

On balance, the EU approach to Rare Earth Elements has innovated and integrated most of the best practices and fresh ideas coming from heterogeneous sources. The EU is targeting sustainable mining within its boundaries which is an economic, geopolitical, and environmental but moral obligation at the same time. Such an approach is constantly evolving thanks to the contribution of all the relevant stakeholders, committed to raising both environmental and social standards for a better world. It is time for the EU to take more responsibility and, beyond domestic sourcing, to promote and boost circularity and recycling in order to attain its objectives in the Rare Earth Elements' universe.

3.2 Green-Tech transition is nothing without Rare Earth Elements

The current economic and geopolitical climate has emphasised the primal urge of increasing EU resilience and strategic autonomy as well as to materialise the twin digital and green transitions. Nowadays, the most profitable and advanced industries in the 27 Member States are unsurprisingly the tech industry, with the Artificial Intelligence sector on top of that, the automobile and the healthcare industries[118]. In all these industrial ecosystems, Rare Earth Elements are essential to their financial success and prosperity in the long term. The brightest example is that demand for rare earths used in permanent magnets for digital technologies, electric vehicles and wind generators is expected to increase tenfold by 2050[119] when Brussels' decarbonization pathways to a net-zero Europe is completed.

118 "What Are the Most Profitable Industries in the EU?" EUbusiness, October 28, 2020. https://www.eubusiness.com/focus/20-10-28.

119 "Speech by Vice-President Šefčovič at the Press Conference on Critical Raw Materials Resilience in the EU." European Commission, September 3, 2020. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1558.

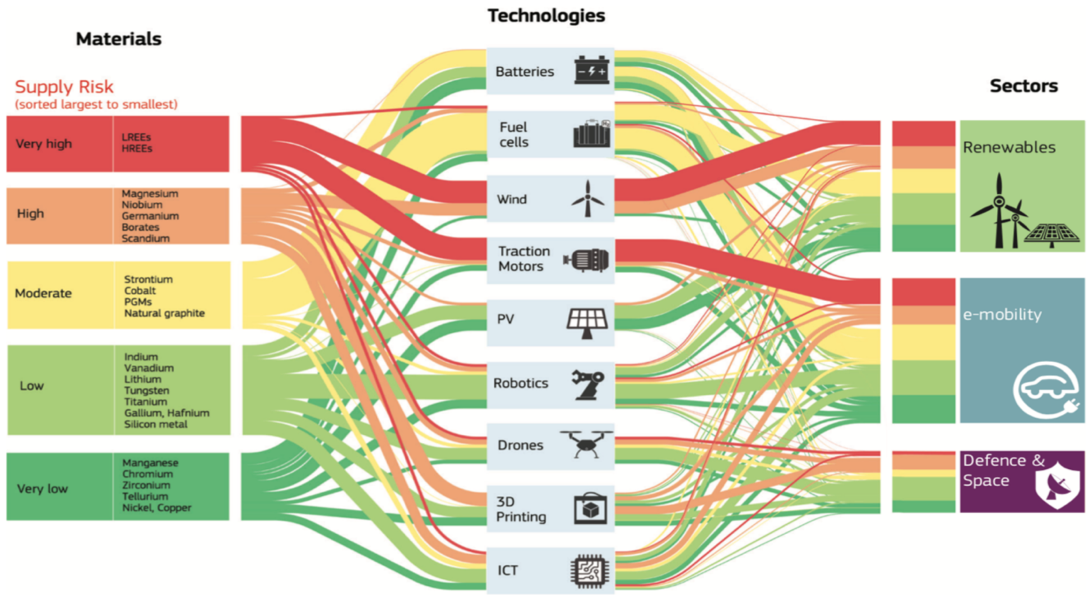

Table 2: Critical Raw Materials essential to the Green-Tech transition, their current supply risks and application to the most relevant sectors. *Source:* European Commission. 2020. Critical materials for strategic technologies and sectors in the EU - a foresight study. Luxembourg: Publications Office of the European Union.

Such a compelling but mandatory trajectory is totally dependent on the EU Green Deal, which in turn, relies on rare earths and all the other Critical Raw Materials for most. As can be evinced in *Table 2*, there could be no Green-Tech transition without Rare Earth Elements. The EU is summoned to achieve its objectives of resource security as well as reducing strategic dependencies for its energy transition metals, Rare Earth Elements in the first place. Several initiatives and structural dynamics will be analysed in order to pave the way for the concretisation of those goals, namely optimized recycling, domestic value chain investment and more active global sourcing[120].

However, the European Union is facing multiple gaps and flaws in its structure and industry that have rendered access to these resources extremely complicated and competitive. Brussels is fortunate enough that, except for China, all the other superpowers all over the world are dealing with similar problems to the extent that they are gradually joining their efforts and forces. Given the European Union's international climate leadership, the hopes to develop a secure and sustainable supply chain in this regard are placed on Brussels.

The vulnerabilities that exist in the rare earths supply chain are affecting all the industrial ecosystems mentioned above and, more recently, the EU defence sector beleaguered by the 2022

[120] KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.

Russia's military aggression against Ukraine. In the wake of supply disruptions from the Covid-19 pandemic and the Russo-Ukrainian conflict, in the subsequent sections, a focus will be dedicated to these scenarios and their repercussions on the demand and supply of these commodities. Nevertheless, even before such hostilities, the EU has been required to cope with those existing gaps that are putting the squeeze on the long-awaited Green-Tech transition.

China is the rare earths' undisputed leader because its extraction, processing and separation capacities are the most advanced and it may count on the most innovative techniques and procedures. The EU's lack of resilience in this regard is precisely determined by its dysfunctional capacities in this area, especially in the recycling and refining processes where Brussels has been identified as the most promising actor for rare earths and lithium. The actual problem is that most of the minerals mined within Europe are forced to leave the EU boundaries for processing, thus contributing, for instance, to the almost total dependency on China for rare earth permanent magnets. Alongside, the EU provides only 8% of traction motors[121], where rare earths are crucial raw materials, with Japan competing with China for decreasing the supply chain dominance of Beijing. Last but not least, the EU provides only 1% of the raw materials for wind energy[122] whose supply is (once again) constrained by the Chinese quasi-monopolistic role.

The global energy transition is 'metal intensive'[123] and Europe's transition to a digital and sustainable open society is therefore only achievable through a strategic and comprehensive approach to raw materials. The latter are the most relevant ingredients to electric vehicles, batteries, solar panels and wind turbines that represent the sought-after conventional alternatives in order to replace fossil fuel needs. The EU has devised its Green Deal in accordance with the 2015 Paris Agreement which set, as top political priorities, meeting universal energy access and reducing air pollution to name a few. Alongside, the International Energy Agency has developed the Sustainable Development Scenario (SDS) where advanced economies, amongst which the EU, are urged to reach net-zero emissions by 2050, therefore aligning totally with the EU Green Deal ambition to achieve a climate-neutral economy in three decades.

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[121] European Commission. 2020. Critical materials for strategic technologies and sectors in the EU - a foresight study. Luxembourg: Publications Office of the European Union.

[122] *Idem*

[123] KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.

The much-coveted EU strategic autonomy cannot prescind from a competitive value chain and efficient domestic production concerning Rare Earth Elements; the European Commission is working on remodelling and advancing the existing industries (automotive and wind industry), restoring old-fashioned and lost industries (solar PV industry) and establishing new activities and business (battery and permanent magnet industry)[124]. Nevertheless, the cornerstone of such a revolution is the implementation of multiple mining projects that have encountered a deep level of uncertainty within the continent. Despite a relevant political ambition to establish a local production value chain by 2030, there are disparate impediments that are putting a strain on mining activities, ranging from the low social acceptance amongst local communities to innovative technologies on the verge to be developed but unrealized.

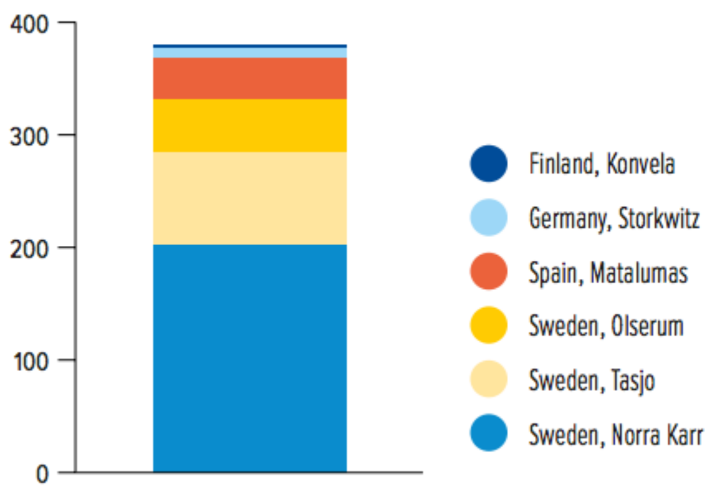

Table 3: European Rare Earth Elements reserves by mining projects. *Source*: KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.

As it can be seen in *Table 3*, the Rare Earth Elements' supply to the European market could be effectively satisfied for a good part by certain projects, specifically the Norra Karr mining project[125] in Sweden and related ones in the Scandinavian peninsula. Nonetheless, those projects are constrained by never-ending permitting, due to tightening environmental regulations, and local opposition. Alongside, other projects including rare earths and critical minerals such as

124 *Idem*

125 Duxbury, Charlie. "Sweden's Ground Zero for the EU's Strategic Materials Plan." POLITICO, November 24, 2020. https://www.politico.eu/article/swedish-ground-zero-for-eu-strategic-materials-plan/.

lithium in Serbia[126] or Spain[127] face fierce opposition that has rendered it almost impossible to predict whether Europe will succeed in growing its supply and domestic production.

On balance, Rare Earth Elements are among those EU Critical Raw Materials that are fundamental in order to achieve the Green Deal in its entirety. Currently, only a small portion of these commodities is locally produced in Europe to the extent that, differently from other regions in the world, recycling has gained strong momentum and is expected to be at the forefront of such a process. Innovation in recycling but even processing, mining and exploration may be achieved through the establishment of a circular economy and a secure supply chain, dynamics that have been entrusted to the European Raw Materials Alliance (ERMA), led and managed by the European Institute of Innovation and Technology (EIT) Raw Materials. Brussels has paved the way for a functional pathway that can perform at full only through cooperation at all levels.

3.2.1 The ERMA & Europe's Rare Earth Elements: an indissoluble marriage

On September 3, 2020, the European Commission announced its Action Plan on Critical Raw Materials and published its fourth list of Critical Raw Materials in order to reduce concretely Europe's dependency on third countries, especially on Beijing concerning rare earths. Such an enlightening report offers a dedicated and integrated strategy of four key recommendations and ten related actions devised by the co-participation of 180 stakeholders from industry, academia, government organisations and NGOs. The final objective is to implement specific proposals for a pan-European State-led investment drive that will skyrocket the current zero production: ERMA aims at establishing a European rare earth industry capable of delivering 20% of EU demand by 2030[128].

Europe's Rare Earth Elements are indissolubly married to such an organization whose primary (and urgent) task is to cope with an inexistent European rare earths industry in the least

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126 "Rio Tinto Lithium Mine: Thousands of Protesters Block Roads across Serbia." The Guardian. Guardian News and Media, December 5, 2021. https://www.theguardian.com/world/2021/dec/05/rio-tinto-lithium-mine-thousands-of-protesters-block-roads-across-serbia.

127 Dombey, Daniel. "Spain's Rush for Lithium Falls Foul of Local Opposition." Financial Times, October 20, 2021. https://www.ft.com/content/459191d9-774d-4a2b-8ec6-ba472017b05e.

128 Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

time possible. Brussels has good potential to become a leader in the sector on a par with Australia, Japan and the US; it would be fundamental that all these superpowers are proactively engaged in developing domestically these resources given the immense challenges posed by China's rare earth magnet monopoly. The foundation of such an ambitious project is certainly both public and private financing that is expected to be allocated by the singular national recovery plans. ERMA has already identified 14 projects along all the potential rare earths supply chain: as can be observed in *Table 4*, all the segments are evenly distributed throughout the continent, with mining projects in Finland, Norway and Sweden, separation in Poland, metallurgy in Estonia, recycling in Belgium and France and magnet making in Germany and Slovenia.

The latter represents a cumulative €1.7 billion investment which is intended to increase European magnet production from 500 tons per year to 7,000 tons by 2030[129]. Alongside, ERMA is intensively working on a new raw materials bridge fund to de-risk project[130] and a dedicated Important Project of Common European Interest[131] (IPCEI) to de-risk investment in order to reproduce a successful scenario similar to that in the area of batteries.

[129] Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.
[130] "A project worth 150-200 million euros a year to help finance projects". Source: Onstad, Eric. "Europe Urged to Launch Fund to Spur Rare Earth Magnet Output." Reuters. Thomson Reuters, September 30, 2021. https://www.reuters.com/business/energy/europe-urged-launch-fund-spur-rare-earth-magnet-output-2021-09-30/.
[131] "A transnational project with an important contribution to the growth, employment and competitiveness of the European Union industry and economy funded by state aid". Source: "What Is IPCEI on Batteries?" IPCEI Batteries, https://www.ipcei-batteries.eu/about-ipcei.

Table 4: European Rare Earth Elements projects within the 27 Member States. *Source*: Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

Currently, Europe has only one rare earths separation facility that is remarkable, Estonia's Neo Performance Materials, and isolated magnet makers, such as Vacuumschmelze in Germany. ERMA is calling on all the European stakeholders to commit to developing an integrated and cross-border network of facilities. Cooperation and integration lie at the heart of the European project and, whenever they are fully achieved, the supranational organization has maximized its full potential.

The European Union is seriously undertaking its intent to become a rare earths superpower. Brussels has started a diversification throughout the entire supply chain, from rare earths to magnet recycling; the most recent events have demonstrated how mandatory it is to vary and develop alternative sources of supply, especially in the energy sector where bottlenecks and shortcomings are a day-to-day situation. This is the reason why dialogue between downstream market players is taking place throughout the 27 Member States with manufacturers in the automotive, defence, digital and wind energy sectors contributing to the resilience of this value chain. The ERMA's ambition is to replicate the 2.9 billion euros investment in the battery materials sector of January 2022[132] for the rare earths sector. Furthermore, there are several pathways to be investigated, ranging from State subsidies to support projects using European rather than Chinese magnets to the application of the carbon border adjustment mechanism[133] to rare earths supply chain.

Last but not least, as already discussed, the European Union could be a leader of such rare earths' revolution, but it will need the support of other players in order to make a difference. An integral part of the EU Action Plan is the development and the strengthening of partnerships with resource-rich countries, essential to diversifying the supply of Critical Raw Materials. Third countries are fundamental not only because of their resources but rather because they may contribute to the improvement of the research and innovation sectors as well as social and environmental criteria. ERMA has been called upon to implement these partnerships, especially with African countries, and the first noteworthy achievement has been the endorsement of the Raw Material partnership with Canada at the last EU-Canada summit[134].

On balance, several mechanisms have been listed, devised and implemented across the EU. The quest for a sustainable supply chain is the most important challenge to be overcome in order to position the rare earths' sector at the heart of an innovative European Circular Economy. The Green Deal has been the starting point and the EU is now more than ever committed to achieving it to its greatest extent as well as to finalising its specific strategic autonomy policies. ERMA has been ultimately identified as the most relevant actor that is working nowadays even on the formulation of a "sustainability standard and certification scheme in order to enable the build-out of rare earth recycling capacity"[135]. The next section will be precisely devoted to the importance of recycling and, therefore, of the secondary supply not to throw away all the good work.

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[132] Carroll, Sean Goulding. "Brussels Approves €2.9 Billion Investment into Battery Innovation." EURACTIV, January 27, 2021. https://www.euractiv.com/section/batteries/news/brussels-approves-e2-9-billion-investment-into-battery-innovation/.

[133] The Carbon Border Adjustment Mechanism will put a carbon price on imports of a targeted selection of products so that ambitious climate action in Europe does not lead to 'carbon leakage'. Source: "Carbon Border Adjustment Mechanism: Questions and Answers." European Commission, July 14, 2021. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661.

[134] "Eit Raw Materials Summit." European Commission, June 28, 2021. https://ec.europa.eu/commission/commissioners/2019-2024/breton/announcements/eit-raw-materials-summit_en.

[135] Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

3.2.2 The EU's strategic autonomy in Rare Earth Elements through Recycling and Innovation

The global demand for rare earths has skyrocketed in the most recent times and will have an unprecedented boost from the energy transition in the coming years. Recycling end-of-life products has been already an important driving factor for supply in the rare earths market. However, the secondary supply potential is currently constrained by the existing volume of materials that is not sufficient to develop a comprehensive and sustainable alternative route to the extent that debates about recycling are already heated but not yet pivotal.

Rare Earth Elements have been traditionally characterized and commercialized through an undisputed primary supply, meaning their production from raw ore through mining and processing. Nevertheless, all the relevant stakeholders have realized how unsustainable the market will be in the coming decades if a noteworthy secondary supply is not developed. This is connected to the rapid increase in global metals demand that will not be met only through primary supply. It is expected that, in the next 15 years, rare earths will be gradually supplied through alternative sources that will take the centre stage between 2030 and 2040[136], whenever clean energy technologies are eventually available to recycle.

