सत्यमेव जयते

Department of Science & Technology,
Government of India

Council on
Energy,
Environment
& Water

Critical Non-Fuel Mineral Resources for India's Manufacturing Sector

A Vision for 2030

VAIBHAV GUPTA, TIRTHA BISWAS, AND KARTHIK GANESAN

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CEEW Report
July 2016
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A report on 'Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030'.

Disclaimer: The views expressed in this report are those of the authors and do not necessarily reflect the views and policies of CEEW or NSTMIS Division (Department of Science and Technology).

The National Science and Technology Management Information System (NSTMIS), a division of Department of Science and Technology (DST) has been entrusted with the task of building the information base on a continuous basis on resources devoted to scientific and technological activities for policy planning in the country.

The Council on Energy, Environment and Water (CEEW) is one of South Asia's leading policy research institutions. CEEW addresses pressing global challenges through an integrated and internationally focused approach. Visit us at http://ceew.in/ and follow us on Twitter @CEEWIndia.

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Foreword

प्रो. आशुतोष शर्मा
Prof. Ashutosh Sharma

सचिव
भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय
विज्ञान और प्रौद्योगिकी विभाग
Secretary
Government of India
Ministry of Science and Technology
Department of Science and Technology

The global demand for minerals has increased steadily over the last 50 years and it is likely that demand will continue its upward trend in response to the pullulating global population, burgeoning prosperity and consumerism of BRIC economies as well as the exploding demand for modern rare-mineral intensive technologies. Mineral consumption has diversified through time in conjunction with technological advances; as the unique chemical properties of a growing number of elements of the periodic table have been utilised for innovative and efficient uses. Most people are not aware that modern cars, flat screen televisions, smartphones and a variety of day to day utility products rely on range of materials such as cobalt, lithium, antimony, molybdenum, copper, gallium etc., that have gained prominence in recent years. Securing the supply of these, to satisfy exponential demand for consumer products, civil engineering, transport and energy infrastructure among others in a sustainable fashion, has become a major challenge to many resource dependent countries.

This study, by the Council on Energy, Environment and Water (CEEW), presents a list of critical minerals and their impact on manufacturing sector and competitiveness, directly arising from supply constraints (including recycling potential, substitutability, etc.) associated with these minerals. The study also focuses on criticality associated with strategic minerals that were envisaged in earlier studies carried out by the planning bodies - for needs in key sectors such as defense and space technology.

I am proud that the National Science and Technology Management Information System (NSTMIS), a division of DST, entrusted with the task of building a continually improving knowledge base of scientific and technological activities and evolving trends, has supported this unique CEEW study. DST is committed to promoting new areas of scientific research and collaborating with various organisations to further R&D in emerging areas.

This study is timely in the wake of the recent National Mineral Exploration Policy 2016 and would assist policy-planners and decision making authorities to develop targeted strategies for securing India's needs of identified critical minerals – in pursuit of sustainable industrial growth. In addition, the analysis will further trigger discussions on innovative models for incentivising exploration and mineral resource development, bilateral supply agreements, and global governance reform that will impact mineral trade. In addition, I hope this study promotes R&D in important areas such as recovery of secondary minerals, recycling of minerals and finding useful substitutes in applications which use these critical minerals.

I compliment the CEEW research team for creating this first-of-its kind framework for evaluating mineral resources that are critical for India. I encourage other public and private research entities to take up such innovative projects that will aid India's rapid economic and social development.

(ASHUTOSH SHARMA)

Foreword

बलविन्दर कुमार, आईएएस
सचिव
BALVINDER KUMAR, IAS
Secretary

भारत सरकार
खान मंत्रालय
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Minerals are critical inputs to industry and will play a pivotal role in the success of the Make in India campaign. The demand for a diverse range of mineral resources in India is proliferating due to rising population, changing lifestyles, pursuit of new and sustainable technologies and environmental concerns. Today, with increase in demand, every mineral is susceptible to supply constraints. My Ministry stays committed to achieve optimal utilisation of India's mineral resources through scientific, sustainable and transparent mining practices, geo-scientific exploration and the associated research and development.

In recent years, the Ministry of Mines has introduced a series of progressive reforms including amendments to key policies, acceleration in mineral exploration activities, transparency in the auction process, capacity enhancement at select mining facilities, use of green technology to reduce carbon footprint, etc. Earlier this month, we announced the *National Mineral Exploration Policy, 2016 (NMEP)* for enhancing and prioritising exploration activities by incentivising the participation of private sector. This is the first time that atomic mineral prospecting and production has been opened to the private sector to accelerate new finds, acknowledging the importance of these minerals in numerous strategic and industrial applications.

To further augment the exploration of mineral reserves in an effective and competitive manner, we have decided to digitize and provide baseline geo-scientific data in the public domain. To achieve this, GSI is tasked to cover entire Overall Geological Potential (OGP) area for geochemical and geophysical surveys by 2018-19 and 2020-21 respectively. In the NMEP, we have also proposed to set up a not-for-profit autonomous body called the National Centre for Mineral Targeting (NCMT) to add value to the mineral exploration sector through collaborative research, training and information dissemination programs.

I compliment the research team at the Council on Energy, Environment and Water (CEEW), a leading think-tank, for providing a first-of-its kind framework to identify critical minerals required for boosting Indian manufacturing. Not only does the study inform policy planners on the determinants of supply risks and the economic importance of minerals but it also provides recommendations to usher in required institutional reforms. This study by CEEW could also provide direction to the newly created NCMT in creating a work plan and prioritising action on various minerals of importance to India.

I would recommend all policy makers, industry leaders, researchers, and investors in the mining and mineral sector to use this study as a strategic tool for identifying and anticipating the potential supply bottlenecks for minerals crucial to the manufacturing sector. As this study emphasises, our prime focus will remain on making India a resource secure as well as a resource efficient country.

Acknowledgements

At the outset, **Council on Energy Environment and Water** (CEEW) would like to thank the Department of Science and Technology for recognizing the need for this study – both for the economy and the research community. The study would not have been possible without the generous grant support they have provided under the CHORD (NSTMIS) programme.

We would like to acknowledge the constant feedback and critical inputs received during the entire course of this study from **the project advisory committee**. We deeply appreciate the time they have spent to share their knowledge, experience, and perspectives with the research team.

CEEW would also like to recognise the cooperation of several individuals, organisations and public departments in providing useful data and insights on research related aspects around mining, mineral processing, recycling/recovery of waste, research & developments, and manufacturing requirements.

The project advisory committee comprised the following distinguished experts -

a) **Mr. S Vijay Kumar (Chairperson of the advisory Committee)**
He is as a Distinguished Fellow at The Energy Research Institute (TERI). In addition he is a panel member of International Resource Panel at UNEP. During his 37 year career as a member of the Indian Administrative Services, he has served in the Ministry of Mines from as Additional Secretary and then Secretary (between 2008 and 2011). One of his notable achievements includes drafting and piloting the Mines and Minerals (Development and Regulation) Bill, 2011 and taking it through till Cabinet approval.

b) **Dr Parveen Arora (Scientist-G)**
He is advisor and Head of CHORD (NSTMIS) Division of the Department of Science and Technology (DST), New Delhi, Government of India. He played a crucial role in strengthening the innovation and S&T monitoring system in India and is closely associated with international bodies such as UNESCO, OECD and other member countries in developing guidelines and benchmarking for STI indicators.

c) **Dr Gautam Goswami**
He heads the TECHNOLOGY VISION 2035 programme of TIFAC, DST. Prior to this assignment, he worked closely with Dr A P J Abdul Kalam in implementing many projects of Technology Vision-2020 Projects in different parts of the country. Dr Goswami also heads the Climate Change programme of TIFAC.

d) **Mr R K Bansal**
He is currently an independent professional (~ 38 years of experience), advising diverse industry sectors including mining, mineral beneficiation, non-ferrous metallurgy, environmental management and general management in large mining and metallurgical operations. He

is a recipient of the Hindustan Zinc Gold Medal from the Indian Institute of Metals (IIM) for his contributions to sustainable development of mining and non-ferrous metallurgical industry. He also served as the CEO for the Sustainable Mining Initiative (SMI) and Additional Secretary General at the Federation of Indian Mineral Industries (FIMI) for more than 3 years.

e) **Dr L Pugazhenthy**
He is the Executive Director of the India Lead Zinc Development Association (ILZDA). He is a metallurgical engineer with over 40 years of experience in the nonferrous metals industry. He has served on various committees of the Government of India, especially in introducing appropriate environmental legislations and creating better awareness for organized collection and environment-friendly recycling of used lead-acid batteries (ULAB).

f) **Mr A K Bhandari**
He retired as the Deputy Director General, Geological Survey of India. He also worked as Director (Technical) for Technical Policy & Planning Committee, Ministry of Mines and Director for Center for Techno-Economic Mineral Policy Options (C-Tempo), a registered society under Ministry of Mines. He joined FIMI as advisor in February, 2013 and is the CEO of the Skill Council for Mining Sector (SCMS)

g) **Prof G S Roonwal**
Former Professor and Head of the Department of Geology, University of Delhi and Director, Centre of Geo-resources, University of Delhi (South Campus). He is at present (Honorary) Visiting Professor in the Inter-University Accelerator Centre, an autonomous institute of UGC-MHRD. He is a prominent geoscientist of international stature. He is a winner of the National Mineral Award of the Ministry of Mines, Government of India, and has received several awards and medals from professional societies.

h) **Dr M Mohanty**
He has been working in DST as Scientist with effect from Jan 1998. He has been associated with various scientific programs of DST related to Earth Sciences. Currently he is looking after the Programme Advisory Committee on Earth and Atmospheric Sciences as Member Secretary of the Committee for funding of Extramural research projects under Science and Engineering Research Board, a statutory body under DST, Government of India, New Delhi.

About CEEW

The Council on Energy, Environment and Water (http://ceew.in/) is one of South Asia's leading not-for-profit policy research institutions. CEEW addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high quality research, develops partnerships with public and private institutions, and engages with wider public.

In 2016, CEEW was ranked the best in South Asia in two categories three years running (Global Go To Think Tank Index); among the top 100 out of 6846 think-tanks in nine categories. This included CEEW being featured on a prestigious list of 'Best Managed Think Tanks' and 'Best Independent Think Tanks'. In 2016, CEEW was also ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings. In 2013 and 2014, CEEW was rated as India's top climate change think-tank as per the ICCG standardised rankings.

In nearly six years of operations, CEEW has engaged in more than 100 research projects, published well over 50 peer-reviewed books, policy reports and papers, advised governments around the world over 160 times, engaged with industry to encourage investments in clean technologies and improve efficiency in resource use, promoted bilateral and multilateral initiatives between governments on more than 40 occasions, helped state governments with water and irrigation reforms, and organised more than 125 seminars and conferences.

CEEW's major projects on energy policy include India's largest energy access survey (ACCESS); the first independent assessment of India's solar mission; the Clean Energy Access Network (CLEAN) of hundreds of decentralised clean energy firms; India's green industrial policy; the $125 million India-U.S. Joint Clean Energy R&D Centers; developing the strategy for and supporting activities related to the International Solar Alliance; modelling long-term energy scenarios; energy subsidies reform; decentralised energy in India; energy storage technologies; India's 2030 renewable energy roadmap; solar roadmap for Indian Railways; clean energy subsidies (for the Rio+20 Summit); and renewable energy jobs, finance and skills.

CEEW's major projects on climate, environment and resource security include advising and contributing to climate negotiations (COP-21) in Paris; assessing global climate risks; assessing India's adaptation gap; low-carbon rural development; environmental clearances; modelling HFC emissions; business case for phasing down HFCs; assessing India's critical mineral resources; geoengineering governance; climate finance; nuclear power and low-carbon pathways; electric rail transport; monitoring air quality; business case for energy efficiency and emissions reductions; India's first report on global governance, submitted to the National Security Adviser; foreign policy implications for resource security; India's power sector reforms; resource nexus, and strategic industries and technologies for India's National Security Advisory Board; Maharashtra-Guangdong partnership on sustainability; and building Sustainable Cities.

CEEW's major projects on water governance and security include the 584-page National Water Resources Framework Study for India's 12th Five Year Plan; irrigation reform for Bihar; Swachh Bharat; supporting India's National Water Mission; collective action for water security; mapping India's traditional water bodies; modelling water-energy nexus; circular economy of water; and multi-stakeholder initiatives for urban water management.

About the Authors

Vaibhav Gupta

Vaibhav Gupta is a Programme Lead at the Council on Energy, Environment and Water (CEEW), His research interests include – energy and resource efficiency, industrial ecology, and collaborative environment management. His current research focuses on greenhouse gas emission estimates of India's manufacturing sector. He is also carrying out a study that identifies the most critical non-fuel mineral resources for the manufacturing sector of India. Some of his previous research work addresses vulnerabilities in India's energy infrastructure, identifies strategic industries and technologies for manufacturing in India, and, state of environmental clearance procedures in India. Prior joining CEEW, he worked with a prominent mining company of India in the roles and responsibilities of engineering, environment management (ISO 14000), project planning and liasoning with government departments.

Vaibhav holds a master's degree in Environmental Science & Engineering from the 'center for mining environment' at Indian School of Mines (ISM), Dhanbad. He also holds a post graduate diploma in 'environmental law' from National Law School of India University (NLSIU), Bangalore. He is affiliated as a life member with the *Mining Engineers' Association of India* (MEAI).

Tirtha Biswas

Tirtha is a Research Analyst at the Council on Energy, Environment and Water (CEEW). His research interest lies in mineral resource security and sustainable developments. His current work is in identifying the critical minerals for sustainable economic growth and future development of Indian manufacturing industry.

He holds a dual degree in Masters in Mineral Resource Management and Bachelors in Mineral Engineering from Indian School of Mines, (IIT) Dhanbad. Before joining CEEW he was an exchange student in University of Porto, Portugal where he worked on several projects like reducing the environmental impact by treatment of acid-mine drainage from an abandoned tungsten mine. Also, he was a vacation research scholar at the University of Queensland, Brisbane where he assisted in development of an Online Risk Management module RISKGATE. RISKGATE is an on-line body of knowledge (BOK) that complements existing risk management processes to provide event-specific controls for people in the Australian coal mining industry who conduct and/or develop risk assessments, audits, incident investigations and management systems.

Karthik Ganesan

Karthik Ganesan is a Research Fellow at the Council on Energy, Environment and Water (CEEW), India. As a member of the team at CEEW his research focus includes the development of long-term energy scenarios for India (based on an in-house cost-optimisation model) and energy efficiency improvements in the industrial sector in India. Linked to his work in industrial efficiency is his role as the principal investigator in an effort to identify critical mineral resources required for India's manufacturing sector. In addition, he supports on-going work in the areas of energy access indicators for rural Indian households and carried out a first-of-a-kind evaluation of the impact of industrial policies on the RE sector in India.

Prior to his association with CEEW he has worked on an array of projects in collaboration with various international institutions, with a focus on low-carbon development and energy security. His published (and under review) works include Rethink India's Energy Strategy (Nature, Comment) the Co-location opportunities for renewable energy and agriculture in North-western India: Trade-offs and Synergies (American Geophysical Union), Valuation of health impact of air pollution from thermal power plants (ADB), Technical feasibility of metropolitan siting of nuclear power plants (NUS), Prospects for Carbon Capture and Storage in SE Asia (ADB). His role as a research assistant at a graduate level focused on the linkages between electricity consumption and sectoral economic growth using a time-series approach.

Karthik has a Master in Public Policy from the Lee Kuan Yew School of Public Policy at the National University of Singapore (NUS). His prior educational training resulted in an M.Tech in Infrastructure Engineering and a B.Tech in Civil Engineering from the Indian Institute of Technology, Madras in Chennai.

Executive Summary

In India, the growth of domestic manufacturing has not been able to match the rapid growth in the demand for consumer goods and technology-enabled products, neither in scale nor in terms of diversity. The Make in India program, which was launched by the current government, is well timed to provide the necessary impetus for domestic manufacturing. However, a thriving industrial base needs a steady supply of raw materials and must anticipate future demand. Existing policies and actions recognise India's dependence on the outside world for a sustained supply of oil and natural gas (and coal also in recent times) and there is a much better understanding of the country's long-term demands, and as a result efforts have been made to diversify the supply basket, acquire assets overseas and incentivise domestic exploration. However, the same level of understanding of the demand for non-fuel minerals is not prevalent. The notion of 'strategic minerals' or 'critical minerals' is relatively new to policy makers in India as compared to other major economies of the world. The current organisation of ministries and departments in India, and the delineation of their roles and responsibilities, limit the scope for cross-cutting analysis and policy-making. Ensuring mineral resource security for the manufacturing sector requires concerted efforts on multiple fronts, and at present no institution (barring the national security establishment, which looks at conventional security issues) exists, that possesses the necessary resources to address this challenge.

From a review of existing studies and literature, it evident that developed countries have made significant inroads in understanding mineral resource security and that it is matter of concern today for all nations aspiring to achieve sustained and environmentally sustainable economic growth. This study helps in identifying the mineral demand of India's manufacturing sector. ***The main aim is to assess the impact of critical minerals on the manufacturing sector directly arising from supply constraints (such as the impact of recycling potential and substitutability).*** The study provides the necessary evidence-based analysis for policy makers as they take steps to ensure a sustainable supply of minerals to meet the increasing consumption needs of the economy. ***The total number of non-fuel minerals considered in this study is 49.*** They were identified mainly on the basis of their economic contribution to the manufacturing sector. This list also includes *'strategic minerals'* as defined by the Planning Commission study (2011).

The framework adopted for this analysis is similar to those that have been used in pioneering studies (to analyse mineral resource criticality) in developed economies. It takes into consideration both ***economic importance*** and ***supply risks*** in evaluating criticality. Economic importance is an indirect measure of the quantum of use of a mineral in a particular (sub) sector, and factors in the contribution of this (sub) sector to the overall manufacturing GDP as well (Figure 1). ***Even if a mineral is used in small quantities, in a high-value-add manufacturing sector it can be more critical as compared to a mineral used in large quantities in a low-value-add manufacturing sector.*** The economic importance of the mineral is the overall ***score*** arising from the distribution of its usage across the manufacturing sectors of varying economic importance (as measured by value addition).

The evaluation of economic importance takes into account two factors: (**i**) **the overall economic structure** (**and that of the industrial sector within it**)**; and** (**ii**) **the consumption pattern of a mineral in each industrial sub-sector.** The overall supply risk pertaining to each mineral resource is determined on the basis of the following indicators: (i) **domestic endowment of the resource;** (ii) **geopolitical risk associated with trade in that resource;** (iii) **level of substitutability at the end-use application; and** (iv) **potential share of the recycled mineral in the primary manufacturing of products.**

What will be critical in the future?

The figure below illustrates the relative importance of 49 minerals that find use (currently as well as in the future) in the Indian manufacturing sector, for the year 2030. The risk matrix is partitioned into four zones, as shown in the figure below, and can be interpreted as follows:

a. **Zone I:** high economic importance and high supply risk (most critical)

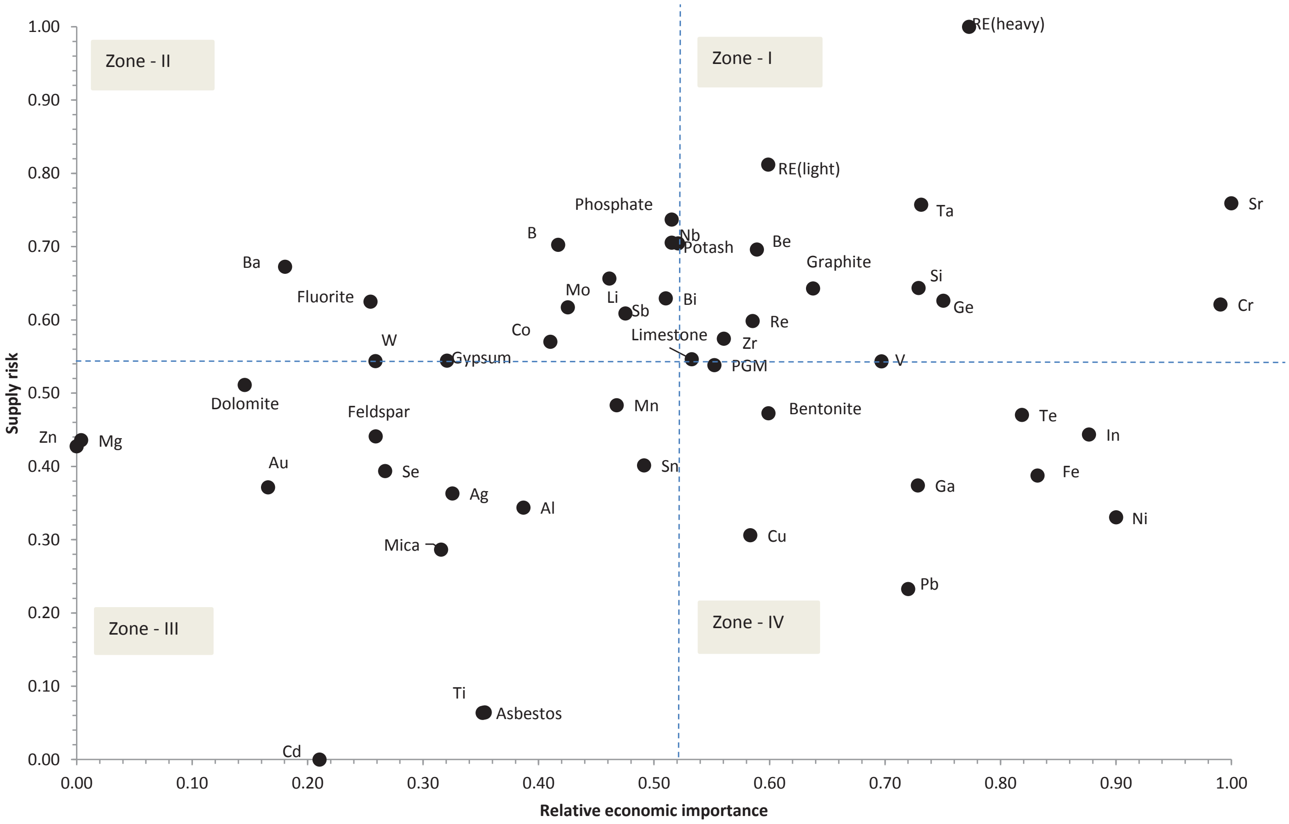
b. **Zone II:** low economic importance and high supply risk (moderately critical)

c. **Zone III:** low economic importance and low supply risk (least critical)

d. **Zone IV:** high economic importance and low supply risk (moderately critical)