Recycling in this sector has gained strong momentum because, from a theoretical perspective, the magnificent physical properties that characterize Rare Earth Elements make them indefinitely recyclable. The difference with fossil fuels and other single-use materials is evident: at their end-of-life stage, these commodities leave ample room for manoeuvre for reprocessing, thus paving the way for similar goods of the same quality. Nevertheless, the actual problem is that not all metals may be recycled at a sufficient scale yet, amongst them Rare Earth Elements whose recycling rate is currently less than 1%[137]. There is a plethora of challenges and shortcomings to be addressed in order to skyrocket recycling processes at their optimum level.

Since the EU has currently an uncertain pipeline for new mining and refining projects, recycling has been indispensable. However, even the most ambitious projects are constrained by certain flaws: rare earths' complexity to be refined and collected is the first and foremost obstacle

[136] KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.
[137] Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. "Rare Earth Magnets and Motors: A European Call for Action." Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.

to overcome. Imperfect collection and improper treatment often prevent the possibility to recycle successfully certain metals to the extent that, in certain cases representing the bulk of the circumstances, materials are lost. Moreover, not every stakeholder has developed relevant expertise in order to recycle materials and this has prompted several problems throughout all the supply chain. In the rare earths' universe, recycling is fundamental when it comes to analysing permanent magnets that are hardly recycled today.

In the Brussels' headquarters, developing and incentivising a recycling industry for permanent magnets has become a top political priority to which everyone is committed considering that 16,000 tons of rare earth permanent magnets are exported from Beijing to Europe each year[138], thus representing 98% of the EU's internal market. According to the 2022 report *Metals for Clean Energy - Pathways to solving Europe's raw materials challenge* written by KU Leuven and commissioned by Eurometaux, Europe's metals association, by 2050, 90% of permanent magnets in wind turbines and 70% in electric vehicles are expected to be recycled and return to the market as end-of-life secondary supply[139]. The forecasts speak of 2 kilotons of dysprosium, 15 kilotons of neodymium and 4 kilotons of praseodymium as end-of-life secondary supply injected into the market in the coming decades.

Such an insightful study emphasises that the most critical challenge is to "scale up efficient permanent magnet recycling technologies with positive economics"[140]. There is a difference between those goods recycled from wind turbines, characterized by a good recycling potential due to their smaller dimensions, and those from electric vehicles, which are hardly expected to bypass the shredding process. However, the EU has implemented several viable solutions through a multitude of projects: in 2013, the European Rare Earth Magnets Recycling Network (EREAN), an intensive intersectoral and interdisciplinary collaboration, has performed extensive research on recycling, investigating the entire materials loop, from urban mine to magnet. In 2015, the Rare Earth Recycling for Europe project (REE4EU) fulfilled great achievements in establishing a permanent magnet recycling process for the first time in Europe.

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[138] KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.
[139] *Idem*
[140] *Idem*

In recent times, SUSMAGPRO[141], which stands for Sustainable Recovery, Reprocessing and Reuse of Rare Earth Magnets in a European Circular Economy, aims at developing a pilot supply chain from recycled neodymium magnets. The EU has allocated €14 million in order to achieve the pre-established objectives by 2023; on a national level, it is worthwhile mentioning that the French company Carester is intensively working on innovative technologies in order to recover permanent magnets from Rare Earth Elements used in end-of-life equipment[142].

On the whole, the most challenging dynamics along the Rare Earth Elements supply chain are emerging in the current decade since the supranational market, because of the import dependency, is exposed and vulnerable to the global markets' fluctuations. At this stage, Brussels is laying the groundwork for strategic autonomy in this sector, through the development of domestic production and structured partnerships with all the other superpowers. Between 2040 and 2050, Europe's industrial ambition will be realised through an efficient and concrete secondary supply, which is expected to reach recycling rates higher than 75% concerning rare earths and other Critical Raw Materials such as lithium. Now more than ever, the EU is called upon to create a rare earth recycling facility where it can recycle and produce regenerated permanent magnets without compromising on the quality. It represents a titanic challenge which however is within the reach of the 27 EU Member States. Even because, in a world where the Covid-19 after-effects and the Russo-Ukrainian conflict take the centre stage, the EU has the duty to preserve its own security and, therefore, its defence sector which relies on these sought-after commodities.

3.3 The interdependence of the EU defence industry and REEs market

The EU defence industry has been devised in order to guarantee the protection and the security of European citizens as a primary EU responsibility. Nevertheless, it is worth always remembering that security and defence are a national prerogative of the 27 Member States because, differently from security organizations like NATO, the EU was not born as a military but rather as a trade and economic entity. In recent times, Brussels has been somewhat obliged to

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[141] "Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SUSMAGPRO)," https://cordis.europa.eu/project/id/821114.

[142] "French Government Recognises Strategic Importance of Rare Earths with Major Investment in Permanent Magnet Recycling." European Raw Materials Alliance (ERMA), June 4, 2021. https://erma.eu/french-government-recognises-strategic-importance-of-rare-earths-with-major-investment-in-permanent-magnet-recycling/.

raise its defence and security ambitions as well as create an efficient industry in order not to lag behind on the world stage. The latter needs the EU to be a stronger security and defence actor following unexpected circumstances, ranging from Brexit to a less idyllic relationship with the US, from intense technological competition to the latest Coronavirus pandemic and the Russian invasion of Ukraine.

The war in the European neighbourhood, Europe's gravest security crisis in decades, has prompted Brussels to take draconian measures and enormous efforts in its response. The EU defence industry has been called upon to intervene concretely from a military perspective; as with several economic sectors, this industry relies on the use of Rare Earth Elements for the manufacture of components used in military applications: for instance, these goods are essential in precision guide munitions, satellite communications, targeting lasers and remotely piloted aircraft systems[143]. Alongside, effective aeronautic applications are composed of high-performing alloys that require a conspicuous portion of these metals, especially for what concerns jet fighters, helicopters and missile systems[144].

Rare Earth Elements are therefore fundamental and necessary for the production and the manufacture of defence-related subsystems and components; even though their demand has been traditionally steady, following the current status quo and the geopolitical and military uncertainty that hover globally, the European defence industry is expected to cope with limited production capacities and flaws along the whole supply chain. As tensions ramp up between Russia and the West, fears about the possibility of the outbreak of a Third World War are growing, even if there is to say that, even though this threat should not be underestimated, a global conflict is not expected to take place. However, this raises the level of attention that is devoted to rare earths and their connection to the defence sector.

It is perfectly normal to wonder whether there could be problems concerning Rare Earth Elements in the defence sector if many defence applications need the same material deployed in the civil sector. This paradoxical scenario is easier to be interpreted than expected: the defence sector requires special steels or alloys that must be characterized by higher purity or special

[143] European Commission. 2020. Critical materials for strategic technologies and sectors in the EU - a foresight study. Luxembourg: Publications Office of the European Union.
[144] *Idem*

composition. Being dependent on imports of these commodities is a pain in the neck to the EU because any potential disruption in the rare earth supply chain would entail serious consequences on the defence capabilities of the 27 Member States. Differently from the US where there is a small stockpile of rare earths preserved to cope in case of certain supply shortages, the development of EU weapons systems is totally reliant on imports to the extent that Brussels has implemented targeted supply measures to secure it.

China has the potential to interrupt suddenly the export of these commodities as geopolitical leverage or, more realistically, because it will not be able to supply all markets. Certainly, Beijing will prioritise exclusively its own market and security thus triggering serious repercussions on national and international security; to come up with an effective solution, the EU interventionist measures should emphasise a vertical integration of the supply chain aimed at securing the provision for the defence industry through direct contracting and investments; alongside, Brussels should establish a strategic reserve by storing rare earths in order to be prepared for any potential shortage in this scenario.

The scarcity of rare earths is a heated topic that is often analysed as an economic and commercial one; however, its security relevance is gaining strong momentum in light of the current geopolitical and military events to the extent that a shortage in this regard could jeopardise international security. In the next section, a preliminary analysis of the consequences triggered by the Russian invasion of Ukraine on the rare earths market will be provided in order to emphasise how relevant the connection between these Critical Raw Materials and the security of every individual is.

3.3.1 Case-study: the Russian invasion of Ukraine and its consequences on REEs market

The current military offensive in Ukraine has prompted serious concerns over the state of global resources, especially those where the two countries hold a relevant quota. For instance, both Moscow and Kyiv are major producers and exporters of grain and wheat, whose shortage is causing huge repercussions in terms of food security; alongside, in terms of energy security, Russia has the world's largest reserves of natural gas as well as it is the third-largest oil producer[145] with about 60% of Russia's oil exports going to OECD Europe[146].

While disruptions, shortages and price fluctuations concerning these food and energy commodities are shocking and putting on a strain the global supply chain, other less-discussed resources are expected to have a major negative impact on key industries as well; specifically, precious metals and Critical Raw Materials will become pivotal in case the conflict endures for a few months and beyond. To mention a few, Russia, with its 10% of the global reserves, is the second-largest producer of platinum, used as a catalyst in the production of acids, plastics and explosives. The Russo-Ukrainian conflict has skyrocketed its prices to the extent that the latter have reached its highest point in 9 months[147]. Alongside, the Kremlin is responsible for 50% of the global production in terms of palladium, used in a series of crucial industries for the European security, with automobile manufacturing on top. Following the outbreak of the conflict, even its prices have increased by more than 24%.

The comprehensive picture is gruesome and disgraceful for all the people involved and, despite great proclamations, an immediate and successful solution has not yet been found. The fear is that such a conflict may be prolonged for long and therefore have severe implications even on rare-earth metal prices across key application industries. The connection is immediately obvious: the uncertainty of the Russo-Ukrainian conflict is obliging all the countries to batten down the hatches. Especially those governments that are within the Russian sphere of influence and range of action are striving for strengthening their defence and military capabilities as well as increasing their budgets. In February 2022, Germany has allocated €100 billion in order to establish a special armed forces fund, increasing its defence spending above 2% of its GDP[148].

The intersection between these environments, security and Rare Earth Elements has been a less-discussed topic because these commodities have been more associated with environmental and economic concerns. However, the geopolitical and military side behind them

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[145] IEA (2022), Russian supplies to global energy markets, IEA, Paris https://www.iea.org/reports/russian-supplies-to-global-energy-markets

[146] *Idem*

[147] "Platinum Price Inching towards 9-Month Highs on Expanding Russian Sanctions." InvestingCube, March 4, 2022. https://www.investingcube.com/platinum-price-inching-towards-9-month-highs-on-expanding-russian-sanctions-commodities/.

[148] Rogers, Iain. "Germany to Create Special €100 Billion Armed Forces Fund." Bloomberg, February 27, 2022. https://www.bloomberg.com/news/articles/2022-02-27/scholz-says-germany-to-create-special-eu100b-armed-forces-fund.

has never been discarded to the extent that, nowadays, such developments and potential disruption are scarier. Rare-earth manufacturing and pricing prospects will be inevitably influenced by the continual change of direction of the war, forcing countries within the EU to find immediate countermeasures. For instance, Berlin has implemented strengthened partnerships with Australian high-tech metal producer Northern Minerals for mining rare-earth metals such as neodymium and praseodymium, essential for its green transition and leadership within the supranational organization.

However, this may not be sufficient. In recent times, the launch of the US-Europe rare earth supply chain in order to reduce dependency on China for these commodities has broadened the European horizons, making several stakeholders believe that the sought-after diversification of the sources had begun. Nevertheless, they have not come to terms with the Kremlin. The mixed rare earth carbonates exported from the two North American companies for further processing to Estonia is an outstanding project that allows the European Union to sell them to downstream firms for the production of rare earth permanent magnets. The Silmet rare earth separation plant, located in the Baltic town of Sillmäe, is Europe’s only commercial facility that is administered by the Canadian company Neo Performance Material. According to the latter, 70% of the rare earth feedstock it processes is imported from a Russian company; therefore, a protracted supply disruption triggered by European sanctions on Russia would have a knock-on effect throughout the continent.

Silmet is reliant on Russian-originated feedstocks and, despite they account for a small share, Moscow supplies Europe with rare earths; if this is no longer possible, Brussels will be forced to turn (once again) to China, thus making all the efforts in order to reduce the dependency practically worthless. In the short term, it seems that the only possibility is to patch over the shortcomings with the Chinese commercial counterparts since global sanctions directly affecting Russia, and therefore its rare earth supply, are inevitable. Europe’s objective of easing its dependency on Beijing is a long-term ambition that challenges the current status quo all over the world.

In the Rare Earth Elements’ universe, this political and military turmoil is expected to have the most critical repercussions across the automotive industry, where European markets may be characterized by commercial schizophrenia and inertia. Since Ukraine is amongst the largest producers of nickel and aluminium, fundamental materials in the development of batteries and EV components, the continuation of the conflict may stop the production and the technological advancements that in recent times have been achieved since the resources themselves would be scarce. Alongside, permanent magnets that are composed of neodymium, praseodymium and dysprosium are likely to become deficient in supply.

If the production and supply lines from both Moscow and Kyiv are turned down for long, the European automotive industry will be hit the hardest, thus complicating all the efforts in order to attain the European Green Deal objectives and challenges. Several automotive companies have already cut off shipments from Russia and slowed down their production in order not to incur huge economic losses. Nowadays, the EU finds itself in a critical juncture: whenever the situation was about to normalize in the aftermath of the Coronavirus crisis, another shocking calamity hit the international security. In the light of the precarious nature of the ongoing war, nobody is able to forecast the effects, catastrophic or reasonable, the rare-earth industry will face. On balance, the predictions are bleak, and the rare earth supply chain is expected to be characterized by a prolonged recession; short-term disruption, especially in the context of Neodymium, Dysprosium and Praseodymium global demand, could turn the tables, this is the reason why it is of utmost importance to analyse their dynamics and how they will affect the European and international security.

3.4 How Neodymium, Dysprosium and Praseodymium global demand and dynamics will influence European security

The global demand for permanent magnets and therefore for Neodymium, Dysprosium and Praseodymium is expected to grow at a Compound Annual Growth Rate (CAGR) of 9.5% by 2026[149]. Such an outstanding increase is connected to an ever-growing demand for automobiles and EVs in major economies such as the EU, China, Japan and India. Specifically, a hybrid EV will require about 2 kg to 3 kg of rare earth magnets[150], with the demand for neodymium iron boron magnets increasing heatedly.

[149] "Permanent Magnet Market by Type (Neodymium Iron Boron Magnet, Ferrite Magnet, Samarium Cobalt Magnet), End-Use Industry (Consumer Electronics, General Industrial, Automotive, Medical Technology, Environment & Energy), and Region - Global Forecast to 2026." Market Research Firm, https://www.marketsandmarkets.com/Market-Reports/permanent-magnet-market-806.html

[150] *Idem*

As displayed in *Table 5*, these Rare Earth Elements will be progressively required in the next decades, with global dysprosium demand increasing by 433%, a boost inferior only to that of lithium concerning clean energy technologies[151]. China has monopolized this segment of the market and the EU currently does not have the possibility to mine any rare earth elements domestically; Brussels is incessantly working on creating new mines but the timeframe, between three and five years, is forcing the EU to find (simultaneously) alternative solutions.

Lithium	2,109%	Silicon	62%
Dysprosium	433%	Terbium	62%
Cobalt	403%	Copper	51%
Tellurium	277%	Aluminium	43%
Scandium	204%	Tin	28%
Nickel	168%	Germanium	24%
Praseodymium	110%	Molybdenum	22%
Gallium	77%	Lead	22%
Neodymium	66%	Indium	17%
Platinum	64%	Zinc	14%
Iridium	63%	Silver	10%

Table 5: growth percentage of metal required in 2050. *Source*: KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.

The Russian invasion of Ukraine has emphasised how hazardous and unstable it is for the European Union to be reliant on an autocracy concerning a resource. The Russia-natural gas scenario is replicable by the China-Rare Earth Elements duo; since it is projected that the 11 million EVs on the current roads will become roughly 230 million by 2030[152], the EU should strategically invest in the rare earths value chain in order to get these commodities in a permanent way. The leading global supplier to the automotive and industrial sectors within the EU, the German Schaeffler Group, has already realised how relevant it is to strengthen a sustainable supply chain for electric motors; the company has agreed to a five-year deal with Norway's

151 KU Leuven. 2022. Metals for Clean Energy - Pathways to solving Europe's raw materials challenge. Leuven: Eurometaux.
152 IEA (2021), Global EV Outlook 2021, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021

REEtec to supply these goods from 2024 onwards[153], an outstanding initial step towards a local supply chain for Europe.

The green energy revolution has a cost, but it will entail several positive effects, starting with tackling climate change to increase the levels of security within the 27 Member States. The latter should cooperate on a stronger policy to ensure a livelihood for the automotive industry during the transition. For instance, the EU is even working on replacing neodymium with copper in the development of electric motors, but the performance is not equal, thus demonstrating how important these three Rare Earth Elements are in the achievement of the global objectives.

On the mining side, in the next five years, dependency on China will be reduced as new mines will become operational in other regions. Projects have been activated and are on the verge to be developed in every corner of the world. In the ultimate chapter, after having analysed the role of Italy within the Rare Earth Elements and its renovated stance as a Western-energy alternative to China, ample space will be devoted to the next frontiers of these commodities: for instance, the important reserves in Greenland and Afghanistan and their geopolitical implications and dynamics for the future of national and international security.