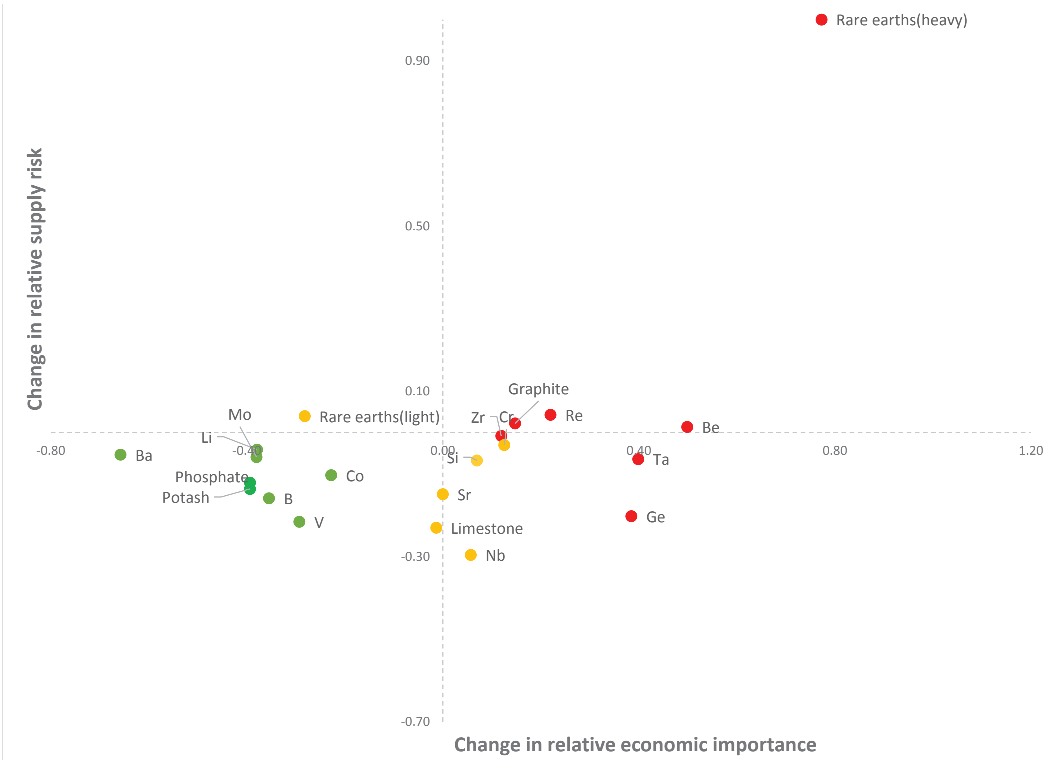
A 20 year time frame is chosen to provide a future perspective on critical mineral resources. The reason being that, any measurable impact of the current policies on the manufacturing and mineral sector (mining and processing) is visible only over such a period. The structure of the manufacturing sector, mining output, geopolitical will be visible only in the medium to short-term while technology has impact only in the medium to long term. This analysis focuses on the medium term – an intersection where the impact of multiple factors can be seen.

SNAPSHOT OF CRITICAL MINERALS FOR THE YEAR 2030



Source: CEEW analysis

TRANSITION OF MINERALS INTO THE CRITICAL ZONE FROM 2011 TILL 2030



Red: Minerals which will become critical in 2030; **yellow:** minerals which are critical both in reference year and future year; **green:** minerals which will are only critical in the reference year

Source: CEEW analysis

It can be seen from the figure above that over a period of 20 years, a change in the overall manufacturing structure has an impact on the level of criticality associated with various minerals. It is the transition in criticality, between the two periods, that is most significant. Nine new minerals have been added to the most critical zone by 2030. This transition can largely be attributed to their increased economic importance (movement along the X-axis), and, to a lesser extent, to the heightened overall supply risk. This is of more interest because risk (associated with supply) mitigation enters hitherto unchartered territory. From the policy maker's perspective, it is important to track the key drivers influencing such developments. The table below highlights the minerals that are likely to be critical to India's manufacturing sector in 2030 and the reasons why they take on more importance.

KEY DETERMINANTS OF THE TRANSITION OF MINERALS TO THE MOST-CRITICAL QUADRANT

S.No	Critical minerals – 2030	Key parameters to impact economic importance	Key parameters to impact Supply risk
1	Rhenium	Super-alloys in aerospace and machinery uses rhenium as a principal alloying element	India is currently 100% import dependent, with no declared resource/reserve so far, as it is mainly obtained as a by-product of copper/molybdenite ores.
2	Beryllium	Current use is exclusively in the paper sector (very low value add), in future finds its use in a diversified group of sectors	Complete import dependency with 99% of global supplies controlled by US and China only. For most of the applications, substitutes are difficult to find.
3	Rare earths (Heavy)	a) All the major green technologies depend on heavy rare earths imparting the special properties to them b) Extensive applications within the defense industry	India is 100% import dependent, with 94% of global supplies controlled by China. India bears mainly deposits for lighter rare-earth elements (in form of monazite).
4	Germanium	Decline in its consumption from steadily growing machine manufacturing, while gaining demand from high value sectors (electronics and metals)	India is likely to continue with 100% import dependency. It is a secondary mineral. recovered mainly as a by-product of Zinc (also from silver, lead and copper). Recyclability is low and alternative substitutes are a difficult find.
5	Graphite	Diversification of its use from electronics alone into other value add sectors as well	Majority of the resources of graphite are unexplored and those identified are of poor grade. Only 5% of declared resource have been translated into viable reserves. India can minimise future risk by carrying out survey and exploration activities to open new mines.
6	Tantalum	Decline in its consumption from steadily growing machine manufacturing, while gaining demand from high value sectors (electronics and metals)	No declared resource available in India, while 95% of global supplies are controlled by a single country Brazil. Substitutes are difficult to find, whereas recycling potential is also low.
7	Zirconium	Rising demand from the high value chemical manufacturing and electronics sector	75% of domestic resource is already identified as a viable reserve. Although R/P is very high (53 years), but lesser options for substitutes and difficulty in recycling makes it susceptible to high risk.

KEY DETERMINANTS OF THE TRANSITION OF MINERALS TO THE MOST-CRITICAL QUADRANT

S.No	Critical minerals – 2030	Key parameters to impact economic importance	Key parameters to impact Supply risk
8	Chromium	All were identified critical in the reference year (2011) as well.	Major application is in manufacturing of stainless steel for which nearly no substitutes are available at prevailing cost and efficiency. Potential environmental hazard, and has low R/P
9	Limestone		a) No substitute is available at present for its use in cement manufacturing. b) Recovery/recycling from cement is less likely, as construction work has a high lock-in period. c) Import dependency would rise from 0% to 20% if no accretion of reserves happens in coming 20 years.
10	Niobium		100% import dependency; No reserve/resource declared by ministry of mines
11	Rare earths (light)		India is 100% import dependent, Its reserves are associated with coastal beach sands of India, but its mining is not open for private sector till date
12	Silicon		Obtained from sand, which is abundantly available. However, processing of specific grade of sand into Silicon is highly energy intensive. Much of the silicon grade resource is yet to get translated into reserve category.
13	Strontium		India has not declared any resource for them and is 100% import dependent. 90% of global supplies are controlled by China and Spain. Hence, there are higher chances of supply side monopoly in global trade.

Source: CEEW compilation

Takeaways and Recommendations

The two-dimensional framework adopted to evaluate criticality, and the methodology used to arrive at measures of economic importance and supply risk, constitute a large portion of the value of this first of a kind exercise that CEEW has undertaken. It has the potential to be a strategic tool in the hands of Indian policy makers, industry leaders, researchers, and investors in the mining and mineral sector for identifying and anticipating the potential supply bottlenecks for minerals crucial to the manufacturing sector. Our recommendations, stemming from our experience in carrying out this study and based on the results emerging from the criticality framework employed, can be categorised under three broad heads as below:

i. Institutional reforms to aid better analysis and anticipation

ii. Domestic interventions: Enhanced exploration and R&D in mining and mineral processing) technologies

iii. International interventions: Strategic acquisition of mines and signing of diplomatic and trade agreements

a. Institutional reforms to aid better analysis and anticipation

Lack of coordination between various stakeholders and insufficient institutional capacity are the key barriers for advanced and integrated planning at the national level. The Geological Survey of India (GSI) and Indian Bureau of Mines (IBM) (both under the Ministry of Mines) can play a much more significant role in mineral planning. National Mineral Exploration Policy (NMEP) has been introduced at an opportune moment and gives specific directives for prioritisation of critical minerals in industry and strategic minerals for national security. However, better coordination between several departments and ministries (as shown in Figure 13 of the report) is necessary to carry out the analytics that will truly result in the optimisation of resource exploration planning. The NMEP also talks about setting up a not-for-profit autonomous body - the National Centre for Mineral Targeting (NCMT), to do this task. The institutional arrangements discussed later in this report and the nature of analysis carried out would be a useful starting point for such a think-tank within the Ministry of Mines.

b. Domestic interventions: Enhanced exploration and R&D in mining and mineral processing technologies

A clear understanding at the national level, of India's mineral resource base, is a prerequisite for any kind of strategic planning for resource security. Currently, less than 10% of India's total landmass has been geo-scientifically surveyed for an assessment of the underlying mineral wealth. This is a big deterrent for private exploration agencies to invest, as they require good baseline data to justify risky investments. Further, the recently amended MMDR Act, 2015 advocates for a transparent regime for the grant of mining leases, but it certain provisions such as the non-exclusive reconnaissance permit act as deterrents to private investment. The expectation of returns when risk capital is employed is also high and provisions of royalty to RP holder (from the subsequent miner) are not seen as lucrative.

As recognised by the NMEP (2016), a prioritisation of exploratory activities is essential to make best use of the limited amount of resources available with the government. The study proposes a useful decision-tree analysis, overlaid with indicators of criticality of specific mineral, which then provides a priority order for exploration efforts. This is not a definitive approach but also identifies interventions at other levels – trade, recycling or finding technical substitutes. The study also highlights minerals with low or no reserves in India, and the ones, which are available only as an associated, or by-product from other mineral processing. These include bismuth, cadmium, gallium, germanium, indium, molybdenum, rhenium, selenium and tin, and all require specific attention at the national level.

The R&D ecosystem in India is still at a nascent stage and framework prioritises a set of minerals for which research – by way of identifying substitutes is crucial in order to mitigate supply risks in the near future. ***However, it is clear that finding substitutes or being able to recycle better does not fully mitigate supply risks and new sources are necessary for all minerals identified as critical.***

c. International interventions: Strategic acquisition of mines and signing of diplomatic and trade agreements

India is dependent on imports for more than half of the minerals covered in this study. The reasons, as stated before, are (a) lack of clarity on resource availability; (b) lack of recovery of secondary/by-product minerals; (c) non-establishment of commercial and technical viability of resources (proven reserves); and (d) rapid depletion of existing (proven) reserves and the fact that they constitute a small share of estimated reserves.

Across the world, countries are developing strategies to secure raw materials required for various economic activities. Diplomatic ties between countries play a crucial role in international trade relations, specifically in the acquisition of overseas mining rights and their development, and can have a telling impact on long-term security of resource supply. Strategic diplomatic efforts help to mitigate risks on the supply side. The table below illustrates a list of go-to countries for mineral specific supply contracts.

DEVELOPMENT OF INTERNATIONAL TRADE AGREEMENTS FOR THE LONG TERM

Mineral	Category	Primary/ Secondary	Source Mineral (S)	Major supplier countries		
				Country -1	Country -2	Country -3
Germanium	No resources	secondary	Zinc, Copper, Lead	China (85%)	Finland (10%)	USA (3%)
Niobium		primary	--	Brazil (95%)	Canada (4%)	Rest of world (1%)
Rhenium		secondary	Copper	Chile (57%)	USA (19%)	Poland (11%)
Strontium		Primary	--	China (79%)	Spain (11%)	Mexico (5%)
Tantalum		primary	--	Brazil (95%)	Canada (4%)	Rest of world (1%)
Rare earths(heavy)		primary	--	China (94%)	Russia (5%)	Malaysia (1%)
Rare earths(light)	Resource: Yes Reserve: No	primary	--	China (94%)	Russia (5%)	Malaysia (1%)
Beryllium	Resource: Yes Reserve/Resource < 50%	Primary	--	USA (88%)	China (11%)	Mozambique (1%)

Source: CEEW compilation using IBM (IBM, 2014a) and World Mineral Statistics (BGS, World Mineral Statistics, 2016)[1]

Similarly, acquisition of overseas mining rights is also a diplomatic strategy adopted by many countries. Given India's nascent mining industry and limited expertise, the government may not be able to pursue this option aggressively. Instead, India can strategically develop joint partnerships with existing global players (private firms or governments) in these countries.

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[1] BGS: British Geological Survey

RECOMMENDED MINERALS FOR ACQUIRING OVERSEAS ASSETS

Mineral	Category	Name of major reserve/resource bearing Countries
Lithium	No resources	Chile; China, Argentina, Australia
Niobium		Brazil
Strontium		China
Tantalum		Brazil, Australia, Mozambique
Rare earths(heavy)		China, Brazil, Australia
Barium	Domestic reserve more than 50% of resource	China, Kazakhstan, Turkey, Thailand
Feldspar		Portugal, Poland, Czech Republic
Zirconium		China, South Africa, Mozambique

Source: CEEW compilation using (IBM, 2014a)

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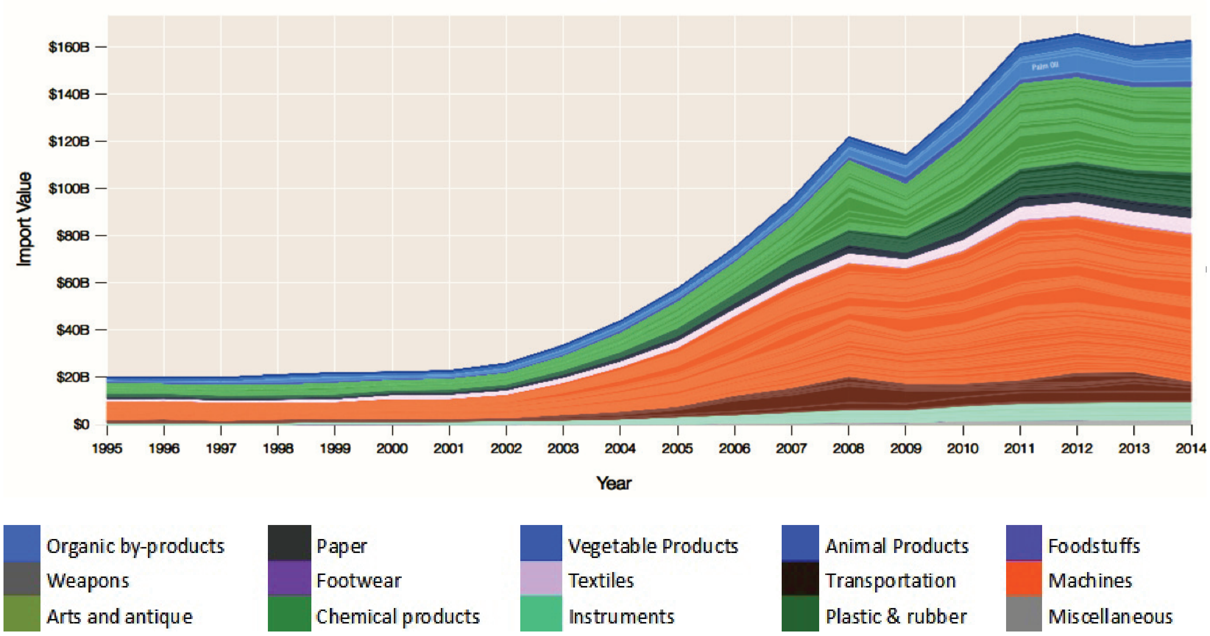
List of Abbreviations

ASI	Annual Survey of Industries
BERR	The Department for Business, Enterprise and Regulatory Reform
BMWi	Bundesministerium für Wirtschaft und Energie
BRGM	The Bureau de recherches géologiques et minières
CPCB	Central Pollution Control Board
CRM_Innonet	Critical Raw Materials Innovation Network
CSTEP	Center for Study of Science, Technology & Policy
CTEMPO	Centre for Techno Economic Policy Options
DIPP	Department of Industrial Policy and Promotion
ESTEP	The European Steel Technology Platform
FICCI	Federation of Indian Chambers of Commerce & Industry
FIMI	Federation of Indian Mineral Industries
GSI	Geological Survey of India
IBM	Indian Bureau of Mines
IDSA	Institute for Defence Studies and Analyses
MECL	Mineral Exploration Corporation Limited
MOCI	Ministry of Commerce and Industry
MOEFCC	Ministry of Environment, Forest and Climate Change
MOSPI	Ministry of Statistics and Programme Implementation
MRC	Montana Refining Company
NCMT	National Centre for Mineral Targetting
NMEP	National Mineral Exploration Policy
OECD	Organisation for Economic Co-operation and Development
SPCB	State Pollution Control Board
UNFC	United Nations Framework Classification
UNIDO	United Nations Industrial Development Organization
USGS	United States Geological Survey
WGI	Worldwide Governance Indicators

1. Introduction

In India, the growth of domestic manufacturing has not been able to match the rapid growth in the demand for consumer goods and technology-enabled products, neither in scale nor in terms of diversity. This is evident from the gradual increase in import dependency for a range of consumer goods in the last two decades (Figure 1). In particular, the sudden rise in the demand for electronics goods after 2004 has made a significant contribution to India's increasing trade deficit (although energy imports have contributed the most) (Mishra, 2016).

FIGURE 1: INDIA'S RISING CONSUMER GOODS IMPORTS



Source: *(Observatory of Economic Complexity, 2015)*

Figure 1 makes a strong case for the growth of the domestic manufacturing sector, which needs to shift its composition with the changing times, the evolving lifestyle of people, as well as technology transitions in other parts of the world. In particular, the mining sector in India has remained a poor performer, with its contribution to GDP declining to 2 per cent from 3.4 per cent in 1993 (FICCI, 2013).[2] A thriving industrial base needs a steady supply of raw materials and must anticipate future demand. The Industrial Revolution began with a handful of applications like textile manufacturing and iron making which primarily relied on minerals like iron, copper, and zinc. As noted earlier, population growth, changing lifestyle, technological progress, and market dynamics have diversified the use of mineral[3] resources in catering to our daily needs. Clear and focused policy reforms are required today for the manufacturing sector and to increase the stagnant contribution of the mining sector to GDP.

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[2] FICCI: Federation of Indian Chambers of Commerce & Industry.

[3] Unless specified otherwise, minerals in this study refers to non-fuel minerals/elements and metals

Contrary to the contention of the Club of Rome, that the world as a whole is running out of resources, Tim Worstall[4] argues, in his monograph (*The No Breakfast Fallacy: Why the Club of Rome was wrong about us running out of minerals and metals)* that world will not run out of mineral resources any time soon. He contends that in the long-run, substitutes, extensive recycling, and market forces (through price shifts) will unleash a supply that will last us for a much longer period. He is also of the view that most researchers and commentators do not understand the true extent of the reserves and resources of the various minerals that we consume. While this argument is true at the global level, constraints still exist in individual countries, such as their ability to pay for resources, their technology-readiness levels, and their ability to source minerals from producing countries. These limitations are also magnified in the short to medium term as little change can be brought about to extract supplies from hitherto unknown resources. One can argue that it is this fear of failing to meet the needs of tomorrow that drives the efforts of today to find newer sources.