[153] "Schaeffler Strengthens Sustainable Supply Chain for Electric Motors." Press Releases | Schaeffler Group, April 19, 2022. https://www.schaeffler.com/en/news_media/press_releases/press_releases_detail.jsp?id=87800193.

CHAPTER FOUR

ITALY & THE NEXT FRONTIERS OF RARE EARTH ELEMENTS: WHAT THE FUTURE HOLDS

4.1 The older and newer frontiers of Rare Earth Elements

The concentration of production of Rare Earth Elements in specific countries and regions raises the critical issue of supply vulnerability especially considering their fundamental role in new energy technologies and national security applications. Similarly to other Critical Raw Materials, non-availability may entail and trigger a resource conflict that could represent an actual threat with negative short- and long-term geostrategic repercussions. According to the Indo-American entrepreneur Naveen Jain, co-founder of Moon Express, the problem is certainly their scarcity to a certain extent but rather those elements are not homogenously distributed throughout the Earth; his objective of reaching and mining the Moon[154] in order to cope with that scarcity of Rare Earth Elements could represent a utopia in the eyes of many. However, several projects have already been launched and the necessary infrastructures are on the verge to be implemented, thus demonstrating how rare earths are thoroughly integrated into our everyday and future life.

The 2010 rare earth crisis between China and Japan, when Beijing blocked a routine shipment of these commodities to Tokyo following a Senkaku boat collision incident, prompted speculations about the leveraging of Rare Earth Elements as geopolitical, economic and military bargaining chips. After a decade, little has changed from this perspective; debates about structural

[154] Caminiti, Susan. "The Billionaire's Race to Harness the Moon's Resources." CNBC, June 19, 2014. https://www.cnbc.com/2014/04/02/the-global-race-to-harness-the-moons-resources.html.

problems and impediments of the rare earths' supply chain have not found the squaring of the circle yet but magnificent and relevant steps forward have been undertaken, especially by certain actors such as the EU, to the extent that the future looks brighter and more promising. However, what has been a noteworthy change is the Green-Tech revolution, of which we are all well aware and part of, that cannot prescind from these goods.

In the previous chapter, the current scenario of Rare Earth Elements has been comprehensively investigated, with reference to the history, geography and politics of these commodities. After the above-mentioned crisis which prompted a renewed impetus to the dynamics of territorial and geopolitical ambitions, a wave of global exploration has started all over the world because the major stakeholders identified asymmetry in the global production as the most critical problem to be solved. Several studies and experts believe that Western economies will remain profoundly dependent on the Red Dragon for the current decade; however, as in other parts of the world (and even beyond our planet) new mines will become operational, such dominance and reliance on China for rare earths is expected to come to its end. Or at least, this is the intention and purpose of all the actors involved in such an intricate context.

Over the past three years, supply chain vulnerability has remained a pressing topic that has deteriorated following the advent of several economic, geopolitical and military calamities, namely the Covid-19 pandemic, climate change's deleterious effects and, last but not least, the conflict in Ukraine. Volatility in rare earths' exports, as a result of the sanctions prescribed for Russia, is paving the way for China to tighten its grip on these metals. The relative market is unstable and hysteric because nobody can afford a shortage of these precious elements, otherwise, the Green-Tech revolution could dissolve in the blink of an eye and trigger serious repercussions on each sector of our society.

When talking about the next frontiers of Rare Earth Elements, within the European Union, mining market players are focusing their attention on Italy's subsoil and seabed. The latter is expected to contain huge resources in this regard, as demonstrated by the growing demand for new concessions to exploit old and closed mines in Piedmont, Lombard and Sardinia[155]. The quest for rare earths is a major geological, geopolitical and economic objective of Rome that is finding

[155] Madeddu, Davide. "L'auto Elettrica FA Rinascere Le Miniere Piemontesi." Il Sole 24 ORE, November 8, 2021. https://www.ilsole24ore.com/art/la-riscoperta-miniere-italiane-AE02icd.

potential throughout the Alps and the Apennine ridges. Following the Russian invasion of Ukraine, the diversification of the energy sources is the primary goal of the Italian government which is making tremendous efforts in order to achieve its strategy. The analysis of the Italian panorama is directly connected with the identification of the next frontiers of Rare Earth Elements, amongst which are Greenland, Afghanistan and the Outer Space; despite different histories and regulatory frameworks, certain zones have been identified as the latest frontiers for exploration where the major powers have the possibility to get there first and open a new and definitive chapter of the rare earths' saga which will keep us glued for the next decades.

4.2 Italy and Rare Earth Elements: geological, geopolitical, economic and security perspectives

In most recent times, wide-ranging national discussions concerning Italy as a mining and energy power within the European Union have been steadily carried out. Mineral resources are still considered a pivotal element in the development and advancement of human civilization. Despite their extraction and refining processes entail social and environmental costs, it is unrealistic to see the economic ascent of a country that is not characterised by extensive usage of these resources. In accordance with European guidelines and projects, Italy is developing an appropriate strategy that encompasses both the State and the Regions where the keywords are efficiency, reuse, recovery and sustainable management of geo-resources; all these terms are often associated with Rare Earth Elements and, especially in the framework of recycling, Italy has been identified at the forefront of such processes.

The development of targeted policies aimed at achieving a sustainable mineral extraction industry cannot be separated from extensive knowledge and awareness of all the economic, geological, environmental and geopolitical aspects that constitute the rare earths' world. Italy has a long mining history that dates back to pre-Roman times. According to the "Istituto Superiore per la Protezione e la Ricerca Ambientale" (ISPRA), between 1870 and 2018, roughly 3,000 mineral sites have been identified in Italy[156], with a predominance along the Alps, in Piedmont, Tuscany and Sardinia. In 2018, more than 120 mineral concessions have been granted[157] and new

[156] ISPRA database. Source: "Dati e Indicatori." Istituto Superiore per la Protezione e la Ricerca Ambientale, https://www.isprambiente.gov.it/it/banche-dati.
[157] *idem*

licenses, involving the extraction of Rare Earth Elements, have been registered in Piedmont and Lombardy.

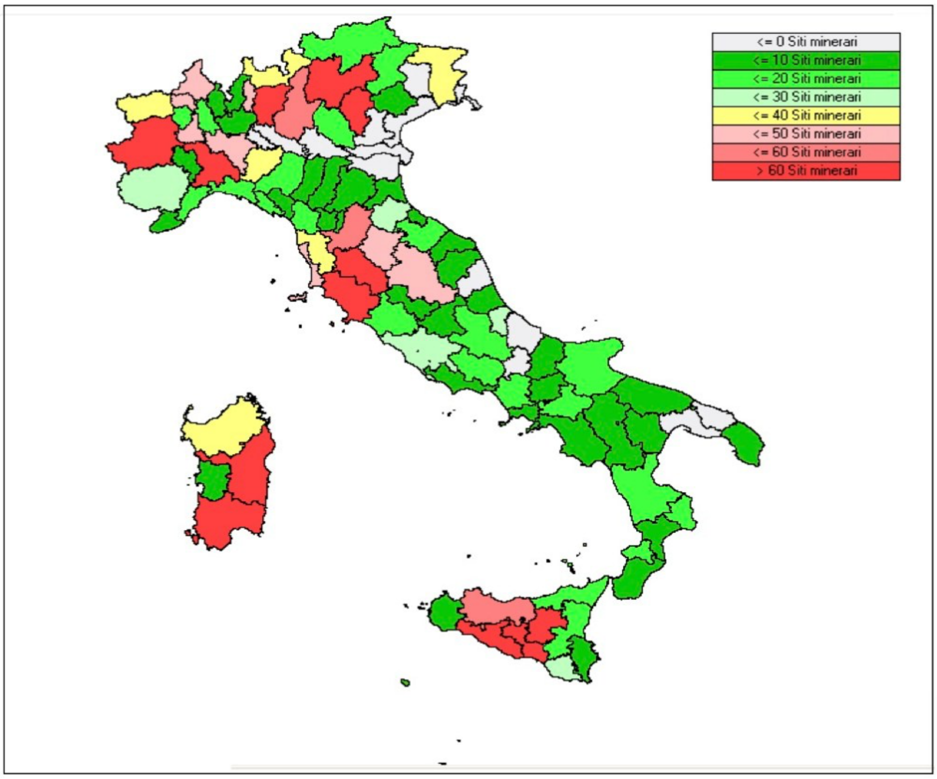

Table 1: the Italian mineral sites in 2018. *Source*: "Dati e Indicatori." Istituto Superiore per la Protezione e la Ricerca Ambientale, https://www.isprambiente.gov.it/it/banche-dati.

Such a proactive initiative is an integral part of an international modus operandi and pathway, especially a European one, where efforts to reduce dependency on foreign imports are on the order of the day. The EU has prepared the ground for a diversification of the sources and an efficient and sustainable supply chain concerning Rare Earth Elements; now, it is up to the single Member States to devise and implement the appropriate strategy. There is a common idea that revisiting old mining sites could be a major step forward in light of new technologies and the rising price of metals[158]. As a matter of fact, the use of state-of-the-art technology could help the stakeholders to mitigate the environmental impact of those mines that had created serious problems in the past.

158 Madeddu, Davide. "L'auto Elettrica FA Rinascere Le Miniere Piemontesi." Il Sole 24 ORE, November 8, 2021. https://www.ilsole24ore.com/art/la-riscoperta-miniere-italiane-AE02icd.

Throughout the continent, the creation and re-activation of mines may provide a long-term boost for local economies that have been severely affected by the most recent calamities all over the world, the Covid-19 pandemic on top. The resumption of the mining activity needs five to ten years in order to be effective and, despite tremendous efforts and investments, it may not be enough. In the short-term, Italy, as the other Member States of the European Union, is expected to remain almost totally reliant on non-EU countries for its Critical Raw Materials. This is the reason why Rome is called upon to devise a new mining strategy in line with the European guidelines and principles.

First and foremost, Italy is almost obliged to invest in the promotion and use of secondary raw materials, specifically e-waste recycling rates in order to obtain Rare Earth Elements; alongside, an integral part of the strategy should be the recovery of associated elements contained in imported raw materials, such as rare earths from phosphate rock; diplomatic initiatives aimed at establishing partnerships for raw materials with non-EU countries in order to diversify its sources of supply for Critical Raw Materials and, subsequently, securing them, such as rare earths from Norway and Greenland; last but not least, it is fundamental the contribution of all research, university and industry bodies in order to promote the revaluation of existing deposits throughout the country.

Italy, through the cooperation between the State and the Regions, has all the credentials to effectively assess its mineral potential and, on the basis of this, to devise an approach oriented toward environmental protection and circular economy methods, such as Urban Mining[159], reuse and recycling. In Waste Electrical and Electronic Equipment (WEEE), there are Rare Earth Elements are contained at good rates[160]; recycling them is a cost-effective technology is amongst the top priorities in metallurgy because, according to the principles of Circular Economy, a sustainable recycling chain needs to valorise the whole waste[161].

[159] Lukowiak, Anna, Lidia Zur, Robert Tomala, Thi Ngoc LamTran, Adel Bouajaj, Wieslaw Strek, Giancarlo C. Righini, Mathias Wickleder, and Maurizio Ferrari. 2020. "Rare earth elements and urban mines: Critical strategies for sustainable development." Ceramics International, Vol. 46, Issues 16, Part B (November): 26247-26250.

[160] Sethurajan, Manivannan, et al. 2019. "Recent advances on hydrometallurgical recovery of critical and precious elements from end-of-life electronic wastes - a review." Critical Reviews in Environmental Science and Technology, Vol. 49, no. 3 (January): 212-275.

[161] *Idem*

According to the European Parliament, "E-waste is the fastest growing waste stream in the EU and less than 40% is recycled"[162]. Italy will be at the forefront of such an innovative process through the adoption of its Recovery Plan, where the ambition for the transition to a circular economy will be concretised through €1.5 billion to strengthen waste management capacity in the cities; alongside, €600 million have been allocated for the implementation of flagship circular economy projects in order to compensate the scarcity of Critical Raw Materials such as Rare Earth Elements[163]; specifically, €150 million will be invested in Waste Electrical and Electronic Equipment supply chains[164], thus demonstrating how serious the Italian ambitions are concerning reuse and recycling of precious metals.

On balance, Italy aims at becoming a model country within the European Union, and beyond, through the development of a Circular Economy in compliance with the guiding criteria of the European Circular Economy Action Plan (CEAP)[165], adopted by the European Commission as one of the primary foundation stone of the Green Deal. To this end, Rome has developed its National Recovery and Resilience Plan (NRRP)[166], where huge investments will be devoted to the "Green Revolution and Ecological Transition"; alongside, in January 2022, Italy has introduced its four thematic working groups on Critical Raw Materials[167] in order to conceive sustainable access to these resources in a concrete way. All these initiatives will be thoroughly investigated in the next section in order to evaluate at what stage Italy currently is and what specific role the country may serve in the global Green-Tech transition.

4.2.1 The Italian Strategy to secure Rare Earth Elements

In response to the tragic economic consequences of the pandemic crisis, the EU has adopted its Next Generation EU[168] in order to provide financial support to all its 27 Member

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162 "Waste in the EU: Facts and Figures." European Parliament, April 26, 2022. https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic.
163 "Italy's Recovery Plan: A Booster to the Circular Economy of Weees." EIT RawMaterials, February 21, 2022. https://eitrawmaterials.eu/italys-recovery-plan-a-booster-to-the-circular-economy-of-weees/.
164 *Idem*
165 "A New Circular Economy Action Plan - For a Cleaner and More Competitive Europe." European Commission , March 11, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM%3A2020%3A98%3AFIN.
166 "The National Recovery and Resilience Plan (NRRP)." MEF, May 26, 2021. https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/.
167 "Mise – Avvio Dei Lavori Del Tavolo Tecnico Nazionale Materie Prime Critiche." ANIMA Confindustria meccanica varia, March 2, 2022. https://www.anima.it/media/news/tutte-le-news/mise-avvio-dei-lavori-del-tavolo-tecnico-nazionale-materie-prime-critiche.kl.
168 "NextGenerationEU," https://europa.eu/next-generation-eu/index_en.

States. Such a European initiative is intended to make Europe more robust than ever and speed up the transition to the future. Brussels has allocated €750 billion between the EU Member States, half of them in the form of grants, and together with the EU long-term budget of €1.074 trillion for the 2021-2027 multiannual financial framework, they represent unprecedented long-term financial support to all stakeholders. The centrepiece of such a massive plan is the Recovery and Resilience Facility[169] which provides each Member State with €672.5 billion in loans and grants. Brussels has settled on specific priorities to be dealt with such as the European Green Deal and the Green-Tech transition.

Italy, one of the most affected countries in Europe already characterized by a deficit economy, has taken up the challenge in the best possible manner. In 2020, the Italian GDP fell by 8.9%, more than the other Member States' average amounting to a 6.2% decrease[170]. In the new millennium, Italy has struggled in keeping pace with the most advanced European economies, with its GDP growing by 7.9% while the German, French and Spanish increase was respectively 30.2 %, 32.4 % and 43.6 %[171]. Poor productivity performance and trends, inadequate infrastructures, outdated technologies, excessive delays in the adoption of structural reforms and one of the lowest digitalisation levels within the EU[172] are only a few of the most relevant problems that beset the Mediterranean country.

To come up with an effective solution, Italy is materializing a consistent reform package and massive investments thanks to €191.5 billion in resources through the Recovery and Resilience Facility[173] and €30.6 billion through the Complementary Fund, established by Italian Decree-Law No. 59 of 6 May 2021. Concurrently, Rome has committed €26 billion for the implementation of specific works through the Development and Cohesion Fund[174] as well as €50.6 billion through the REACT-EU programme[175]. All these subsidies and targeted policies

[169] "Recovery and Resilience Facility." European Commission, May 23, 2022. https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en.
[170] "National Recovery and Resilience Plan," September 29, 2021. https://www.governo.it/it/node/17027.
[171] *Idem*
[172] Johnson, Joseph. "EU: Digitalization Levels by Country 2020." Statista, June 29, 2021. https://www.statista.com/statistics/1245595/eu-digitalization-level/.
[173] "The National Recovery and Resilience Plan (NRRP)." MEF, May 26, 2021. https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/.
[174] *Idem*
[175] "Tutti Gli Interventi e Le Risorse Di React-EU: 14,4 Miliardi, 67,6% Al Sud." Ministro per il Sud e la Coesione territoriale, April 1, 2022. https://www.ministroperilsud.gov.it/it/approfondimenti/schede/tutte-le-misure-e-le-risorse-di-react-eu/.

and investments have been structured around three pillars: digitalization, social inclusion and ecological transition.

In order to address the structural weaknesses of the Italian economy, Rome is focusing a lot on energy and the related ecological and environmental transition. Mission 2 of the Italian Recovery and Resilience Plan is precisely entitled "Green Revolution and Ecological Transition" to which €68.6 billion have been allocated, roughly the 31.05% of the total value of the NRRP. The primary objectives are improving the sustainability and resilience of the economic system and, concurrently, promoting an inclusive environmental transition; the development of renewable energy sources and a sustainable circular economy cannot prescind from the strengthening of waste recycling processes, as it can be seen in *Table 2*, where Italy aims at recycling more than 55% of the electric material.

Table 2: the most important objectives of the Italian Green Revolution and Ecological Transition. *Source*: "The National Recovery and Resilience Plan (NRRP)." MEF, May 26, 2021. https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/.