The endowment of natural resources (minerals included) is disproportionate across geographic boundaries, and few countries possess the technical knowhow of extraction and processing of most minerals. This has resulted in a concentration of production of several minerals. Resource security plays a crucial role in economic development, as it is an important driver of a competitive manufacturing sector. Sudden supply shocks or constrictions in the supply chain make a mineral critical, especially if there are no substitutes available in specific applications. This impact is larger if these products contribute to significant value addition in the economy. Supply risks can be manifested at any of the four stages in the value chain of minerals: **extraction** (exploration and mining), **conversion** (processing of ore into usable form), **transfer** (infrastructure, trade, and geopolitical restrictions), and **consumption** (efficient use in the manufacturing of products). Thus, a country with limited supplies of such minerals and with ambitious plans for manufacturing has to think strategically about the overall availability of these minerals.

Keeping in mind India's current economic realities, and the need for a well-planned and smooth transition to an efficient, low-carbon economy, it is essential for national-level policy makers to factor in all the needs of a future-ready and sustainable manufacturing sector. The proliferating demand for minerals, in the rest of the world, has led to the shrinking of the already limited supply pool. This poses an even bigger challenge in securing minerals that are not available domestically. Moving forward, India needs to acknowledge the importance of minerals and ensure that coordination is brought in between all stakeholders in the value-addition chain of minerals.

This study offers policy makers a detailed analysis on the determinants of criticality associated with minerals and the economic importance of minerals. Such an understanding is imperative for taking definitive steps in planning for the manufacturing sector, advancing the mining industry, improving the terms of foreign trade, and spurring changes in science and technology research in India. This following sections of this chapter draw attention to the impending challenges in devising targeted policies, and the subsequent sections illustrate our framework for first identifying critical minerals and then makes specific recommendations for addressing this 'criticality'.

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[4] An expert on rare earth elements (REEs) and an Adam Smith Institute Fellow.

A. Mineral Resources, Unmapped and Untapped: Exploration is key for sustained supplies

India's mineral resource base is diverse and comprises nearly 85 minerals.[5] However, there is little clarity on how much of this mineral wealth is economically extractable. Much of the resource base is yet to be scientifically explored and classified as per internationally accepted standards as technically and economically feasible.

The Geological Survey of India (GSI), under the Ministry of Mines, is responsible for surveying minerals and for disseminating baseline information on the country's mineral wealth. A majority of India's total landmass (98 per cent) has already been covered by the GSI by way of baseline geological surveys (Ministry of Mines, 2011). However, the pace of reconnaissance surveys and prospecting activity for the generation of detailed data on India's mineral wealth is extremely slow. As of 2011, only 4 per cent of the country's total land mass had been evaluated through geochemical surveys, while 30–40 per cent of India's total landmass has been covered through geophysical surveys (Ministry of Mines, 2011).

The Ministry of Mines itself recognises that this compares poorly with other countries that are endowed with mineral resources. Australia serves as a good comparison. Although Australia's land area is roughly 2.3 times that of India, more than 90 per cent of its landmass has been put through geophysical and geochemical surveys (Ministry of Mines, 2011). Australia's thriving mining industry contributes a large share (8.5 per cent) to GDP, whereas India's mining industry is still lingering around the 2 per cent mark (Ministry of Mines, 2011). While this does not suggest that mining could contribute as high a share to India's GDP, it is certain that there is room to expand the contribution from the mining sector, especially given the geological composition of peninsular India (where a bulk of the obvious geological potential or OGP can be found).

Good-quality baseline data (surveys, spectral maps, etc.) are essential for attracting investments and for carrying out exploration that confirm the presence of mineral deposits. However, private sector investors have so far kept away due to unavailability of reliable baseline data or regressive legislation (the present non-exclusive reconnaissance permit regime) that provides little financial incentive. A recent move by the Ministry of Defence (in early June 2016) to remove restrictions on data dissemination is a welcome step, as it enables the Ministry of Mines (through GSI) to provide digitised data reports for the purposes of prospecting and detailed exploration (Singh, 2016). However, prioritisation of the exploration activities (as emphasised in National Mineral Exploration Policy, 2016) is crucial in order to optimise investments, given the high risk associated with these investments. Surprisingly, survey maps available with GSI are of much better resolution than what is available in Australia. However, this has not led to further prospecting and exploration to establish a firm resource base as per the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC).

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[5] Indian Bureau of Mines.

B. Limited institutional capacity and lack of strategic planning

The notion of 'strategic minerals' or 'critical minerals' is relatively new to policy makers in India as compared to other major economies of the world. The current organisation of ministries and departments in India, and the delineation of their roles and responsibilities, limit the scope for cross-cutting analysis and policy-making. Ensuring mineral resource security for the manufacturing sector requires concerted efforts on multiple fronts, and at present no institution (barring the national security establishment, which looks at conventional security issues) exists, which possesses the necessary resources to address this challenge.

The Indian Bureau of Mines (IBM), a subordinate agency under the Ministry of Mines, has the mandate to drive the optimum utilisation of mineral resources by establishing coordination between the centre, states, industry, academia, and other stakeholders. IBM is the *de jure* regulator for the mining sector and also the primary repository of all information pertaining to resources, reserves, utilisation, imports, ore processing, and use of processed metals in final end-use sectors. However, despite the availability of extensive data (and its own mandate), IBM (by way of its publications) provides little insight into changing consumption trends and future-looking scenarios that would aid in understanding the mineral requirement in India in the medium term.

GSI has been unable to deliver on its key mandate of mapping out extensive areas of the country with regard to the potential of mineral resources. This is largely a result of the lack of financial resources and the absence of a trained workforce with the requisite technical expertise. Similarly, IBM lacks the enhanced analytical capacity and ability to drive inter-ministerial coordination to deliver efficiently on its strategic functions (Indian Bureau of Mines, 2016).

That mineral exploration is a high-risk- high-return venture is an established fact. So far, the legislations that govern exploration have failed to encourage private sector investments in this area (despite allowing for 100% foreign direct investments[6] in the sector). Moreover, the risk taking capacity of GSI and other public sector undertakings like MECL is severely limited because of immense scrutiny of their investment decisions and the returns associated with these investments (which, in this case, are not guaranteed and may not represent the best value for public resources).

Sluggish development of the mining sector has prevented investments in the associated value chains in the mineral and manufacturing processes that are mineral intensive. Currently, for large industrial consumers, it is easier to source their mineral needs from the global market, but with increasing consumption and intensifying competition for global resources, the resource-security angle must be given attention. The National Mineral Policy (2008) does talk about the co-benefits of a symbiotic relationship between mining/mineral development and the growth of downstream industries (Ministry of Mines, 2008). However, no such linkage exists between the mining/mineral sector and the mainstream manufacturing industries in terms of information flow.

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[6] With certain exceptions.

Given these realities, India's view of resource security has been myopic at best (and absent in many instances), especially when it comes to mineral resource acquisition and the development of long-term trade ties for sourcing supplies from countries that hold reserves in significant quantities. So far, the Indian manufacturing sector has not been faced with a situation where it cannot source a mineral from the global marketplace (albeit at high prices). As a result, 'buy whenever you need' has been the operating mantra. However, such a strategy is likely to be suboptimal and risky (with the possibility of not being able to source even at a high price) in a resource-constrained situation, as has been the case in the past when India has faced restricted supplies of specific minerals (Chander, 2015) .

C. Insufficient research and development contribution to the sector

India's gross expenditure on research and development (R&D) activities has been low (~ 1 per cent of overall GDP) as compared to the developed economies (Gupta, Ganesan, & Ghosh, 2016) Limited funding impacts domestic research programmes in specific sectors (including the mining and mineral processing industry). It is argued that the demand for these minerals (or metals) is small within the country, and as a result there is no driver for research. However, this is clearly not a chicken and egg situation, and instead is simply a manifestation of the lack of strategic thinking and not understanding the lag between the research phase and the commercialisation phase for these minerals.

The absence of suitable technologies (indigenous development or technology licensing regimes) in the country is evident from the case of titanium. India planned to begin the production of space-grade titanium alloys at Chavara (in Kerala), but the domestic mining and mineral processing industry has not come up with the necessary technology and process flow sheets to convert raw ores (rutile and ilmenite) into the usable form (titanium sponge) in a cost-effective manner. Despite possessing the third largest reserves of titanium in the world, India's dependence on imports to satisfy the needs of a thriving space industry continues.

"Rising cost of production, declining quality of ore, and delays in administrative clearances led to stagnation of mine productivity of non-fuel minerals in 2009–10 (IBM, 2014b). Coupled with the situation in the mineral processing sector, this has resulted in a loss in economic value add (exporting raw ores and importing processed metals) and an increasing trade deficit of non-fuel minerals since 2004–05 (at an alarming annual rate of 15.2 per cent)."

2. Motivation and Scope

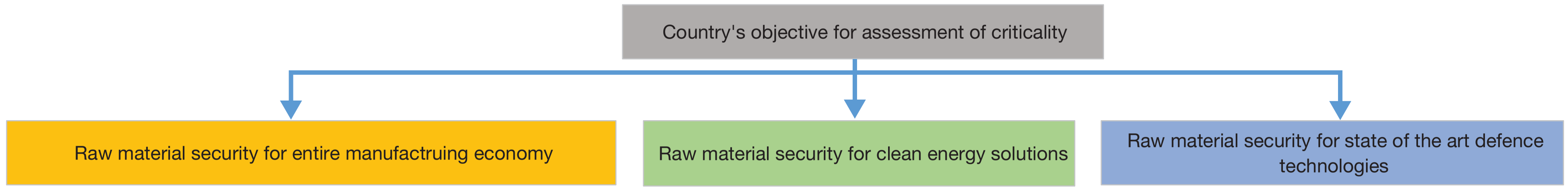
2.1 Motivation

The basket of minerals deemed "critical" changes constantly over time. In the last few decades, advancements in technology have made it possible to use more elements in the periodic table. Many metals that were earlier just the focus of research (and prototypes) are now essential for modern applications, especially in the field of clean energy and state-of-the-art defence technologies. Interestingly, many of these new metals are rare in their occurrence and often mined in a few select countries, and this renders them susceptible to supply risks. Many countries have begun to overhaul their mineral strategies to factor in the changing demand and supply scenarios as well as shifting geopolitical realities. China has recently acquired Congo's largest cobalt mine (Sanderson, 2016a), stockpiled USD 2 billion worth of copper (Sanderson, 2016b), and their gold miners are continuously scouting for overseas resources (Mukherji, 2016), while Japan is making efforts to secure rare earth elements (REE) requirements (Reuters, 2014). These actions, while short term or fleeting in nature, point to the rising tendency to engage in resource-nationalism and the resulting fallouts.