Italy is committed to specific activities and reforms following the Ministerial Decree for the adoption of the National Strategy for Circular Economy[176]: first and foremost, a new digital

[176] "Ministry of Ecological Transition Approves Decrees on Circular Economy and Monitoring Systems for Climate Risks." Italia Domani, August 10, 2021. https://italiadomani.gov.it/en/news/approvati-i-decreti-mite-sui-progetti-per-l-economia-circolare-e.html?keep.

waste traceability system will be developed in order to skyrocket its secondary market for raw materials; alongside, Italy is providing tax incentives in order to encourage and promote recycling activities and the secondary raw material supply chain; a revision of environmental taxation system on waste is another major step forward in order to render recycling a more attractive and convenient activity throughout the national territory; last but not least, a reform of the Extended Producer Responsibility (EPR) system[177] in order to achieve the EU targets in this sector through the creation of a specific supervisory body under the presidency of the Ministry of Ecological Transition (MITE).

With specific reference to the latter, the European Commission is totally engaged in modifying and adapting our habits and the way in which we produce energy in order to make it less harmful to the environment than ever. An economically and environmentally Italian sustainable society should be based on the convergence of several factors and driving forces such as a cooperative approach by all national stakeholders, investments in technology and an ability to design innovative models able to undo the previous mistakes and negligence; there are infinite solutions and improvements that can be fully achieved in order to pave the way for a sustainable society that may welcome the next generations: adopting a circular economy model and accomplishing the long-awaited ecological transition are the first steps to take.

In the Italian panorama, recycling is a particular high priority where waste must be treated as a resource since natural ones are scarce. According to the Global E-waste Monitor 2020 report[178], Italy has generated 1.063 kt of e-waste[179], one of the higher rates worldwide; precisely the European Union is the most attentive actor in this regard since it aims at developing the most thriving and efficient Secondary Raw Materials supply chain. However, still today, there is a lack of targeted strategies that Italy is trying to address. As a matter of fact, in Mission 2 of the NRRP, Rome aims explicitly at "the construction of new plants and modernization of existing recycling

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[177] "Extended Producer Responsibility (EPR) is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products". *Source*: "Extended Producer Responsibility." OECD, n.d. https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm.

[178] Forti, Vanessa, Cornelis P. Balde, Ruediger Kuehr, and Garam Bel. 2020. "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential." Bonn, Geneva and Rotterdam: United Nations University/United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association.

[179] idem

plants for the closure of the waste cycle with the production of secondary raw materials"[180]. Certainly, moving from words to deeds is not straightforward and cannot be done overnight.

Within the European Union, the most critical leak in the system is precisely the lack of an efficient system that is able, on every level, to take the product and recycle it into new material. According to the 2021 Third Report on Circular Economy by the Circular Economy Network[181], Italy generates the highest economic value per material consumption unit, i.e. €3.3 in GDP while the European average is €1.98[182], and has transposed the most of the EU directives on waste and circular economy into legislative decrees; alongside, Italy has a good rank concerning the employment in the repairing, reuse and recycling sectors while has the lowest number of patents filed amongst the most performing EU economies[183]. There are optimal conditions and some issues to iron out even if the pathway undertaken by Rome seems to be the most adequate one.

All the aforementioned issues are of utmost importance at the national level. In cooperation with ENEA, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development, EIT RawMaterials Hub – Regional Center Southern Italy was established in June 2019 by the EIT RawMaterials[184]. Since then, its primary objectives and areas of operation have been recycling and reuse, circular economy and substitution. Nowadays, such an innovative stakeholder is focused on the entire raw materials value chain with a long-term strategy based on urban mining, exploration, training and education. To provide a concrete example, in 2020, the REPLAY project was implemented in order to raise awareness about e-waste in interactive events throughout Italy, Finland and the Netherlands. Such an initiative has been positively welcomed by all the European stakeholders that have encouraged Italy to take advantage of the moment.

In the realm of the European Green Deal and Rare Earth Elements, in 2021 the Italian Ministry of Economic Development has devised a comprehensive strategy and launched the

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180 "The National Recovery and Resilience Plan (NRRP)." MEF, May 26, 2021. https://www.mef.gov.it/en/focus/The-National-Recovery-and-Resilience-Plan-NRRP/.

181 "The Third Circular Economy Report - Focus: the Role of Circular Economy in the Transition to Climate Neutrality," 2021. https://circulareconomynetwork.it/wp-content/uploads/2021/03/Synthesis_The-third-circular-economy-report.pdf.

182 *Idem*

183 *Idem*

184 "Hub - Regional Center Southern Italy." EIT RawMaterials, July 30, 2020. https://eitrawmaterials.eu/regional-center-southern-italy/.

national technical committee on Critical Raw Materials[185]: the ultimate objectives are to strengthen the coordination and cooperation at the national level while strengthening the potential in terms of circularity and sustainability of supply; last but not least, Italy is at the forefront of creating economic and market conditions geared towards a secure supply of Critical Raw Materials and Rare Earth Elements.

Such an ambitious project has been followed by the January 2022 creation of the four thematic working groups on Critical Raw Materials[186]: working group 1, "Needs Analysis", aims to evaluate future needs and criticalities concerning these resources over time, with a specific comparison between the EU counterparts and the Italian steps forward; working group 2, "Mining", coordinated by the Italian Institute for Environmental Protection and Research, ISPRA, is responsible for the identification of primary and secondary mining activities, emphasising primarily the potential of recovering these resources from previously abandoned sites; working group 3, "Eco-design", is shedding light on the Italian eco-design potential in order to reduce the demand for Critical Raw Materials, while the primary goal of working group 4, "Urban Mining", is to assess the potential of urban mining activities, focusing on WEEE, as well as to develop best practices and streamline rules and procedures to be followed worldwide.

Most of the productive sectors in Italy have long suffered from the disruption caused by the Coronavirus pandemic which has mostly penalised the underserved and poorer part of the local population. The Italian vulnerabilities are to a certain extent more evident than in other countries because its dependency, especially concerning Rare Earth Elements used in military and technological applications, is amongst the most perceived and hard-fought. The Russo-Ukrainian has severely exacerbated the Italian panorama, forcing the current government to deem diversification of energy sources the top political priority. Certainly, such a change of direction is possible but only if sustainable and secure access to these commodities is attained.

Italy is devising its national Critical Raw Materials strategy that will be focused on a system for mapping existing and future input and output flaws and sources. Nowadays, it is of

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[185] "Materie Prime Critiche." Mise, May 16, 2022. https://www.mise.gov.it/index.php/it/impresa/competitivita-e-nuove-imprese/materie-prime-critiche/materie-prime-critiche.

[186] "Mise – Avvio Dei Lavori Del Tavolo Tecnico Nazionale Materie Prime Critiche." ANIMA Confindustria meccanica varia, March 2, 2022. https://www.anima.it/media/news/tutte-le-news/mise-avvio-dei-lavori-del-tavolo-tecnico-nazionale-materie-prime-critiche.kl.

utmost importance to investigate the presence of Rare Earths' frontiers all over the world and get the maximum benefits. In the next sections, despite different regulatory frameworks and development histories, several new frontiers of these goods will be investigated in order to provide a comprehensive and final picture of the future of Rare Earth Elements.

4.3 The next frontiers of REEs: Greenland, the frozen land of metals

Greenland is amongst the snowiest place in the world despite a nomenclature that evokes quite the opposite. On an international level, this Viking land is the notoriously disputed subject of climate change and its potential repercussions if draconian measures will not be taken in the near future. However, demand for extractives and concerns about future armed conflicts are turning such a remote area into a crucial participant in the global economy. Experts believe that Greenland could become a globally strategic source of extractives because, according to the 2008 US Geological Survey[187], the region is home to significant reserves of zinc, copper, cobalt and, specifically, Rare Earth Elements.

In 1984, a Danish declaration rendered Greenland a nuclear-free zone[188] banning radioactive materials and, consequently, rare earth mining. Their geological coincidence with uranium and thorium was publicly criticised by the then Danish government but did not encounter any opposition until the 2008 global financial crisis. At that time, rare earth mining was considered a ticket to prosperity, geopolitical relevance and, to some extent, independence. Such a stagnant economy forced the local government to hold the 2013 referendum in order to abolish the zero-tolerance policy for rare earth mining[189], paving the way for several mining companies to explore the island's mineral potential.

Greenland is traditionally a region open to investments from all countries, thus arousing the interest of China, the EU and, in more recent times, the US. When discussing the potential of Greenland, Rare Earth Elements are depicted as the most relevant hope in order to diversify the local economy, predominantly based on fishing and subsidies from Copenhagen, and therefore attain the independence that, in the past, seemed utopia. Conversely, the opponents believe that

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[187] Bird, Kenneth, and Gautier, Donald. "USGS Fact Sheet 2007-3077: Assessment of Undiscovered Oil and Gas Resources of the East Greenland Rift Basins Province." USGS Publications Warehouse, 2007. https://pubs.usgs.gov/fs/2007/3077/.

[188] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

[189] *Idem*

the ecological devastation and the social decay caused by large-scale mining operations may shock the local equilibrium and alter the peaceful living of Greenlanders.

Such an open-door policy has prompted European investors, considering their almost total reliance on their Chinese counterparts, to demand a more preferential treatment when it comes to investigating mining in local areas. However, transforming Greenland into a hinterland for continental Europe's rare earths needs is a coveted (for the EU) but not so convenient (for Greenland) project because China dominates the global supply of these commodities and its expertise and investments would be extremely welcomed throughout the area. This is the reason why, in 2016, Shenghe Resources Holding Co Ltd became Greenland Minerals LTD's largest shareholder and strategic partner. The local firm owns the famous Kvanefjeld, an undeveloped site that is located in the middle of Greenland as can be seen from *Table 3*; such an unexplored place is believed to be the world's second-largest deposit of rare earths[190], an extraordinary potential that, if exploited commercially, could solve many issues concerning the supply of these elements.

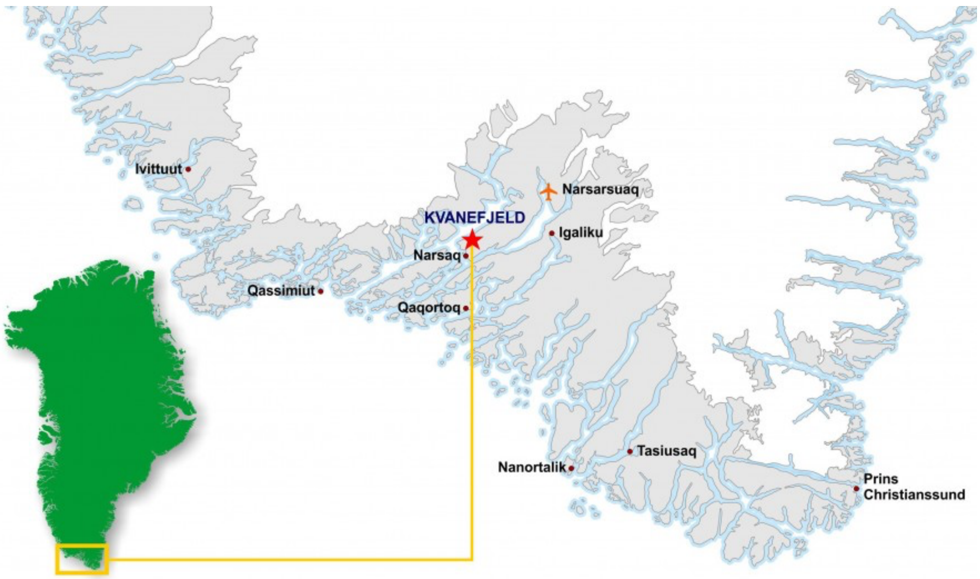

Table 3: Kvanefjeld's geographical position. *Source*: "A Specialty Metal Project of Global Significance." Greenland Minerals LTD, https://ggg.gl/project/.

[190] "'Red-Carded' Australian Miner Signals Intention to Play on in Greenland." Mongabay Environmental News, July 13, 2021. https://news.mongabay.com/2021/07/red-carded-australian-miner-signals-intention-to-play-on-in-greenland.

Due to its monopolistic posture, Beijing is inevitably growing its footprint in Greenland and both the EU and the US have been extremely worried about such a scenario. Nevertheless, according to the report "The Case for a Five Eyes Critical Minerals Alliance" by the Polar Research and Policy Initiative of February 2021[191], it is the United Kingdom that is making great strides concerning the local mining potential, supported by Canada and Australia. All these countries, which are proactive actors in investigating new sources for Rare Earth Elements, dominate the list of companies that have recently obtained mineral exploitation, exploration and processing licenses[192]. Brexit has strengthened the United Kingdom-Greenland partnership to the extent that 12 British companies hold 28 mining licenses in Greenland's minerals sector[193] aimed at developing an integrated North Atlantic supply chain of Rare Earth Elements. The US may only benefit from such a context while China is 'immune' to certain commercial developments. And the EU?

Brussels' strategy to secure its supply of Rare Earth Elements by integrating the sought-after resources of Greenland is seriously jeopardised. Despite Greenland being administered by Denmark which retains control over foreign, defence and security policy, this does not entail that the EU would be able to secure its long-term plan to source more rare earth metals. The Kuannersuit deposit, bigger than the EU's biggest known deposit of rare earths located in Sweden, Norra Kärr, may help Brussels to achieve its executive Action Plan on Critical Raw Materials[194]. However, local concerns about the environmental impact of mineral extraction are a major obstacle that is intended to kill the EU's dreams and ambition.

Nowadays, the convergence of climate change, geopolitics, and desires for Rare Earth Elements' control, make Greenland a new global mining frontier where all the superpowers may collide with each other. This region has a vast resource potential that is expected to be exploited by the most prolific countries in the local mining sector. Experts argue that cooperation between the UK, Canada, Australia the US and New Zealand is vital in order to safeguard the strategically important sectors such as defence and security, green energy and technology[195]. The final

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191 Menezes, Dwayne Ryan. 2021. "The Case for a Five Eyes Critical Minerals Alliance Focusing on Greenland." Polar Research and Policy Initiative.

192 *Idem*

193 *Idem*

194 Duxbury, Charlie. "EU's Plan to Source Rare Earths Takes a Hit in Greenland." POLITICO, June 1, 2021. https://www.politico.eu/article/rare-earth-mining-project-greenland-eu-radioactive-uranium/.

195 Menezes, Dwayne Ryan. 2021. "The Case for a Five Eyes Critical Minerals Alliance Focusing on Greenland." Polar Research and Policy Initiative.

objective, despite tremendous hindrances, is to strengthen the cooperation in mining finance, resource intelligence and develop a secure and sustainable supply chain able to reduce the dependency on China[196].

In the coming years, Greenland will represent one of the top three rare earths' new frontiers where the most important superpowers, the UK, Canada, Australia the US and New Zealand in the first place, and the EU and China in the second one, will compete in order to grab the vitamins of the modern society that, now more than ever, are fundamental for the international security.

4.4 The next frontiers of REEs: Afghanistan, the Asian Eldorado

Despite totally different regulatory frameworks, Afghanistan and Greenland are depicted, both by China and the Atlantic countries, as two of the latest rare earths' frontiers for exploration. During the 1960s and 1970s, the USSR and its Eastern European allies analysed the Asian country's geological resources through extensive surveys[197]; however, such commodities remained buried in the soil due to the tumultuous geopolitical history of Afghanistan. In 2010, there was a turning point: the US Geological Survey (USGS), together with Afghanistan Geological Survey (AGS), conducted the most comprehensive geological survey of the country[198]. The outcome was astonishing: the two agencies discovered 24 specific areas of interest across Afghanistan's 34 provinces where Critical Raw Materials and, specifically Rare Earth Elements, could be found in abundance.

In a war-torn country such as Afghanistan, which has never known peace and stability, such a breathtaking discovery received significant media attention all over the world. Since then, rare earth deposits, the American and European sorrow, have been investigated in conduits by specific programs and expeditions, worth trillions of dollars since the Afghan soil is equally full of gold, iron, copper and other nonferrous metals[199]. US geologists, under military cover, have discovered vast deposits of rare earths that could help to solve world shortages in this regard and, hopefully, wipe out transnational crime and opium production controlled by the Taliban. In the

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[196] *Idem*

[197] Shroder, Jr, J. F. 1983. "USSR and Afghanistan mineral resources." United States.

[198] Klinger, Julie Michelle. 2017. Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes. Ithaca: Cornell University Press.

[199] "Afghan Mineral Wealth Put at $1-3 Trillion-Minister." Reuters. Thomson Reuters, June 25, 2010. https://www.reuters.com/article/afghanistan-mining/afghan-mineral-wealth-put-at-1-3-trillion-minister-idUKLDE65O0FS20100625.

aftermath of the American departure from Central Asia, Rare Earth Elements represent the most relevant factor in order to provide security and prosperity to a beleaguered nation.

Nevertheless, experts are fully aware that building an efficient and sustainable rare earth mining system is an Olympic challenge that could not happen overnight. There are several issues to be taken into account that may jeopardise the goodness of the project: Afghanistan is characterised by structural problems such as corruption, political dysfunction, an inexistent rule of law and democracy as well as inefficient supply lines in order to transport its mineral wealth. Precisely this lack of infrastructure is often used as a political justification because governments all over the world are not willing to invest in a country where economic freedom, voluntary exchange and property rights have never taken root comprehensively.