More substantially, concerned about the important role that many of these minerals are expected to play in the years ahead, a few developed economies have published strategy papers and reports on the importance of minerals and their role in national security. Whatever be the driver for these studies on improving raw material security—a focus on the manufacturing sector, strategic defence needs, battling climate change with low-carbon clean energy solutions, or other social drivers—the underlying factors that determine mineral criticality remain the same—economic importance and the risk of supply restrictions (Figure 2).

Many studies have evaluated mineral criticality in the developed world with the objective of understanding the needs and raw material security of the manufacturing sector. The European Commission Enterprise and Industry (now referred to as the European Commission's Internal Market, Industry, Entrepreneurship and SMEs) carries out a study to identify critical raw materials for the European Union (EU) on a quadrennial basis. The first study (European Commission Enterprise and Industry, 2010), conducted in 2010, analysed a group of 41 minerals used throughout Europe. The method of analysis of criticality was based on a two-dimensional framework of relative economic importance and relative supply risk scores. Minerals scoring high on relative economic importance and relative supply risk are categorised as critical. The follow-up study (European Commission Enterpise and Industry, 2014), released in 2014, using the same framework, analysed a wider range of minerals (54 minerals). In addition, some minerals like REEs were split into lighter and heavier groups in order to highlight their different criticality scores, thereby underscoring the subtle differences even within seemingly homogeneous groups (to the lay reader) of minerals.

FIGURE 2: A SUMMARY OF THE EXISTING LITERATURE ON MINERAL CRITICALITY



Relevant Studies

Agency	*Time horizon*	*Methodology*	*Future estimates*
European Commission (2010)	Base year	Quantitative	No
European Commission (2014)	<10 years	Quantitative	Demand forecast
OECD, 2030-2015	>15 years	Quantitative	Macro-Economic Model
Oakdene Hollins, UK (2008)	Long term (unspecified)	Quantitative; score based ranking matrix	Demand forecast
Fraunhoufer Institute - Germany (2009)	2006-2030 (25 years)	Quantitative (based on market research statistics)	Demand forecast
National Research Council (2007) - USA	Base year	Quantitative; score based matrix	No
Planning Commission - INDIA, 2011	< 5 years	Quantitative approach to estimate demand	Demand forecast
FIMI, 2014	Unspecified	Policy analysis on exploration & secure supplies	No

Relevant Studies

Agency	*Time horizon*	*Methodology*	*Future estimates*
JRC, European Commission (2011)	<10 years	Quantitative	Demand forecast
Department of Energy (2010, 2011) - USA	0-15 years	Quantitative & Qualitative	Identified critical minerals
CSTEP- INDIA, 2012	2010-2030 (20 years)	Quantitative & Qualitative	Demand estimates

Relevant Studies

Agency	*Time horizon*	*Methodology*	*Future estimates*
Department of Defense- USA (2013)	<05 years	Quantitative & Qualitative	Demand forecast & stockpile position
IDSA- INDIA, 2014	Unspecified	Qualitative & Quantitative (Score based matrix)	No

Source: *CEEW compilation*

In 2014, the Environment Directorate of the Organisation for Economic Co-operation and Development (OECD) carried out a similar study (Environment Policy Committee, 2015), but with a focus on OECD countries. The report adopts the same framework as used by the European Commission to analyse a set 51 minerals. However, it used a dynamic macroeconomic model, ***ENV-Linkages***, to estimate the economic growth (and typology) in various scenarios and the corresponding mineral demand.

Both government departments and independent institutions in the United Kingdom and Germany have carried out studies on the impact of raw material security on their respective economies. A study titled ***Material Security: Ensuring Resource Availability for the UK Economy***" by the Department for Business, Enterprise & Regulatory Reform, published in 2008, analyses 69 minerals (excluding fuel minerals) (BERR, 2008). The study uses a framework to identify minerals that are *"insecure"* or important from the raw material security perspective. The framework has two dimensions highlighting material risk and supply risk respectively. The minerals are ranked along the two dimensions ranging from one to three, with one indicating the "low" and three signifying the "high" criterion severity. The factors considered for scoring material risk are global consumption levels, lack of substitutability, global warming potential and total material requirements. The factors considered for scoring supply risk are scarcity, monopoly supply, political instability, and vulnerability to the effects of climate change in the supplier region.

Another study conducted by the French Geological Survey evaluated the impact of emerging technologies on raw material resource security (BRGM, 2008). Thirty-two emerging technologies were selected based on the anticipation that they would see industrial-scale adoption by 2030. Subsequently, the annual mineral demand emerging from these technologies was estimated. The demand in 2030, expressed as a multiple (or fraction) of today's total global production, is the key metric of risk here. A high value of the indicator suggests the need for expansion of global production or for developing substitutes in specific applications.

The United States has also embraced the notion of criticality of raw material resources. It has a large mineral resource base and is a leading producer of important minerals such as gold, silver, copper, and lead. However, its exploration budget share, which stood 20 per cent (of the worldwide exploration budget) in 1990, declined to a mere 8 per cent in 2010 (U.S. House of Representatives, 2014). The lack of exploration over this period has resulted in stagnant domestic production and dwindling of domestic reserves. This had led import dependency to rise from 30 non-fuel minerals to almost 67 minerals while also seeing a significant jump in the quantum of imports. This chain of events was the driver for the U.S. National Research Council (2008) to review mineral criticality with the objective of understanding raw material security for the manufacturing sector. The study (U.S. National Research Council, 2008) investigated the importance of non-fuel minerals in the modern US economy. It also highlighted the extent to which the availability of these minerals would be impacted in the short to long term and identified the types of data and research studies needed to aid policy makers to mitigate supply restrictions. This study analysed 11 minerals in view of their end-to-end use (a life cycle approach) by considering availability of resources from virgin, secondary, and tertiary (embedded-mineral) sources to assess criticality. The vertical axis of the framework highlights the "importance in use", which takes into account the specific applications of the minerals in important industry sectors also, accounting for the degree of substitutability within them. The horizontal axis represents the extent of availability and reliability of mineral supplies.

Across the globe, many countries are shifting their focus towards greener and cleaner energy solutions. These solutions, however, require technologies that use a diverse set of minerals, and concerns about the supply of these minerals also drive countries to conduct criticality assessments of the raw materials (minerals). In a bid to counter climate change, the EU has created a Strategic Energy Technology Plan (SET-Plan) to infuse new life into R&D in low-carbon technologies required to meet the ambitious reduction targets for greenhouse gases (GHG). The Joint Research Centre (JRC) (European Commission) and the Institute for Energy and Transport carried out a study (Moss, Tzimas, Kara, Wills, & Kooroshy, 2011) to examine the risks associated with reliance on these minerals in six low-carbon energy technologies of the SET-Plan (nuclear, solar, wind, bioenergy, carbon capture and storage [CCS], and electricity grids). The study provides a quantitative estimate of the average annual demand for 60 minerals used in deploying these technologies between 2020 and 2030 and then compares this demand with the corresponding total global production of the minerals in 2010. The ratio determines the "relative stress" on the global supplies of the minerals owing to the deployment of the technologies in Europe. Those metals demanding 1 per cent or more of the current global supply (each year) between 2020 and 2030 are termed as significant metals in the SET-Plan.

A study titled ***"Critical materials strategy"*** by the U.S. Department of Energy (DOE) (U.S. Department of Energy, 2010), with a similar focus on clean energy technologies, examined the role of REEs and other materials. It analysed seven clean energy technologies (wind turbines, electric vehicles, photovoltaic cells, fluorescent lighting, grid storage batteries, magnetic refrigeration and nuclear power etc.) and the criticality associated with their material requirements. The criticality assessment framework is driven by the priority setting among the different types of clean energy, which then translates into the importance of the minerals used by them and the supply risks associated with them in both the short and long terms. An update to this study (U.S. Department of Energy, 2011) highlighted that a few of the REEs were critical in the short term, while cobalt, gallium, nickel, and manganese were not considered critical, at least in the short term.

Studies on mineral criticality also have been carried out with the objective of understanding mineral inputs for modern defence equipment. The US Department of Defense studied 76 minerals and evaluated whether they would have shortfalls, and whether inefficient and non-reliable production would fail to meet the country's demand in the case of the "2013 Base conflict scenario" (U.S. Department of Defense, 2013). The scenario assumes one year of conflict and three years of recovery or regeneration. The outcomes are the result of a modelling exercise that evaluates the mineral demand from all sectors of the economy, and subsequently comparing the material supply with the demand while keeping in mind a number of conflict-related factors (unavailability of supply, war damage, shipping losses, infrastructure degradation/damage, foreign competition, etc.).

Although the focus areas of these studies were diverse, their outcomes provided sufficient evidence for the respective countries to develop policies to promote exploration and to ensure mineral security. For instance, the U.S. Senate passed the Critical Minerals Policy Act of 2013 (within the purview of the U.S. mineral policy) to promote the adequate, stable, and reliable supply of raw materials for sustainable industrial productivity, while keeping national security as the focus of such a strategy (113th Congress, 2013). The member states of the EU have come up with policy interventions for securing long-term supplies while emphasising the need for maintaining resource efficiency in industrial production. The French strategic materials plan (2010) identifies areas that are susceptible to raw material supply risks (Defra, 2012a).[7] The German government's raw materials strategy targets policy interventions for safeguarding sustainable raw materials supplies for German industry while promoting competitiveness and resource efficiency supported by research and innovation (BMWi, 2010).[8] Finland's minerals strategy outlines policy recommendations for the government to exploit known and potential mineral resources while ensuring global competitiveness and self-sufficiency in terms of material resources for Finnish industry (Geological Survey of Finland, 2013). The Dutch policy on raw materials highlights three key goals—ensuring security of raw material supply, reducing national demand for raw materials, and improving the efficiency and sustainability of raw material consumption in the economy (Dutch Ministry of Foreign Affairs, 2013). The UK study "Resource Security Action Plan: Making the most of valuable materials"[9] provides a *'business action framework'* that addresses resource risks and a plan of action for the government to act upon, based on the existing industrial partnerships (Defra, 2012b). Sweden's minerals strategy details the approach needed to increase competitiveness of the Swedish mining industry, and to maintain the country's position as the leading mining nation in the EU (Swedish Ministry of Enterprise, Energy and Communications, 2013).

2.1.1 What are the developments in India?

It is evident from the efforts made by developed countries so far that resource security is a matter of concern today for all nations aspiring to achieve sustained and environmentally sustainable economic growth. A brief review of all the exploration and mining-related policies and acts adopted by the Government of India indicates that no significant efforts were made towards safeguarding sustainable mineral supplies (Figure 3) for the country. However, some studies highlight the efforts needed in specific application areas, but not the demands of the entire economy. An early initiative in this direction came from the Planning Commission of India (now NITI Aayog), when it constituted a working group to focus on 'mineral exploration and development' as well as 'metals and minerals – strategy based upon the demand and supply for [the] mineral sector', as inputs to the 12th Five Year Plan.[10] The working group report presented the status quo of mineral exploration activities, supply strategies, infrastructure and financing, and R&D issues in the mineral sector (Planning Commission, 2011). The recommendations indicate the need for expedited exploration, overseas mineral acquisition, resource efficiency, recycling of minerals, and finding substitutes through suitable R&D. The report made mineral-specific recommendations as well. It also noted the great need for an understanding of the economics associated with a mineral, in terms of its end-use consumption and the quantification of supply risks associated with individual minerals. All these are vital for policymakers to set national priorities to target action more effectively.

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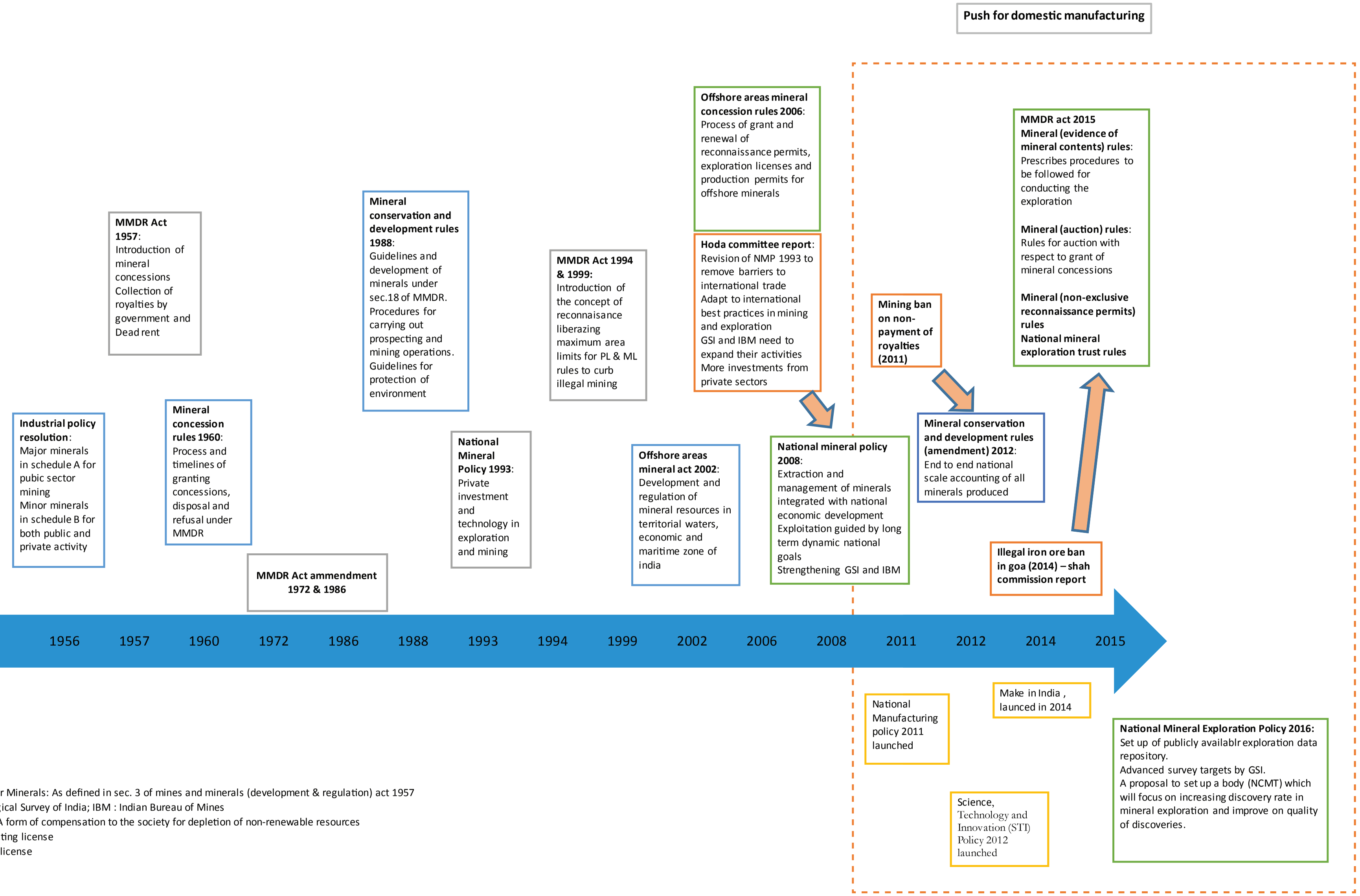
[7] Defra: Department for Environment Food and Rural Affairs.

[8] BMWi: Federal Ministry of Economics and Technology.

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69511/pb13719-resource-security-action-plan.pdf

[10] WG – Working Group (includes both sub groups I and II).

FIGURE 3: THE TIMELINE OF MINERAL EXPLORATION AND MINING POLICIES AND LEGISLATIONS IN INDIA



Industrial policy resolution: Major minerals in schedule A for pubic sector mining
Minor minerals in schedule B for both public and private activity

MMDR Act 1957: Introduction of mineral concessions
Collection of royalties by government and Dead rent

Mineral concession rules 1960: Process and timelines of granting concessions, disposal and refusal under MMDR

MMDR Act ammendment 1972 & 1986

Mineral conservation and development rules 1988: Guidelines and development of minerals under sec.18 of MMDR.
Procedures for carrying out prospecting and mining operations.
Guidelines for protection of environment

National Mineral Policy 1993: Private investment and technology in exploration and mining

MMDR Act 1994 & 1999: Introduction of the concept of reconnaisance
liberazing maximum area limits for PL & ML
rules to curb illegal mining

Offshore areas mineral act 2002: Development and regulation of mineral resources in territorial waters, economic and maritime zone of india

Offshore areas mineral concession rules 2006: Process of grant and renewal of reconnaissance permits, exploration licenses and production permits for offshore minerals

Hoda committee report: Revision of NMP 1993 to remove barriers to international trade
Adapt to international best practices in mining and exploration
GSI and IBM need to expand their activities
More investments from private sectors

National mineral policy 2008: Extraction and management of minerals integrated with national economic development
Exploitation guided by long term dynamic national goals
Strengthening GSI and IBM

Mining ban on non-payment of royalties (2011)

Mineral conservation and development rules (amendment) 2012: End to end national scale accounting of all minerals produced

Illegal iron ore ban in goa (2014) – shah commission report

MMDR act 2015
Mineral (evidence of mineral contents) rules: Prescribes procedures to be followed for conducting the exploration

Mineral (auction) rules: Rules for auction with respect to grant of mineral concessions

Mineral (non-exclusive reconnaissance permits) rules
National mineral exploration trust rules

National Manufacturing policy 2011 launched

Science, Technology and Innovation (STI) Policy 2012 launched

Make in India , launced in 2014

National Mineral Exploration Policy 2016: Set up of publicly availablr exploration data repository.
Advanced survey targets by GSI.
A proposal to set up a body (NCMT) which will focus on increasing discovery rate in mineral exploration and improve on quality of discoveries.

Major/Minor Minerals: As defined in sec. 3 of mines and minerals (development & regulation) act 1957
GSI : Geological Survey of India; IBM : Indian Bureau of Mines
Royalties : A form of compensation to the society for depletion of non-renewable resources
PL : Prospecting license
ML: Mining license

Source: CEEW compilation

In another effort, the Ministry of Mines constituted a steering committee in 2011 to review the status of the availability of REEs and energy-critical elements, and to investigate the development or adoption of exploration, extraction, and mineral processing technology for a predetermined list of critical (deemed-to-be-critical) minerals. The findings from the steering committee report highlighted the resource base and the potential demand of the minerals by 2030, in the domain of upcoming clean technologies such as solar, wind, electric vehicles, and energy-efficient lighting (CTempo and CSTEP, 2012). Since many of these minerals would be new inputs used in Indian industry, this report also highlighted the issues faced by domestic institutions and agencies in carrying out active R&D. It also identified technical constraints in India in processing (at scale) most of these minerals, as they are not found in their primary forms and have to be extracted as secondary minerals (as byproducts) during the extraction of the host mineral. Recycling and substitution by alternative materials was also recognised as an opportunity for Indian institutions to look at actively. This report highlighted some crucial action points for the government, extending across the value chain of minerals (mining to end-of-life cycle use). However, the study did not address the issue of prioritising actions, given the technological and budgetary constraints.

To understand the strategic requirement of minerals in India's defence sector, the Institute for Defence Studies and Analyses (IDSA) assessed (Lele and Bhardwaj, 2014) the risk factors associated with mineral availability by using two different approaches. First, a market assessment was carried out using Porter's five forces model; and second, a risk factor assessment was conducted based on a psychometric assessment using the Likert Scale. The indicators analysed in determining the risk factors were mineral availability risk, import dependency on a particular country, imports, and probable future demand. The final score was determined by calculating a simple average of the individual scores of the indicators. The study's conclusion pointed to the current and future risks faced by the Indian defence industry, while highlighting the fact that minerals like cobalt, germanium, molybdenum, and tungsten are in the high-risk zone.

A significant aspect that is conspicuous by its absence, in the existing studies on India, is a quantitative assessment of their relative importance in the overall economy. The studies carried out by major global economies emphasize the important issue that the "criticality" of resources depends on a country's economic structure and resource endowments. The outcomes of these studies are different depending on their examination of a country's resource endowments, its manufacturing structure, and the technologies in place (which affects the ability to substitute and recycle). As highlighted earlier, India is likely to be one of the fastest growing economies in the next two decades and is projected to be the third largest by 2030 (PTI, 2014). The manufacturing sector is slated to increase its contribution to GDP. This change in structure would then change the basket of raw materials that are consumed. There is a pressing need for a study that highlights the importance of minerals (through the lens of criticality) as raw materials in a changing domestic manufacturing environment in India.

This study seeks to fill this knowledge gap in India about what constitutes a critical mineral resource, while taking into account the expected changes in the economic structure of the country. While there are studies that highlight the lacunae in national policies on the mining and the minerals sector, such as those by industry associations like the Federation of Indian Mineral Industries (FIMI), there is no clear analytical basis for identifying specific minerals against which action must be taken. This study aims to identify a set of such minerals and to assess their relative importance in the economy by 2030.