Afghanistan represents a Rare Earth Elements' Eldorado that could be the most important ingredient of the long-term solution to their supply problem. The American withdrawal has paved the way for a Chinese "Black Hand" on the Asian country: its Belt and Road Initiative could fill the void in the nation left by the American counterparts since Afghanistan is a formal member of such an economic initiative[200]. Beijing is planning to improve local living standards and, concurrently, expand its sphere of influence but not in the public spotlight. A tacit agreement could have been reached by the Taliban and the Chinese government; however, there is no record of that. What is certain is that Beijing is gradually gaining access to cheaper foreign energy and minerals in exchange for investments and commitments[201]. Despite Afghanistan is not expected to become a hub of BRI[202], the US decline and the Chinese ascendance are evident, and the latter may help Beijing to create leverage in future negotiations and dynamics.

The Chinese government aims at strengthening its grip on these commodities in order to fulfil its ambitions, for instance connecting the Indian Ocean and Eurasia through high-speed rail lines, maritime connections and pipelines[203]. Such a strategy, based on cooperation, has inevitably Rare Earth Elements as the most relevant ingredient because developing a mining industry may

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[200] Sacks, David. "Countries in China's Belt and Road Initiative: Who's in and Who's Out." Council on Foreign Relations, March 24, 2021. https://www.cfr.org/blog/countries-chinas-belt-and-road-initiative-whos-and-whos-out.

[201] Sacks, David. "Why Major Belt and Road Investments Are Not Coming to Afghanistan." Council on Foreign Relations, August 24, 2021. https://www.cfr.org/blog/why-major-belt-and-road-investments-are-not-coming-afghanistan.

[202] *Idem*

[203] Baruah, Darshana M. "What Is Happening in the Indian Ocean?" Carnegie Endowment for International Peace, March 3, 2021. https://carnegieendowment.org/2021/03/03/what-is-happening-in-indian-ocean-pub-83948.

entail an effective territorial control and influence that, in the current global geopolitical competition, make all the difference. On the one hand, these goods may serve to enhance the already muscular geopolitical stance of China; on the other one, they are depicted as the key to national development.

In the case of Greenland, the quest for rare earths is primarily orchestrated by the Atlantic countries, due to historical, political and geographical reasons; the Afghan richness leans towards the Far East because of its proximity and strategic importance to regional infrastructure development. The crucial difference is that China is not in a hurry to secure new rare earths' frontiers, the same is not yet true for Western superpowers. In the coming years, it is expected that both Greenland and Afghanistan, with their unexploited massive resources, may turn the tide of history. Certainly, in the short-term, it is highly improbable that dramatic changes may happen but, sooner or later, the pursuit of Rare Earth Elements will upset the global balance and the superpowers have started to act in this regard, both on Earth and in space.

4.5 The next frontiers of REEs: Outer Space, the utopian land

The basic premise is that nobody is actively mining the Moon. This ultimate section is intended to investigate all the new rare earths' frontiers and discuss preliminary the potential future dynamics of these commodities in order to finalise a comprehensive picture of them.

Considering the potential shortage of Critical Raw Materials and Rare Earth Elements on our planet, experts and stakeholders, assisted by dreamers, have theorised the possibility to mine the Moon in order to find an alternative solution. Such a utopian project is not directly connected with the rare-earth crisis in 2010 but rather to the first lunar rock samples that were brought back to Earth in 1969[204]. Nonetheless, it was not until that event that this possibility gained commercial and political attention. For decades, mankind has been inspired by space exploration to the extent that Outer Space has become a traditional arena of competition between superpowers. In recent times, alongside public investments, even private ones have thrived and multiplied, thus adding an additional layer of complexity.

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[204] Allen, Philip A., Micheal R. Anderson, Larry A. Haskin, Philip A. Helmke, Randy L. Korotev, Theodore P. Paster, and Kathleen A. Zweifel. 1970. "Rare earths and other trace elements in Apollo 11 lunar samples." Proceedings of the Apollo 11 Lunar Science Conference, Vol. 2 (February): 1213-1231.

Despite high-sounding words and projects, the space mining industry has always remained in its infancy; the 2010 rare earth crisis turned the tables by giving lunar mining proponents an aperture in order to gain consensus about exploiting the Moon's resources in the name of the greater good. Nowadays, experts are discussing the beginning of the era of commercial space mining following NASA's contracts with four companies aimed at extracting lunar regolith by 2024[205]. Certainly, this thesis' section is not designed to analyse and shed light on what quality, quantity and outlay it would be possible to extract on the Moon; rather, it is intended to emphasise how an increasingly growing number of people believe that the extraction of rare earth metals from the lunar surface could be possible.

The quest for Rare Earth Elements in Outer Space is no longer an unfeasible project in the light of the massive investments and steps forward that have been undertaken in the space industry. In the previous decades, the number of public and private actors dealing with space activities has grown exponentially, ranging from SpaceX's Elon Musk and Blue Origin's Jeff Bezos to Virgin Orbit's Richard Branson to mention a few. All these stakeholders are planning to send astronauts to the moon as part of their targeted programs and improve their technologies so as to finalise their exploration projects. According to NASA, the Moon could harbour a massive number of metals[206], thus making it the final rare earths' frontier and, potentially, the latest arena for geopolitical competition and proxy wars.

Similar to the Greenland and Afghanistan scenarios concerning some facets, mining Rare Earth Elements on the Moon is complicated and controversial even from a regulatory perspective. According to Article 1 of the 1967 Outer Space Treaty[207], "the exploration and use of outer space shall be the common province of all mankind"[208]. The evidence is therefore that space belongs to no country; however, several governments are taking specific steps in order to mine the Moon and control a strong supply of rare earth metals. First and foremost, the US are the pioneers and most proactive actors in this regard, following the Artemis Program[209] and the creation of a legal

[205] Bridenstine, Jim. "Space Resources Are the Key to Safe and Sustainable Lunar Exploration." NASA, September 10, 2020. https://blogs.nasa.gov/bridenstine/2020/09/10/space-resources-are-the-key-to-safe-and-sustainable-lunar-exploration/.
[206] Hille, Karl. "Radar Points to Moon Being More Metallic than Researchers Thought." NASA, July 1, 2020. https://www.nasa.gov/feature/goddard/2020/moon-more-metallic-than-thought.
[207] "Outer Space Treaty." United Nations, 1967.
https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.
[208] *Idem*
[209] "Artemis is the first step in the next era of human exploration [...] using innovative technologies to explore more of the lunar surface than ever before". *Source*: "Artemis." NASA, https://www.nasa.gov/specials/artemis/.

infrastructure for mineral exploitation[210] thanks to the 2015 US Commercial Space Launch Competitiveness Act[211].

Washington is taking a leading role in establishing space mining both under national and international law. There is a plethora of actors and agencies that have followed the path, ranging from the European Space Agency and the Indian Space Research Organisation to China's National Space Administration. Such a momentum to the connection between Rare Earth Elements and Outer Space is primarily given to the material application of these commodities, fundamental to space exploration, satellites and missile defence technologies. Certainly, it is almost impossible to believe that mining rare earths for profit on the Moon would be a viable project, but at least it may contribute to easy the hysteria about the potential supply shortages that each country is expected to meet in the long term.

The prospects for space mining will be determined by the technological advancements and improvements governments will be able to bring into play in the coming decades. Progress in lowering the launch and operations costs has already been attained through the adoption of reusable rocket components[212]. Private investors and firms, constituting the so-called NewSpace activities[213], are collaborating in order to create a space market and increase joint investments in this regard. Concerning space resources, two different schools are developing: the most aggressive one which aims at using them in order to meet the incessantly growing rare earths' demand on Earth, and the most visionary one which plans to use these metals in space.

In the long-term, there are no certainties whereas in the short term it is evident that what is found in the space will remain there. The ungoverned nature of Outer Space could represent not only an impediment to extracting resources but also a motive for competition and conflict. On balance, despite uncertainties remaining considerable, sooner or later space exploration and mining will probably be part of the Rare Earth Elements' saga. It is still too early to say if such a

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210 "The United States has the most robust and detailed national space law and regulatory regime addressing space activities of any nation". Source: Smith, Milton. "The Space Law Review: USA." The Space Law Review , December 9, 2021. https://thelawreviews.co.uk/title/the-space-law-review/usa.

211 "U.S. Commercial Space Launch Competitiveness Act," November 25, 2015. https://www.congress.gov/bill/114th-congress/house-bill/2262/text.

212 Roberts, Thomas G., and Kaplan, Spencer. "Space Launch to Low Earth Orbit: How Much Does It Cost?" Aerospace Security, September 2, 2020. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/.

213 Denis, Gil, Didier Alary, Xavier Pasco, Nathalie Pisot, Delphine Texier, and Sandrine Toulza. 2020. "From new space to big space: How commercial space dream is becoming a reality", Acta Astronautica, Vol. 166, (January): 431-443.

scenario will affect positively or neutrally this sector but what is certain is that the Moon represents the ultimate rare earths' frontier that could change the course of history.

CONCLUSION

This academic work aimed to identify the primary characteristics, peculiarities and dynamics of Rare Earth Elements, the 17 chemical elements appearing in the periodic table that are considered the protagonists of the modern society; to shed light on their direct connection with the crucial sectors to international stability and security; to analyse several national scenarios in this regard and their relation to the current and future geopolitical clashes.

These commodities, discovered during the twentieth century, increasingly came to the foreground because, despite a paradoxical nomenclature, they are found in large variety of minerals and are characterised by unique powerful electromagnetic properties. Rare earths' applications are countless, ranging from the energy sector to the technological one, passing through military and defence sectors that, in today's society, are gaining more and more momentum. Nowadays, it is impossible to imagine a world without Rare Earth Elements; this is the reason why this master thesis aimed at raising awareness of these vital goods that, in the long term, will dominate the political, economic and geopolitical arenas.

Chapter 1 has dealt with rare earths' history and industrial applications by providing a comprehensive analysis of the most important actors and stakeholders as well as their differences and similarities with other energy sources. Even if people do not realise it at first glance, these silent heroes of modern technologies are part of our everyday life. They are essential components of computers, smartphones and hybrid cars, but also wind turbines, photovoltaic panels and missile defence systems. Everywhere people turn and interact, there are Rare Earth Elements.

The Green-Tech revolution had the merit to make these commodities more popular, especially within the European Union, the leader of such an epochal momentum. Rare Earth Elements are traditionally famous in countries such as Japan, following the 2010 rare earth crisis, China, the undisputed superpower to the detriment of the US, as well as Australia, the emerging player which aims to upend the established balance of power.

Already during the 1990s, China acknowledged the paramount importance of these elements through the words of his head of state, Deng Xiaoping, who declared that the Middle East had oil as well as China had rare earths. The East Asian country has monopolised the relative market in the recent decades, attaining 60% of the global production and 80% of the refining processes. This crystallisation of the rare earths' universe has prompted experts and stakeholders to raise the level of attention and devise targeted strategies in order not to be hemmed in. The first chapter has therefore shed light on the most relevant dynamics from a general perspective, by focusing on the comparison with other sources of energy. There are certain similarities with oil and gas, amongst which market congestion, prices fluctuations and concentration of resources. What really makes the difference is that people are learning from the previous failures associated with those energy sources in order to adapt comprehensively their approach to the Rare Earth Elements' market. Therefore, even if the scenarios are heterogeneous and marked by differences, such as the impossibility to establish a multilateral body able to regulate the market, there is great hope that future supply chain disruption risks will be averted by extensive knowledge and awareness.

Chapter 2 has provided a comprehensive analysis of all the specific problems and solutions of Rare Earth Elements, ranging from the geological and environmental to the economic and geopolitical dimensions. Although these commodities are found in great abundance, the most critical geological issue is that rare earths are different one from one another. The emphasis is placed on quality rather than quantity because if the extraction, refining and purification processes of these commodities were all similar and effective, there would not be any concern about the securitisation and storage of these materials. Alas, the criticality is precisely that the individual processes entail multiple facets and problems that exacerbate the whole situation since geology of rare earths is the first aspect to understand in order to comprehend the other dynamics and find the crux of the question. Alongside, geology is intrinsically connected with the environment to the extent that environmental geology has gained momentum in the rare earths' world. The latter is defined a not so green technology since these goods have been traditionally criticised because of their toxic chemicals release into the environment. Certain countries, such as China and Malaysia, have paid little attention to this issue whenever production of rare earths skyrocketed at the turn of the millennium, thus resulting in notorious examples such as the cancer village in Dalahai or the toxic lake in a remote area of Inner Mongolia. Equally, the poor regulation of the market and of the environmental standards has sparked a renewed debate on the dark side of Rare Earth Elements, thus emphasising the importance of recycling and reuse that are the greater ambitions in the long term.

Debates over Rare Earth Elements are particularly thorny and megalomaniac when it comes to taking into consideration their economic and geopolitical proportions. These elements are considered to be the future of a global sustainable economy that will be fulfilled after the accomplishment of the Green-Tech transition where rare earths play a leading role. Chapter 2 has provided valuable insights into the existence of 17 different markets, almost one for each element, thus pointing at the critical market fragmentation that characterises this world. As a matter of fact, there are certain segments expected to grow dramatically, such as the demand for neodymium, praseodymium and dysprosium that is proportional to the relative growth of the permanent magnet industry. This is the reason why certain sections are extremely more popular than others; however, whenever analysing the distinctiveness of these markets, it is evident that there are common issues such as price fluctuations and external inputs that are in the spotlight. Economy and geopolitics are intrinsically connected and converge in the rare earths' panorama because of geography: the concentration of the resources is the major risk in this regard since a disruption in the supply chain may shock the relative market as well as reshape the international relations. The 2010 rare earths' crisis was a strong indication that has awakened the sleeping giants all over the world to the extent that targeted solutions have been on the verge to be developed.

Chapter 2 has therefore tried to present the most important solutions in all the specific dimensions that are currently implemented and will be refined in the coming years. From a geological perspective, the quest for new mines all over the world is the *sine qua non* condition to give respite to the sector. There is great potential in each continent in order to break down the undisputed monopoly of China which still controls the 60% of the global production. While the next frontiers have been subsequently analysed, Chapter 2 has shed light on the most proactive actors, namely Australia and the US, and their targeted strategies where the geological aspect is the jumping-off point to pave the way for solutions in all the other dimensions. Nowadays, recycling and reuse are not sufficient to counterbalance the shortage of the primary supply; nevertheless, if the latter one is strengthened, such two important activities will be able to contribute overwhelmingly to the end of the supply disruptions and problems which torment the rare earths' universe. In this regard, Chapter 2 has emphasised the role of utmost importance which has been conferred on the European Union, the acknowledged leader of the global Green-Tech transition and climate change. There are certainly other countries that is worth to mention in the light of their efforts, such as Japan, but what really matters is the unwritten agreement that most actors have carried out in order to dissociate rare earth elements from environmental concerns through recycling and reuse.

This master thesis has equally provided how important it is to diversify the supply sources from an economical perspective in the pursuit of the 2050 net-zero emission scenario. Price variations will remain at the order of the day in this market considering the high level of volatility, a typical feature of metals, and the incidence of external calamities such as the 2022 Russo-Ukrainian conflict or the Covid-19 crisis. Nonetheless, the most relevant stakeholders may devise and adapt targeted strategies on the basis of previous scenarios connected to other commodities such as oil and gas markets. The starting point is to raise awareness and cooperate on an international level through the development of a circular economy model that encompasses economic geology, social inclusion and specific regulations to standardise the market. Last but not least, considering primarily their defence and military applications, Rare Earth Elements are constantly associated not only with economic prosperity but essentially with national security.

The EU and the US are incessantly working on diminishing their almost total reliance and dependence on Beijing concerning these imported raw materials through the modernisation and internationalisation of the relative supply. Specific initiatives have been already implemented, such as the Quadrilateral Security Dialogue (Quad) deal between leaders of Australia, the US, India and Japan or the EU-South Korea agreement concerning extraction and refinement processes; however, this should be only the preliminary stage in order to deal with the security challenges brought by Rare Earth Elements and render their market as profitable as possible. In this regard, this final dissertation has offered a suggestion: in the light of the excellent experience in balancing energy markets, the International Energy Agency, supported by other bodies such as the OECD and IRENA, should take the reins of the situation politically speaking and contribute to get Rare Earth Elements out of the current geopolitical and economic limbo.

Chapter 3 has focused on the EU's leadership in the realm of rare earths' future dynamics. Brussels has a long history concerning the race for Critical Raw Materials, which dates back to its first list in 2011, and is projected towards achieving net-zero emissions by 2050. Inevitably, its focus has been placed on Rare Earth Elements and their utmost relevance in the EU's mega sectors such as defence, transportation and environmental technology. The supranational organisation, differently from the other superpowers that have great mineral potential, is affected by strict regulations and scarce resources within its borders to the extent that Brussels cannot avoid looking outwards. However, as the experience of oil and gas has taught us and reverberate following the 2022 Russian invasion of Ukraine, the diversification of the sources is a precondition in the current world because, sooner or later, the risk to be affected by a shortage of supply of these fundamental elements might come true.

Brussels has undertaken a structured and comprehensive approach to emerge from traditional impasse and stalemate. Even from a geological perspective, the European Raw Materials Alliance is investigating the existence of local potential and the development of specific segments in the rare earths' processes. Becoming a Rare Earth Elements' superpower passes inevitably through a diversification of the sources and the skyrocketing of recycling and reuse activities, a sort of rare earths' revolution based on the specific EU Action Plan. There is a plethora of projects that have been developed within the Brussels headquarters and the feeling is that the EU will eventually attain its objectives and turn the tables in order to make the Rare Earth Elements' market and universe more balanced than ever.

In the final chapter, some insights into the role of Italy concerning Rare Earth Elements have been provided. The connection with national security, from both a military and economic perspective, finds its realisation precisely within the Italian borders, a country traditionally characterised by serious challenges. Rome has realised how fundamental it is not to be caught in the grip, as in the case of natural gas and its dependency on Russia, to the extent that the national government is working on specific dynamics to stand out. The focus has been placed on the promotion and use of secondary raw materials as well as recycling Waste Electrical and Electronic Equipment. The intersection between the EU subsidies and the Italian strategy is evident: a conspicuous part of the financial support provided by Brussels will be invested in the securitisation of Rare Earth Elements and Critical Raw Materials. Italy aims to be at the forefront of the green revolution and ecological transition through its Recovery and Resilience Plan; developing a resilient supply chain through a circular economy is the top political priority that could be attained only through the collaboration of all stakeholders and the development of alternative mining sources in the coming years.

Chapter 4 has attempted to identify definitively which may be the next frontiers of Rare Earth Elements. Certainly, the precondition is the existence of huge resources in the relative soils, a common ground when it comes to mentioning Greenland, Afghanistan and the utopian Outer Space. Both the frozen land of metals and the Asian Eldorado are considered to be the future protagonists of Rare Earth Elements in the light of geological, geographical and historical dynamics. The most important superpowers are already taking steps in testing the ground for exploiting these resources, while the exploration of space mining is in its embryonic form. Nevertheless, despite not having any certainty in the long-term, this master thesis has demonstrated why these environments may be considered the next frontiers of Rare Earth Elements and contribute to meet the global demand of these commodities in the next future.

This master dissertation has challenged conventional wisdom about Rare Earth Elements and the alleged impossibility to cope with the traditional shortcomings and bottlenecks that characterise this environment. Still today, there is a high degree of uncertainty and unfamiliarity surrounding these commodities, thus resulting in hysteria and extreme agitation about the future of Rare Earth Elements. This work has tried to demonstrate that, through planning and investments, this world will represent an added value for everyone rather than an arena where to confront opponents. Certain countries are heading in the right direction and more and more individuals have realised how our world will be reliant on these resources in the coming years.

To better understand the implications and the consequences of these insights, future studies need to address the market weaknesses that exacerbate the comprehensive judgment on the future of Rare Earth Elements. Two final considerations should be made: on the one hand, it is of utmost importance that stakeholders of the related sectors, ranging from energy and technology to military and defence, develop new methods and tools to spread knowledge about the potential of these goods; on the other one, it is mandatory to develop a global cooperation between all the players in order to ease any remaining concern about the added value of Rare Earth Elements because, despite some structural problems, they will remain an important part of our future. The transition to a greener and safer world passes inevitably through improving knowledge of Rare Earth Elements as critical enablers of advanced technologies, developing innovative value chains from mining to reuse and recycling and, last but not least, promoting transparency and optimism about the related industry.

On balance, the future society simply cannot exist without Rare Earth Elements; in order to stop the negative spiral surrounding these vitamins of modern society, a collective and global approach is mandatory to improve the sustainability and security of the related supply chain. Supposedly, people have realized these elements are the basis for almost all industrial value chains and contribute to societal well-being. Building a better future is possible because there are solid grounds for believing that, eventually, global objectives will be attained. And so, it only remains to wait to know what the future holds.

Bibliography

- Allen, Philip A., Micheal R. Anderson, Larry A. Haskin, Philip A. Helmke, Randy L. Korotev, Theodore P. Paster, and Kathleen A. Zweifel. 1970. "Rare earths and other trace elements in Apollo 11 lunar samples." *Proceedings of the Apollo 11 Lunar Science Conference*, Vol. 2 (February): 1213-1231.
- Alves Dias, Patricia, Silvia, Bobba, Samuel Carrara, and Beatrice Plazzotta. 2020. "The role of rare earth elements in wind energy and electric mobility." Luxembourg: Publications Office of the European Union.
- Barakos, George, and Helmut Mischo. 2018. "The potentials of scientific and industrial collaborations in the field of REE through China's Belt and Road initiative." *International Journal of Georesources and Environment*, Vol. 4, n°3 (July): 86-91.
- Bennett, Matthew R., and Peter Doyle. 1999. *Environmental Geology: Geology and the Human Environment*. Chichester: Wiley.
- Brandt, Sönke, Marc Lorin Fassbender, Reiner Klemd, Chandra Macauley, Peter Felfer, and Karsten M. Haase. 2020. "Cumulate olivine: A novel host for heavy rare earth element mineralization." *Geology*, Vol. 49, no. 4 (December): 457–462.
- Colgan, Jeff D. 2021. *Partial Hegemony: Oil Politics and International Order*. Oxford University Press Inc.
- Dang, Duc Huy, Karen A. Thompson, Lan Ma, Hong Quan Nguyen, Son Tung Luu, Minh Thao Nguyen Duong, and Ashlyn Kernaghan. 2021. "Toward the Circular Economy of Rare Earth Elements: A Review of Abundance, Extraction, Applications, and Environmental Impacts." *Archives of Environmental Contamination and Toxicology*, Vol. 81, (November): 521–530.
- Denis, Gil, Didier Alary, Xavier Pasco, Nathalie Pisot, Delphine Texier, and Sandrine Toulza. 2020. "From new space to big space: How commercial space dream is becoming a reality", *Acta Astronautica*, Vol. 166, (January): 431-443.
- European Commission. 2017. *Methodology for Establishing the EU List of Critical Raw Materials: Guidelines*. Luxembourg: Publications Office of the European Union.
- European Commission. 2020. *Critical materials for strategic technologies and sectors in the EU - a foresight study*. Luxembourg: Publications Office of the European Union.
- Forti, Vanessa, Cornelis P. Balde, Ruediger Kuehr, and Garam Bel. 2020. "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential." Bonn, Geneva and Rotterdam: United Nations University/United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association.

- Gauß, Roland, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, and Badrinath Veluri. 2021. “Rare Earth Magnets and Motors: A European Call for Action.” Berlin: Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance.
- Gili, Alessandro, and Carlo Secchi. 2021. *The Global Quest for Sustainability: The Role of Green Infrastructure in a Post-Pandemic World*. Milano: Ledizioni.
- Goodenough, K. M., J. Schilling, E. Jonsson, P. Kalvig, N. Charles, J. Tuduri, E.A. Deady, et al. 2015. “Europe's Rare Earth Element Resource Potential: An Overview of REE Metallogenetic Provinces and Their Geodynamic Setting.” *Ore Geology Reviews,* Vol. 72 (September): 838–856.
- Hafner, Manfred, and Simone Tagliapietra. 2020. *The Geopolitics of the Global Energy Transition*. Cham, Switzerland: Springer Open.
- Jowitt, Simon M., Timothy T. Werner, Zhehan Weng, and Gavin M. Mudd. 2018. “Recycling of the Rare Earth Elements.” *Current Opinion in Green and Sustainable Chemistry,* Vol. 13 (October): 1–7.
- Kalantzakos, Sophia. 2020. “The Race for Critical Minerals in an Era of Geopolitical Realignments.” *The International Spectator,* Vol. 55, no. 3 (September): 1–16.
- Klinger, Julie Michelle. 2017. *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes*. Ithaca: Cornell University Press.
- KU Leuven. 2022. *Metals for Clean Energy - Pathways to solving Europe’s raw materials challenge*. Leuven: Eurometaux.
- IEA. 2021. “The Role of Critical Minerals in Clean Energy Transitions.” Paris, OECD Publishing.
- Lorenz, Tom and Bertau, Martin. 2017. "14. Recycling of Rare Earth Elements" In Handbook of Rare Earth Elements: Analytics, edited by Alfred Golloch, 357-394. Berlin, Boston: De Gruyter.
- Lukowiak, Anna, Lidia Zur, Robert Tomala, Thi Ngoc LamTran, Adel Bouajaj, Wieslaw Strek, Giancarlo C. Righini, Mathias Wickleder, and Maurizio Ferrari. 2020. “Rare earth elements and urban mines: Critical strategies for sustainable development.” *Ceramics International*, Vol. 46, Issues 16, Part B (November): 26247-26250.
- Menezes, Dwayne Ryan. 2021. “The Case for a Five Eyes Critical Minerals Alliance Focusing on Greenland.” Polar Research and Policy Initiative.
- Nicolazzi, Massimo. 2019. *Elogio Del Petrolio: Energia E Disuguaglianza Dal Mammut All'auto Elettrica*. Milano: Giangiacomo Feltrinelli editore.
- OECD. 2016. OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. Third Edition. Paris: OECD Publishing.

- Patil, Ajay B., Viktoria Paetzel, Rudolf P. Struis, and Christian Ludwig. 2022. "Separation and Recycling Potential of Rare Earth Elements from Energy Systems: Feed and Economic Viability Review." *Separations*, Vol. 9, no. 3 (February): 56.
- Pitron, Guillaume, Ondina Chirizzi, and Stefano Liberti. 2019. *La Guerra Dei Metalli Rari: Il Lato Oscuro Della Transizione Energetica e Digitale*. Roma: Luiss University press.
- Sethurajan, Manivannan, et al. 2019. "Recent advances on hydrometallurgical recovery of critical and precious elements from end-of-life electronic wastes - a review." *Critical Reviews in Environmental Science and Technology*, Vol. 49, no. 3 (January): 212-275.
- Shroder, Jr, J. F. 1983. "USSR and Afghanistan mineral resources." United States.
- Silva, Ruberlan G., Carlos A. Morais, and Éder D. Oliveira. 2019. "Selective precipitation of rare earth from non-purified and purified sulfate liquors using sodium sulfate and disodium hydrogen phosphate." *Minerals Engineering*, Vol. 134 (March): 402-416.
- Talan, Deniz, and Qingqing Huang. 2022. "A Review of Environmental Aspect of Rare Earth Element Extraction Processes and Solution Purification Techniques." *Minerals Engineering*, Vol. 179 (March): 107430.
- Termini, Valeria. 2020. *Energia: La Grande Trasformazione*. Bari: GLF editori Laterza.
- U.S. Geological Survey. 2022. "Mineral commodity summaries 2022". United States: U.S. Geological Survey.
- UNEP. 1989. "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, 1989. International Documents on Corporate Responsibility." Basel.
- Yergin, Daniel. 2020. *The New Map. Energy, Climate, and The Clash of Nations*. New York: Penguin USA.

Sitography

- “'Red-Carded' Australian Miner Signals Intention to Play on in Greenland.” Mongabay Environmental News, July 13, 2021. https://news.mongabay.com/2021/07/red-carded-australian-miner-signals-intention-to-play-on-in-greenland/
- “A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals.” Executive Order 13817, December 26, 2017. https://www.federalregister.gov/documents/2017/12/26/2017-27899/a-federal-strategy-to-ensure-secure-and-reliable-supplies-of-critical-minerals
- “A Global Strategy for the European Union's Foreign and Security Policy.” A Global Strategy for the European Union's Foreign and Security Policy | EEAS Website, https://www.eeas.europa.eu/eeas/global-strategy-european-unions-foreign-and-security
- “A New Circular Economy Action Plan - For a Cleaner and More Competitive Europe.” European Commission, March 11, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM%3A2020%3A98%3AFIN
- “A Specialty Metal Project of Global Significance.” Greenland Minerals LTD, https://ggg.gl/project/
- “Afghan Mineral Wealth Put at $1-3 Trillion-Minister.” Reuters. Thomson Reuters, June 25, 2010. https://www.reuters.com/article/afghanistan-mining/afghan-mineral-wealth-put-at-1-3-trillion-minister-idUKLDE65O0FS20100625
- “Artemis.” NASA. https://www.nasa.gov/specials/artemis/
- “Australia Gives Rare Earths US$360 Million Boost to Counter China Dominance.” South China Morning Post, March 16, 2022. https://www.scmp.com/news/asia/australasia/article/3170630/australias-rare-earths-projects-get-us360-million-funding
- “Australia's Lynas Wins Funding for U.S. Heavy Rare Earths Facility.” Reuters. Thomson Reuters, April 22, 2020. https://www.reuters.com/article/us-usa-rareearths-lynas-corp-idUSKCN2240UL
- “Carbon Border Adjustment Mechanism: Questions and Answers.” European Commission, July 14, 2021. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661
- “Carl Auer Von Welsbach – Discoverer of Gas Mantle & Neodymium, Praseodymium Elements.” worldofchemicals.com, May 20, 2015. https://www.worldofchemicals.com/484/chemistry-articles/carl-auer-von-welsbach-discoverer-of-gas-mantle-neodymium-praseodymium-elements.html

- "China Set to Create New State-Owned Rare-Earths Giant." The Wall Street Journal. Dow Jones Company, December 3, 2021. https://www.wsj.com/articles/china-set-to-create-new-state-owned-rare-earths-giant-11638545586
- "China's BYD Wins Chile Lithium Extraction Contract." Asia Financial, January 13, 2022. https://www.asiafinancial.com/chinas-byd-wins-chile-lithium-extraction-contract
- "Climate Change 'Biggest Threat Modern Humans Have Ever Faced', World-Renowned Naturalist Tells Security Council, Calls for Greater Global Cooperation | Meetings Coverage and Press Releases." United Nations. United Nations. https://www.un.org/press/en/2021/sc14445.doc.htm
- "Conflict Minerals Regulation." Trade. https://policy.trade.ec.europa.eu/development-and-sustainability/conflict-minerals-regulation_en
- "Critical Raw Materials Resilience: Charting a Path towards Greater Security and Sustainability." European Commission, September 3, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474
- "Diversifying Rare Earths: Inside Pensana's Angolan and Yorkshire Projects - Mine." Mine, May 10, 2022. https://mine.nridigital.com/mine_mar22/pensana_angola_yorkshire
- "Dysprosium - Element Information, Properties and Uses: Periodic Table." Dysprosium - Element information, properties and uses | Periodic Table. https://www.rsc.org/periodic-table/element/66/dysprosium
- "Eit Raw Materials Summit." European Commission, June 28, 2021. https://ec.europa.eu/commission/commissioners/2019-2024/breton/announcements/eit-raw-materials-summit_en
- "EURARE - Development of a Sustainable Exploitation Scheme for Europe's Rare Earth Ore Deposits," https://cordis.europa.eu/project/id/309373/reporting
- "Executive Order on America's Supply Chains." The White House. The United States Government, February 24, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/
- "Extended Producer Responsibility." OECD, https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm
- "French Government Recognises Strategic Importance of Rare Earths with Major Investment in Permanent Magnet Recycling." European Raw Materials Alliance (ERMA), June 4, 2021. https://erma.eu/french-government-recognises-strategic-importance-of-rare-earths-with-major-investment-in-permanent-magnet-recycling/

- “Germany to Buy 35 Lockheed F-35 Fighter Jets from U.S. amid Ukraine Crisis.” Reuters. Thomson Reuters, March 14, 2022. https://www.reuters.com/world/europe/germany-decides-principle-buy-f-35-fighter-jet-government-source-2022-03-14/
- “Global Wind Report 2021.” Global Wind Energy Council, January 10, 2022. https://gwec.net/global-wind-report-2021/
- “How Rare-Earth Mining Has Devastated China's Environment.” Earth.Org - Past | Present | Future, July 14, 2020. https://earth.org/rare-earth-mining-has-devastated-chinas-environment/
- “Hub - Regional Center Southern Italy.” EIT RawMaterials, July 30, 2020. https://eitrawmaterials.eu/regional-center-southern-italy/
- “International Renewable Energy Agency (IRENA).” IRENA International Renewable Energy Agency. https://www.irena.org/
- “Italy's Recovery Plan: A Booster to the Circular Economy of Weees.” EIT RawMaterials, February 21, 2022. https://eitrawmaterials.eu/italys-recovery-plan-a-booster-to-the-circular-economy-of-weees/
- “Japan Just Found Enough Rare Minerals for 780 Years of Local Demand.” South China Morning Post, July 11, 2018. https://www.scmp.com/news/asia/east-asia/article/2141445/discovery-rare-earth-minerals-japan-coast-secures-780-years
- “Joint Statement from Quad Leaders.” The White House. The United States Government, September 25, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/24/joint-statement-from-quad-leaders/
- “List of Critical Raw Materials.” Raw Materials Information System. https://rmis.jrc.ec.europa.eu/?page=crm-list-2017-09abb4
- “Materie Prime Critiche.” Mise, May 16, 2022. https://www.mise.gov.it/index.php/it/impresa/competitivita-e-nuove-imprese/materie-prime-critiche/materie-prime-critiche
- “Member States - ASEAN.” https://asean.org/about-asean/member-states/
- “Ministry of Ecological Transition Approves Decrees on Circular Economy and Monitoring Systems for Climate Risks.” Italia Domani, August 10, 2021. https://italiadomani.gov.it/en/news/approvati-i-decreti-mite-sui-progetti-per-l-economia-circolare-e.html?keep
- “Mise – Avvio Dei Lavori Del Tavolo Tecnico Nazionale Materie Prime Critiche.” ANIMA Confindustria meccanica varia, March 2, 2022. https://www.anima.it/media/news/tutte-le-news/mise-avvio-dei-lavori-del-tavolo-tecnico-nazionale-materie-prime-critiche.kl

- "National Recovery and Resilience Plan," September 29, 2021. https://www.governo.it/it/node/17027
- "NextGenerationEU," https://europa.eu/next-generation-eu/index_en
- "Oil and Petroleum Products Explained." U.S. Energy Information Administration (EIA), https://www.eia.gov/energyexplained/oil-and-petroleum-products/prices-and-outlook.php
- "OPEC." Encyclopædia Britannica. Encyclopædia Britannica, inc., https://www.britannica.com/topic/OPEC
- "Permanent Magnet Market by Type (Neodymium Iron Boron Magnet, Ferrite Magnet, Samarium Cobalt Magnet), End-Use Industry (Consumer Electronics, General Industrial, Automotive, Medical Technology, Environment & Energy), and Region - Global Forecast to 2026." Market Research Firm, https://www.marketsandmarkets.com/Market-Reports/permanent-magnet-market-806.html
- "Permanent Magnets Market Size Report, 2022-2030." Permanent Magnets Market Size Report, 2022-2030, April 2022. https://www.grandviewresearch.com/industry-analysis/permanent-magnets-industry
- "Promine" June 16, 2020. https://www.eurogeosurveys.org/projects/promine/
- "Recovery and Resilience Facility." European Commission, May 23, 2022. https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en
- "Rio Tinto Lithium Mine: Thousands of Protesters Block Roads across Serbia." The Guardian. Guardian News and Media, December 5, 2021. https://www.theguardian.com/world/2021/dec/05/rio-tinto-lithium-mine-thousands-of-protesters-block-roads-across-serbia
- "Schaeffler Strengthens Sustainable Supply Chain for Electric Motors." Press Releases | Schaeffler Group, April 19, 2022. https://www.schaeffler.com/en/news_media/press_releases/press_releases_detail.jsp?id=87800193
- "Sino-Japanese Controversy over the Senkaku/Diaoyu/Diaoyutai Islands." July 2021. https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/696183/EPRS_BRI(2021)696183_EN.pdf
- "Speech by Vice-President Šefčovič at the Press Conference on Critical Raw Materials Resilience in the EU." European Commission, September 3, 2020. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1558

- "Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SUSMAGPRO)," https://cordis.europa.eu/project/id/821114
- "Tackling The Challenges In Commodity Markets And On Raw Materials." European Commission, February 2, 2011. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52011DC0025
- "The Aster Project Shines a Light on Rare Earths." Agence nationale de la recherche, September 2, 2015. https://anr.fr/en/latest-news/read/news/the-aster-project-shines-a-light-on-rare-earths/
- "The Energy Act of 2020." The Committee On Science Space and Technology, December 21, 2020. https://science.house.gov/bills/the-energy-act-of-2020
- "The European Green Deal Sets out How to Make Europe the First Climate-Neutral Continent by 2050, Boosting the Economy, Improving People's Health and Quality of Life, Caring for Nature, and Leaving No One Behind." European Commission - European Commission, December 19, 2019. https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691
- "The Raw Materials Initiative — Meeting Our Critical Needs for Growth and Jobs in Europe." European Commission, November 4, 2008. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0699:FIN:en:PDF
- "The Third Circular Economy Report - Focus: the Role of Circular Economy in the Transition to Climate Neutrality," 2021. https://circulareconomynetwork.it/wp-content/uploads/2021/03/Synthesis_The-third-circular-economy-report.pdf
- "Tutti Gli Interventi e Le Risorse Di React-EU: 14,4 Miliardi, 67,6% Al Sud." Ministro per il Sud e la Coesione territoriale, April 1, 2022. https://www.ministroperilsud.gov.it/it/approfondimenti/schede/tutte-le-misure-e-le-risorse-di-react-eu/
- "U.S. Commercial Space Launch Competitiveness Act," November 25, 2015. https://www.congress.gov/bill/114th-congress/house-bill/2262/text
- "U.S. Geological Survey Releases 2022 List of Critical Minerals: U.S. Geological Survey." U.S. Geological Survey. February 22, 2022. https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals
- "U.S. Solar Market Insight." SEIA. https://www.seia.org/us-solar-market-insight
- "Usos e Aplicações De Terras Raras No Brasil - CGEE," https://www.cgee.org.br/documents/10182/734063/Terras_Raras_Web_9532.pdf

- "Waste in the EU: Facts and Figures." European Parliament, April 26, 2022. https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic
- "What Are Rare Earth Elements, and Why Are They Important?" American Geosciences Institute, February 1, 2018. https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important
- "What Are the Most Profitable Industries in the EU?" EUbusiness, October 28, 2020. https://www.eubusiness.com/focus/20-10-28
- "What Is IPCEI on Batteries?" IPCEI Batteries, https://www.ipcei-batteries.eu/about-ipcei
- Alves, Renato. "Bolsonaro Wants Brazil to Cash in on the World's Rare-Earth Obsession." The Brazilian Report, August 23, 2021. https://brazilian.report/business/2021/08/23/rare-earth-obsession/
- Areddy, James. "Rare-Earth Miner in U.S. Tackles China, Its Own Past." The Wall Street Journal. Dow Jones Company, December 20, 2010. https://www.wsj.com/articles/SB10001424052748704447604576007290928049906
- Baruah, Darshana M. "What Is Happening in the Indian Ocean?" Carnegie Endowment for International Peace, March 3, 2021. https://carnegieendowment.org/2021/03/03/what-is-happening-in-indian-ocean-pub-83948
- Bird, Kenneth, and Gautier, Donald. "USGS Fact Sheet 2007-3077: Assessment of Undiscovered Oil and Gas Resources of the East Greenland Rift Basins Province." USGS Publications Warehouse, 2007. https://pubs.usgs.gov/fs/2007/3077/
- Bloomberg.com. Bloomberg, October 24, 2021. https://www.bloomberg.com/graphics/2021-china-climate-change-biggest-carbon-polluters/
- Bradsher, Keith. "Amid Tension, China Blocks Vital Exports to Japan." The New York Times. The New York Times, September 23, 2010. https://www.nytimes.com/2010/09/23/business/global/23rare.html
- Bridenstine, Jim. "Space Resources Are the Key to Safe and Sustainable Lunar Exploration." NASA, September 10, 2020. https://blogs.nasa.gov/bridenstine/2020/09/10/space-resources-are-the-key-to-safe-and-sustainable-lunar-exploration/
- Burclaff, Natalie. "Standard Oil Established." Research Guides, January 14, 2020. https://guides.loc.gov/this-month-in-business-history/january/standard-oil-established
- Caminiti, Susan. "The Billionaire's Race to Harness the Moon's Resources." CNBC, June 19, 2014. https://www.cnbc.com/2014/04/02/the-global-race-to-harness-the-moons-resources.html

- Carroll, Sean Goulding. "Brussels Approves €2.9 Billion Investment into Battery Innovation." EURACTIV, January 27, 2021. https://www.euractiv.com/section/batteries/news/brussels-approves-e2-9-billion-investment-into-battery-innovation/
- Chomon, Juan Manuel, and Ganser, Andreas. "How Relevant Are Rare Earths to Europe's Security and Defence?" European Security Defence, October 7, 2021. https://euro-sd.com/2021/10/articles/exclusive/23989/how-relevant-are-rare-earths-to-europes-security-and-defence/
- Crossley, Gabriel, and Min Zhang. "China Says Domestic Competition Hurting Rare Earth Prices." Reuters. Thomson Reuters, March 1, 2021. https://www.reuters.com/article/us-china-rareearths-industry-idUKKCN2AT13G
- Daly, Tom. "China Hikes 2021 Rare Earth Quotas by 20% to Record Highs." Reuters. Thomson Reuters, September 30, 2021. https://www.reuters.com/business/energy/china-hikes-2021-rare-earth-quotas-by-20-record-highs-2021-09-30/
- Department of Industry, Science, Energy and Resources. "2022 Critical Minerals Strategy." Australian Government, March 7, 2022. https://www.industry.gov.au/data-and-publications/2022-critical-minerals-strategy
- Dombey, Daniel. "Spain's Rush for Lithium Falls Foul of Local Opposition." Financial Times, October 20, 2021. https://www.ft.com/content/459191d9-774d-4a2b-8ec6-ba472017b05e
- Duxbury, Charlie. "EU's Plan to Source Rare Earths Takes a Hit in Greenland." POLITICO, June 1, 2021. https://www.politico.eu/article/rare-earth-mining-project-greenland-eu-radioactive-uranium/
- Duxbury, Charlie. "Sweden's Ground Zero for the EU's Strategic Materials Plan." POLITICO, November 24, 2020. https://www.politico.eu/article/swedish-ground-zero-for-eu-strategic-materials-plan/
- Edmondson, Dr James. "Rare Earths in Evs: Problems, Solutions and What Is Actually Happening." IDTechEx. IDTechEx, October 28, 2021. https://www.idtechex.com/en/research-article/rare-earths-in-evs-problems-solutions-and-what-is-actually-happening/25071
- Farchy, Jack, and Warren, Hayley. "China Has a Secret Weapon in the Race to Dominate Electric Cars." Bloomberg.com. Bloomberg, December 2, 2018. https://www.bloomberg.com/graphics/2018-china-cobalt/
- Harrison, Alex. "Ukraine Crisis Drives Rush to Secure Supply in Global Metal Markets." Fastmarkets. Fastmarkets, April 11, 2022. https://www.fastmarkets.com/insights/ukraine-crisis-drives-rush-to-secure-supply-in-global-metal-markets

- Hering, Garrett. “Infographic: Q4'21 US Wind Power by the Numbers.” Infographic: Q4'21 US Wind Power by the Numbers | S&P Global Market Intelligence, April 22, 2022. https://www.spglobal.com/marketintelligence/en/news-insights/blog/infographic-q421-us-wind-power-by-the-numbers
- Hille, Karl. “Radar Points to Moon Being More Metallic than Researchers Thought.” NASA, July 1, 2020. https://www.nasa.gov/feature/goddard/2020/moon-more-metallic-than-thought/
- Hui, Mary. “Japan's Global Rare Earths Quest Holds Lessons for the US and Europe.” Quartz. Quartz, April 23, 2021. https://qz.com/1998773/japans-rare-earths-strategy-has-lessons-for-us-europe/
- IEA (2021), Electric Vehicles, IEA, Paris https://www.iea.org/reports/electric-vehicles
- IEA (2021), Electric Vehicles, IEA, Paris https://www.iea.org/reports/electric-vehicles
- IEA (2021), Global EV Outlook 2021, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2021
- IEA (2021), Transport, IEA, Paris https://www.iea.org/topics/transport
- IEA (2021), World Energy Model, IEA, Paris https://www.iea.org/reports/world-energy-model
- IEA (2022), Russian supplies to global energy markets, IEA, Paris https://www.iea.org/reports/russian-supplies-to-global-energy-markets
- IEA. “World Energy Outlook 2021 – Analysis.” IEA, October 1, 2021. https://www.iea.org/reports/world-energy-outlook-2021.
- Johnson, Joseph. “EU: Digitalization Levels by Country 2020.” Statista, June 29, 2021. https://www.statista.com/statistics/1245595/eu-digitalization-level/
- Kinch, Diana. “Recycling Could Account for 25% of Rare Earths Market in 10 Years: Mkango CEO.” S&P Global Commodity Insights, November 3, 2021. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/110321-recycling-could-account-for-25-of-rare-earths-market-in-10-years-mkango-ceo
- Kit Chapman, Kristy Turner. “The Most Important Village in Chemistry.” RSC Education, October 29, 2018. https://edu.rsc.org/feature/the-most-important-village-in-chemistry/3009670.article
- LynasCorp. “How Are Rare Earths Used - Wind Turbines.” Lynas Rare Earths, January 28, 2022. https://lynasrareearths.com/products/how-are-rare-earths-used/wind-turbines/
- LynasCorp. “Kuantan, Malaysia.” Lynas Rare Earths, January 28, 2022. https://lynasrareearths.com/about-us/locations/kuantan-malaysia/

- Madeddu, Davide. "L'auto Elettrica FA Rinascere Le Miniere Piemontesi." Il Sole 24 ORE, November 8, 2021. https://www.ilsole24ore.com/art/la-riscoperta-miniere-italiane-AE02icd
- Maisonnave, Fabiano. "The Amazon Home of Bolsonaro's Mineral Fantasy." Climate Home News. Climate Home, October 23, 2020. https://www.climatechangenews.com/2020/07/05/amazon-home-bolsonaros-mineral-fantasy/
- Maughan, Tim. "The Dystopian Lake Filled by the World's Tech Lust." BBC Future. BBC, April 2, 2015. https://www.bbc.com/future/article/20150402-the-worst-place-on-earth
- Meyer, Robinson. "Greenland's Rare-Earth Election." The Atlantic. Atlantic Media Company, May 3, 2021. https://www.theatlantic.com/science/archive/2021/05/greenlands-rare-earth-election/618785/
- Name. "Illegal Rare Earth Mining Harms Environment in Myanmar's Kachin State." Radio Free Asia, March 10, 2022. https://www.rfa.org/english/news/myanmar/mining-03102022184456.html
- O'Donoghue, Amy Joi. "It's Rarer than Gold and Critical for Green Energy - and It's about to Be Mined in Utah." Deseret News. Deseret News, March 27, 2021. https://www.deseret.com/utah/2021/3/26/22344673/utah-green-energy-rare-element-for-solar-panels-mined-in-salt-lake-tellurium-rio-tinto
- Onstad, Eric. "Europe Urged to Launch Fund to Spur Rare Earth Magnet Output." Reuters. Thomson Reuters, September 30, 2021. https://www.reuters.com/business/energy/europe-urged-launch-fund-spur-rare-earth-magnet-output-2021-09-30/
- Rare Earth Elements Market - Growth, Trends, Covid-19 Impact, and Forecasts (2022 - 2027), Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/rare-earth-elements-market
- REE4EU, September 4, 2020. https://www.ree4eu.eu/
- Roberts, Thomas G., and Kaplan, Spencer. "Space Launch to Low Earth Orbit: How Much Does It Cost?" Aerospace Security, September 2, 2020. https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/
- Rogers, Iain. "Germany to Create Special €100 Billion Armed Forces Fund." Bloomberg, February 27, 2022. https://www.bloomberg.com/news/articles/2022-02-27/scholz-says-germany-to-create-special-eu100b-armed-forces-fund
- Sacks, David. "Countries in China's Belt and Road Initiative: Who's in and Who's Out." Council on Foreign Relations, March 24, 2021. https://www.cfr.org/blog/countries-chinas-belt-and-road-initiative-whos-and-whos-out

- Sacks, David. "Why Major Belt and Road Investments Are Not Coming to Afghanistan." Council on Foreign Relations, August 24, 2021. https://www.cfr.org/blog/why-major-belt-and-road-investments-are-not-coming-afghanistan
- Scheyder, Ernest. "Pentagon Awards $13 Million in Rare Earths Funding to U.S. Projects." Reuters. Thomson Reuters, November 18, 2020. https://www.reuters.com/article/usa-rareearths/pentagon-awards-13-million-in-rare-earths-funding-to-u-s-projects-idINKBN27Y2F0
- Scheyder, Ernest. "U.S. Needs More Mines to Boost Rare Earths Supply Chain, Pentagon Says." Reuters. Thomson Reuters, October 19, 2021. https://www.reuters.com/business/us-needs-more-mines-boost-rare-earths-supply-chain-pentagon-says-2021-10-19/
- Sharma, Ruchir. "'Greenflation' Threatens to Derail Climate Change Action." Financial Times. Financial Times, August 2, 2021. https://www.ft.com/content/49c19d8f-c3c3-4450-b869-50c7126076ee
- Sink, Justin, and Leonard, Jenny. "Biden Seeks to Boost Rare Earth Element Extraction in U.S." Bloomberg.com. Bloomberg, February 22, 2022. https://www.bloomberg.com/news/articles/2022-02-22/biden-seeks-to-boost-extraction-of-rare-earth-elements-in-u-s
- Smith, Milton. "The Space Law Review: USA." The Space Law Review, December 9, 2021. https://thelawreviews.co.uk/title/the-space-law-review/usa
- Smith, S.E. "Dirty, Dangerous and Destructive – the Elements of a Technology Boom." The Guardian. Guardian News and Media, September 26, 2011. https://www.theguardian.com/commentisfree/2011/sep/26/rare-earth-metals-technology-boom
- Smyth, Jamie. "US-China: Washington Revives Plans for Its Rare Earths Industry," September 14, 2020. https://www.ft.com/content/5104d84d-a78f-4648-b695-bd7e14c135d6

SUMMARY

Rare Earth Elements are often referred to as 'vitamins of the modern society' because they are fundamental to the production of renewable energy, defence applications, production of high-tech as well as electric mobility. A series of calamities all over the world, ranging from the decarbonization of the global economy to the Covid-19 crisis, has paved the way for an arduous quest for these Critical Raw Materials; similar to other scenarios, lithium and cobalt in the first place, Rare Earth Elements themselves are characterised by critical issues that have tarnished their positive nature. These commodities are often associated with geographical concentration, price volatility, supply chain risks and environmental damage. Obviously, the aim of this master thesis is not to discard and ignore such opinions; rather, the objective is to focus on the most adequate solutions to cope with these problems, so that people will be eventually inclined to realise the added value of these resources.

The first chapter of this dissertation analyses these 17 metallic elements that are at the heart of the periodic table. Discovered more than 200 years ago, these goods have gradually gained momentum because of their heterogeneous applications. As a matter of fact, after having described each element and outlined the most salient differences between Light and Heavy Rare Earth Elements, the preliminary sections are devoted to the historical developments and to the most relevant actors in this arena; alongside, since these commodities are essential to renewable energies, some insights into the differences with fossil fuels and the similarities with other Critical Raw Materials are provided. In the second chapter, the emphasis is placed on the most critical

concerns that make Rare Earth Elements appear in a bad light and, consequently, the solutions in the short- and long-term. Geology is the starting point, environmental and economic issues are the most famous ones, geopolitics and security are the consequences of all these factors and dynamics.

The third chapter is dedicated to the European Union, depicted as the most emerging player in this sector, especially by considering its acknowledged role of global leader of the Green-Tech transition. Given the EU's dependence on these commodities from China, speculations about the shortage of these resources is considered to be a growing concern in the Brussels' headquarters. Alongside, since Rare Earth Elements are indispensable to the forthcoming global economic transformation and to the attainment of the EU's net-zero emissions objective by 2050, it is inevitable that the 27 Member States are called to become a superpower in such an industry. Last but not least, the fourth chapter analyses the renewed stance of Italy toward Rare Earth Elements and Critical Raw Materials as well as tries to shed light on the next frontiers of these metals, where it is expected that the scramble for resources will intensify in the coming decades.

When people mention Rare Earth Elements, it is spontaneous to focus on the first word of their nomenclature; and quite often, these goods are referred to as sporadic elements. However, despite such a paradoxical classification, there is a multitude of residual deposits of Rare Earth Elements all over the world and, therefore, they are relatively abundant throughout the Earth's crust. Today's society is characterised by a series of revolutions which impacts on various sectors, amongst which energy and security to name a few. Rare earths are precisely those elements that are essential to the development and strengthening of these industries to the extent that stakeholders talk increasingly more of a Rare Earth Elements' era, characterised by a vast, dynamic and plentiful frontier.

These goods are often associated with a political and security life that is gradually and simultaneously evolving with international relations to the extent that they have already been used as bargaining chips in geopolitical disputes, the 2010 rare earth crisis between China and Japan is the most striking example. Since their discovery in the 18th century by the geologist Lieutenant Carl Axel Arrhenius, who found an astonishing black rock in a Swedish small village, Ytterby, Rare Earth Elements have been scrupulously analysed. Geologists have progressively realised the tremendous potential of these metals; nevertheless, the turning moment has been the declaration of China's paramount leader Deng Xiaoping, during a 1992 visit to the Rare Earths district of Baotou in Inner Mongolia: 'the Middle East has oil, China has Rare Earths'. Such a stunning announcement awakened all the sleeping superpowers all over the world, which realised immediately that China would have used these commodities as a potential leverage and negotiating asset in the next geopolitical dynamics. Rare earths' history taught us this possibility took place sporadically; however, the tensions between China and the US, under the Trump administration, left the doors open to potential disruption in the near future.

Spontaneously, people may wonder why these 17 metallic elements are gaining strong momentum and attention at both national and international level. The answer is undoubtedly to be found in the industrial applications of each element. The most famous elements are Neodymium, Praseodymium and Dysprosium, which are pivotal to the creation of powerful permanent magnets used in a wide range of items, such as mobile phones, electric motors and wind turbines. Their unique magnetic and chemical properties are coveted by almost everyone who aims to emerge in the sector of reference. Alongside, countries need these commodities in order to attain their objective of decarbonising the society as well as of improving their military and defence industries and arsenals. What really makes rare earths special and sought-after is precisely the fact that, whatever you need or interact, there will be a small or large percentage of Rare Earth Elements that is fundamental for the functioning of a plethora of things.

Globally, China is considered the monopolistic player of the rare earths' market, which has created an impressive empire and structure that is hard to counter. This has been primarily possible because Beijing owns more than one-third of the reserves worldwide and accounts for two-thirds of the global production and refining. At first glance, it seems China would remain the undisputed leader for long; however, by investigating the major reserves and deposits worldwide, there are several countries that are expected to rain on China's parade: Brazil, Vietnam, Russia and India have great reserves and potentials, the US, the EU, the UK and Australia are developing targeted strategies and projects in order to exploit resources all over the world and counterbalance the Chinese dominance.

In the wake of certain events such as the Coronavirus pandemic and the 2022 Russian invasion of Ukraine, the connection between Rare Earth Elements and security has skyrocketed considering that missile guidance systems, aircraft engines, communication satellites, precision-guided weapons, require the vitamins of the modern society. Innovations in these sectors and high levels of security would not be possible without Rare Earth Elements to the extent that concerns about any supply chain disruption in this regard create a high degree of hysteria in national governments.

Concurrently, the world is heading toward resilient and sustainable energy systems which are gradually wandering off fossil fuels. Rare Earth Elements contribute to the decarbonisation of the energy system, considering their application in solar panels and wind turbines. Differently from fossil fuels, in particular oil, these commodities are essential in order to promote an optimal functioning of an innovative energy system, even if the regulation of their market is even more complicated than the management of oil resources. This is strictly connected to the existence of the Organization of Petroleum Exporting Countries (OPEC) that is almost impossible to replicate in the rare earths' environment, which is rather dominated by a 'one-nation OPEC' that is China. Despite such a sovereignty, this master thesis tries to demonstrate that no country is able to control an entire critical mineral value chain because there are too many geopolitical dynamics, driving forces and factors that raise the level of media attention and loosen the market monopoly.

Rare Earth Elements are traditionally compared with other strategic metals, particularly cobalt and lithium, because the geographical concentration, an oligopolistic market and price volatility are the common thorny issues. The demand for these Critical Raw Materials is skyrocketing because they are all essential to reduce emissions to zero by 2050 and establish an efficient circular economy in the long-term. The dramatic increase in EVs market emphasises the importance of recycling all these elements that will be the most requested goods in the attainment of the energy transition. The study of the three scenarios and their interconnection helps us to understand where the world is heading and how geopolitical and economic turbulences may upset these markets and the international peace and stability. The Rare Earth Elements' environment is considered to be the most complicated one because there is a superpower, China, as the monopolistic actor, differently from cobalt's DRC and lithium's Chile, and there are no historical records that offer evidence of previous critical situations and related solutions, such as the 1978 cobalt crisis in the province of Katanga.

Chapter 2 therefore attempts to shed light on the most salient geological, environmental, economic and geopolitical problems that are associated with Rare Earth Elements and to identify some plausible solutions. First and foremost, the other three issues would not exist if geological concerns did not represent a real concern. The emphasis is primarily placed on quality rather than quantity because rare earths are not exotic elements. However, these commodities are problematic to be mined and collected since their formation and geological features coincide with hazardous minerals. Furthermore, being 17 different elements, there are no extraction, separation or purifying processes that are identical as well as deposits that guarantee the same item. Currently, only few deposits are sufficiently voluminous to be exploited economically, amongst which the biggest Bayan Obo in Inner Mongolia, to the extent that the 'reserves' problem is the first to be addressed through the opening of new mines.

Alongside, geology and the environment are interconnected in the rare earths' saga since, despite being indispensable for sustainable development, these elements are 'a not so green technology'. During the 1980s and the 1990s, countries such as the US, China or Malaysia did not pay enough attention to the release of toxic chemicals into the environment whenever processing rare earths. The gruesome consequences are still evident: in a remote area of Inner Mongolia, there is a toxic lake battered by waste byproducts while people living in farms and villages, such as the cancer village of Dalahai, have been forced to leave their homes in order to avoid death. In the past, the lack of market regulations paved the way for justified criticism concerning the goodness of the rare earths' potential. Nowadays, the environmental aspect is probably the first parameter to be taken into account; therefore, a greener world reliant on rare earths necessitates adjustments in this regard more than ever.

Certainly, it is an Olympic challenge to standardise and regulate the market since the Rare Earth Elements' universe is composed of 17 distinct elements and, consequently, heterogeneous market dynamics and peculiarities. From an economic perspective, the global recession of 2008-09 and the 2010 rare earth crisis have accelerated price fluctuations and volatility of these commodities; subsequently, shifting to a greener economy in the short-term entails a price to be paid which results in energy inflation and trade disputes. When talking about Rare Earth Elements, experts mention the 'greenflation', namely a significant increase in their price due to the advancement, and therefore greater demand, of renewable technologies. To make matters worse, the Covid-19 crisis and the 2022 Russo-Ukraine conflict are determining the highest levels of inflation in over 40 years, thus pointing at supply chain instability and dislocated prices.

The geopolitical dynamics are represented by the convergence of all the aforementioned concerns and exacerbate eventually every aspect of the rare earths' world. Since these goods are fundamental for economic security, energy security, environmental security, military security and trade security, it is natural that they may be used as bargaining chips and leverage in international relations. China has gradually built an empire which allows Beijing to implement a hostile trade policy for rare earths as an effective geopolitical tool whenever it finds itself in political and economic disputes. The 2010 rare earths' crisis with Japan has highlighted such a strategy, even if there is to say that, to date, the latter has not been directly replicated. Within the 'One Belt One Road' strategy devised by Xi Jinping in 2013, one of the commercial priorities is to carry out transcontinental energy and transport projects where rare earths are essential components. Such a reinvigorated economic and geopolitical posture by Beijing has suddenly given a wake-up call to the other superpowers that cannot sit by and watch. For instance, the EU, the US and Japan have started a cycle of tripartite collaboration in order to decrease their dependence on China, a first step to make geopolitical concerns less invasive than the others.

Chapter 2 investigates the current and potential solutions aimed at providing a comprehensive picture of Rare Earth Elements. From a geological perspective, the opening of new mines and the exploiting of additional reserves is not in question in order to meet future global demand. Since Rare Earth Elements are distributed on an equal basis all over the world, it is of utmost importance to identify emerging market opportunities and maximise the sector's potential. Australia, the US and the EU are the most proactive superpowers which have devised targeted strategies in order to develop processing facilities and boost local production. Certainly, drawing from new reserves will not suffice; recycling and reuse are essential activities in order to avert any supply chain risk. Alongside, they represent an integral part of an environmentally ethical approach that is mandatory to perform in such a market. Nowadays, it is no longer tolerable to put the environmental considerations apart to the extent that specific procedures and techniques, such as selective precipitation and solvent extraction, have been already experimented successfully. The future prerogative is to handle end-of-life materials and recycle them, despite prohibitive costs. The creation of an efficient rare earth recycling industry on a large scale is the sought-after ambition in the coming years.

Economic and geopolitical solutions are interconnected because the diversification of the sources of supply is the major step toward a fully integrated supply chain. Governments are intensively working on the development of a circular economy model for rare earths able to strengthen supply chain resilience, job creation and climate change adaptation. Economic stability is heavily dependent on geopolitical stability: both the US and the EU have guided revolutionary processes to become less reliant on the imported raw materials from China. The 2021 Executive Order on America's Supply Chains and the EU Action Plan on Critical Raw Materials are the two most important strategies that encompass geological, environmental, economic and geopolitical issues. To come up with effective solutions, these superpowers have implemented long-term strategic investments to internationalise the Rare Earth Elements supply and modernise its production; alongside, they have finalised structured partnership aimed to intensify cooperation and increase knowledge and expertise about these commodities. Chapter 2 ends by giving a suggestion: this sector needs a multilateral governance that could be composed of certain transnational bodies and agencies, such as the IEA and IRENA, intended to make the market and supply chain more regulated and sustainable through an interventionist approach.

Chapter 3 investigates the role of the EU which is at the forefront of the Green-Tech transition as well as recycling and reuse activities. The European Green Deal has clearly set the path: Europe aims to be the first climate-neutral continent by becoming a modern, resource-efficient economy. This objective is non-negotiable in the Brussels' headquarters and rare earths are essential ingredients to such an ambition. The EU has a long-standing experience in identifying and dealing with Critical Raw Materials, dating back to the 2008 first list of them. The most recent update has increased the number of materials to 30, amongst which Rare Earth Elements. Brussels, which is currently almost totally dependent on China, has all the credentials to wrest back control of the Rare Earth Elements supply chain and become an industry leader. This is primarily connected to the fact that Europe's supply chain security is essential to deliver the Green Deal and the related digital ambitions.

In 2021, the European Commission adopted its Action Plan on Critical Raw Materials, an innovative strategy based on 10 concrete actions, supervised by the European Raw Materials Alliance, that will contribute to the creation of a European rare earths industry. The EU has already identified 14 projects along the whole supply chain, worth €1.7 billion investment, in order to concretise the diversification of these elements. The EU is the leader of a rare earths' revolution because it has all the credentials to achieve its objectives and make the difference. Recycling is the top commercial priority of the 27 Member States because it is expected that rare earths will be gradually supplied through alternative sources that will take the centre stage between 2030 and 2040. Since the current recycling rate is almost inexistent (i.e., less than 1%), Brussels has taken up the challenge and incentivises a recycling industry for permanent magnets, whose demand is expected to grow intensively in the years ahead. The EU is fully focused on creating a rare earths' industry because these elements are even fundamental to the resilience of the defence and military sector. In the wake of the Russian invasion of Ukraine, Brussels cannot be caught unprepared whenever a security crisis may upset its neighbourhood and boundaries.

The recent events have shocked the market, with schizophrenic prices and prolonged economic recession. Given the importance of rare earths, such as Neodymium, Dysprosium and Praseodymium, in the attainment of the European objectives and maintenance of security and stability, the EU is inevitably called upon to take the reins of the situation and lay the groundwork for strategic autonomy in this sector. This passes through the fulfilment of specific projects as well as the implementation of commercial and economic partnerships with countries which have not yet exploited their resources, the African nations on top. Last but not least, the EU is expected to investigate the existence of new rare earths' frontiers and to arrive there before the others because the competition for these elements is hectic and nobody can afford false moves.

The closing chapter precisely presents the older and newer frontiers of Rare Earth Elements, the countries involved in their evaluation and the Italian position regarding the vitamins of the modern society.

Italy aims at becoming a mining and energy power within the EU since the country, due to economic reasons in the first place, lags behind the other Member States. The Covid-19 crisis has exacerbated the already complicated situation in the Mediterranean country to the extent that Rome has undertaken a targeted and comprehensive strategy for Critical Raw Materials and recycling activities thanks to the economic support coming from Brussels. The Italian Recovery and Resilience Plan has dedicated an entire section to the green revolution and ecological transition, to which €68.6 billion have been allocated, roughly the 31.05% of the total value of the NRRP. The Italian government is focused on the promotion and use of secondary raw materials, specifically e-waste recycling rates in order to obtain Rare Earth Elements. Alongside, the country has adopted its National Strategy for Circular Economy, aimed at providing tax incentives to promote recycling activities as well as opening new mines throughout the territory. Last but not least, Italy has launched its four thematic working groups on Critical Raw Materials in order to raise awareness and knowledge of all the national stakeholders and devise a common approach in order to develop a system for mapping existing and future input and output flaws and sources.

Such a diversification of the sources is directly connected with the potential next frontiers of Rare Earth Elements. This master thesis tries to identify the most fruitful and economically feasible regions where to mine and commercialise rare earths in order to meet the global demand. Traditionally, Greenland is considered a remote but rich area where to find rare earths. In 2008, the US Geological Survey carried out an assessment claiming Greenland is home to significant reserves of zinc, copper, cobalt and, specifically, Rare Earth Elements. Despite political controversies, referenda and local oppositions, sooner or later Greenland is expected to become a new global mining frontier. Certain superpowers have already started to investigate concretely the matter, such as the UK, Canada, Australia and the US. Alongside, Afghanistan has been described as the Asian Eldorado of Rare Earth Elements, following again the geological survey carried out in 2010 by the US Geological Survey. This war-torn country, tormented by civil wars and quick changes of power, has no longer known stability and peace despite an immense potential. Nowadays, rare earths could represent an important solution to the prosperity of the country as well as to the potential supply problems China may face in the coming years.

Last but not least, experts believe that Outer Space may become the ultimate frontier of Rare Earth Elements. Although no one is currently mining the Moon, rare earths have already been found there in 1969. In the near future, the intensification of the competition for space resources may imply that superpowers will confront themselves in order to exploit the Moon's resources in the name of the greater good. Alongside, even private actors are engaged in contributing to the development of a space industry. Since the Moon is expected to harbour a massive number of metals, Outer Space will probably become the latest arena for geopolitical competition and proxy wars. Certainly, nowadays such a possibility is still a utopia because it is evident that what is found in the space will remain there. However, these frontiers complete the framework of the rare earths' era that will become increasingly more important in the next decade.

On the whole, this master dissertation analyses the primary characteristics, peculiarities and dynamics of Rare Earth Elements, their connection with international stability and security as well as their relevance in the current and future geopolitical clashes. Conventional wisdom about the impossibility to cope with the common issues associated to Rare Earth Elements has been challenged; nowadays, there is a myriad of solutions in order to exploit in a sustainable and resilient way the potential of these resources. The future society and the next generations simply cannot exist without Rare Earth Elements that, if managed in the right way, represent unequivocally an added value to the development of a better future.