2.2 Scope

This study helps in identifying the mineral demand of India's manufacturing sector. The main aim is to assess the impact of critical minerals on the manufacturing sector directly arising from supply constraints (such as the impact of recycling potential and substitutability). The study provides the necessary evidence-based analysis for policy makers to consider as they take steps to ensure a sustainable supply of minerals to meet the increasing consumption needs of the economy.

TABLE 1 : MEGA SECTORS

Megasector	% Share
Metals	18%
Chemicals and chemical products	13%
Food & Beverages	10%
Textiles and Apparels	9%
Refining	9%
Transport Equipment	8%
Electronics and Optical products	5%
Other non metallic Minerals (including glass)	5%
Manufacturing NEC, Recycling	5%
Machinery	4%
Rubber , Plastic	4%
Leather	4%
Tobacco	2%
Publishing & Printing	1%
Wood	1%
Paper	1%

Source : CEEW

The total number of non-fuel minerals considered in this study is 49.[11] They were identified mainly on the basis of their economic contribution (in INR terms) to the manufacturing sector. This list also includes *'strategic minerals'* as defined by the Planning Commission study (2011). As discussed in the previous section, these strategic minerals are largely those for which India is extensively reliant on imports.

All manufacturing operations in India are classified according to the National Industrial Classification (NIC) codes adopted by the Ministry of Statistics and Programme Implementation (MOSPI). The classification codes range from the aggregated two-digit level to a granular five-digit level, comprehensively covering all aspects of the domestic manufacturing industry. On the basis of this classification, the entire manufacturing sector has been grouped into 17 'mega sectors' (refer annexure 2)[12] for uniformity and simplicity, while maintaining the extensive coverage of the manufacturing sector. The list has been further reduced to 16 (refer Table 1 : Mega Sectors) by excluding the mega sector whose value addition share (in the manufacturing sector) is low.

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[11] Refer to annexure 1.

[12] Mega-sectors refer to the group of manufacturing sectors considered for this study unless stated otherwise.

3. Methodology

As has been indicated in the previous section, various studies in developed countries have focused on mineral use in specific sectors, and across the economy. While the particular methodology for the evaluation of criticality is different across the studies, the underlying rationale remains the same. This principle stresses that criticality is determined on the basis of considerations of risks and the extent of impacts associated with these risks. For example, the study by the U.S. Department of Energy evaluates criticality based on supply risks and the *'importance of usage'* (impact) associated with these risks. Similarly, an EU study evaluates criticality based on a mineral's *'economic importance'* (impact) and the associated supply risks. The EU study (European Commission Enterprise and Industry, 2014) added the third dimension of environmental risks associated with the processing of these minerals.

The framework adopted for this analysis is similar to the EU study. It takes into consideration both economic importance and supply risks in evaluating criticality. It is a pragmatic approach, as the dimension of economic importance is an indirect measure of the quantum of use of a mineral in a particular (sub)sector, and factors in the contribution of this (sub)sector to GDP (Figure 4). The rationale for this is that a mineral, although used in small quantities, in a high-value-add manufacturing sector can be more critical when compared to a mineral used in large quantities in a low-value-add manufacturing sector. The economic importance of the mineral is the overall ***score*** arising from the distribution of its usage across the manufacturing sectors of varying economic value additions.

The manufacturing sector today requires a wide variety of minerals as raw materials. Some of them have domestic reserves while others need to be imported. The minerals for which India has domestic reserves may also face supply bottlenecks owing to low exploration rates, reserves of uneconomical or low-grade minerals, and lack of appropriate technology for mining and processing them. In addition, the minerals that are imported today or those that may need to be imported in the future are subject to global supply risks. Minerals whose production is concentrated in a restricted number of countries are subject to higher risks of supply restriction and price volatility. These risks are even higher if the minerals are located in politically unstable regions.

The dimension of supply risk goes beyond the mere concentration of production and takes into account other factors like substitutability and recyclability. If a mineral has functional substitutes that are more easily (either locally or otherwise) available, it can lower its risks. This is contingent on the extent to which the physical and chemical properties of the substitute match those of the main mineral. The presence of recycling facilities can also reduce dependence on primary supplies, and this is critical for minerals having very low production rates. Consequently, supply risk is a combination of existing indices that capture these dimensions.

FIGURE 4: A TWO DIMENSIONAL FRAMEWORK TO ASSESS CRITICAL MINERAL RESOURCES

Framework							
Dimensions		(1) Economic Importance		(2) Supply risk			
Factors		Industrial structure	Consumption pattern	National Resource Endowment	Geopolitical Risk	Substitution risk	Recyclability risk
Indicators		Sectoral value add as a percentage of national GDP	Percentage share of total industrial consumption going in the sector	Import Dependency	World Governance scores	Substitutability	Recycling potential
Data Sources	Base Year (2011)	IIP data - MOSPI	Annual Survey of Industries- MOSPI	IBM Data & Ministry of Commerce	World Bank	Literature reviews	Literature reviews
	Future (2030)	Macro-economic analysis (adapted)	CEEW analysis	CEEW analysis	Unchanged	Unchanged	Unchanged

Source: CEEW compilation

3.1 Method of processing and analysis

The analysis of criticality has two distinct parts. The first part presents a static view of criticality for 49 non-fuel minerals across 16 manufacturing sector groups (also called mega sectors). This is an *ex post facto* analysis for 2011. The second part incorporates considerations that are more dynamic, such as changes to the supply conditions of a mineral over time and structural changes in the manufacturing industry by 2030. This has resulted in small variations in the methodology and in the framework to evaluate indicators that determine supply risk and economic importance for each part of the study.

3.1.1 Dimension 1: Economic Importance

The evaluation of economic importance takes into account two factors: (**i**) **the overall economic structure** (**and that of the industrial sector within it**)**; and** (**ii**) **the consumption pattern of a mineral in each industrial sub-sector.**

(i) **Economic structure**

The structure of the industry has a direct effect on criticality. To factor in the structural composition of the industrial sector, the value add (as a percentage of GDP) associated with each sub-sector of the industry needs to be considered (refer annexure 3). The rationale behind this is the fact that a sub-sector having a higher value add than others is economically more important. For example, although India currently consumes lithium, the economic contribution of this mineral is not significant as it is consumed in minute quantities in the pharmaceutical sector. Should this consumption pattern shift to more crucial applications in electronics and other technology-intensive input sectors, the situation could change significantly.

ii) Consumption pattern of a mineral in the economy

The consumption pattern of a mineral across the manufacturing sectors is another crucial factor. It reflects the level of economic importance associated with, or assigned to, each mineral. A mineral represents a higher economic importance if it caters to the demand from high value-addition sectors.

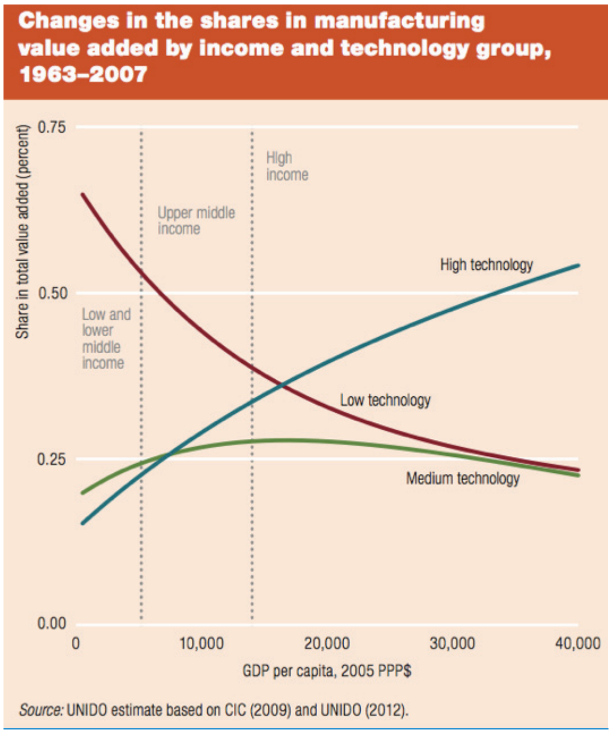
A precise estimation of the consumption pattern of each mineral across the manufacturing sectors in India is arrived at using unit-level data from the Annual Survey of Industries (ASI), a periodic exercise conducted by the MOSPI. ASI extends to the entire country, providing extensive information pertaining to all the factories registered under sections 2m(i) and 2m(ii) of the Factories Act, 1948.[13]

CEEW analysed the information on material inputs and outputs from more than 250,000 manufacturing units registered across India to elicit the consumption pattern of each mineral across the sectors (refer annexure 5).

3.1.2 Future Economic Importance

Minerals that are critical to the growth of the manufacturing industry are identified for a selected year in the future. The year chosen is 2030 because it captures the changes that are likely in the industrial sub-sectors in the medium term. For 2030, one can estimate the likely impact on minerals resulting from the needs and requirements of a growing industry. Future criticality depends on a few unknowns and unforeseen factors such as technology uptake, which are difficult to predict. The choice of technology, in turn, will determine the set of technologies required by the manufacturing sector, affecting substitutability and even promoting the recycling of some minerals. Future economic importance has been evaluated using the same indicators: (i) **future industrial structure;** and (ii) **future consumption pattern of a mineral in the economy** as used in the base year. However, the method of estimation of these indicators is different, and depends on the future scenario under consideration.

FIGURE 5: STRUCTURAL CHANGE OF MANUFACTURING INDUSTRY WITH INCOME LEVEL



Changes in the shares in manufacturing value added by income and technology group, 1963–2007

Source: UNIDO estimate based on CIC (2009) and UNIDO (2012).

Source: Adapted from (UNIDO, 2013)

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13 Those factories employing 10 or more workers and using power, or employing 20 or more workers without power.

(i-a) Future Industrial Structure

The future sectoral composition of the manufacturing industry is a key driver of economic importance. Empirically, it is seen that the structural shift in the manufacturing industry is a function of the progressive shift from low-technology-based industries to high-technology-based industries and the resulting greater value added in the economy. Low-technology-based industries are not capital intensive but are highly labour intensive; medium-technology-based industries are capital intensive and resource intensive; and high-technology-based industries are mainly capital intensive, use resources efficiently while also demanding new and exotic materials. There are complex trade-offs (job creation vs. higher value addition) in taking any of these paths. A comparative global study (UNIDO, 2013) *Industrial Development Report 2013* by the United Nations Industrial Development Organization illustrates, based on empirical evidence, that in countries at per capita income levels below USD 8,000 (PPP corrected) or low-income-level, low-technology-based industries have a major share (Figure 5: Structural change of manufacturing industry with income level). Medium-technology-intensiveness of industries is seen between income levels of USD 8,000 and USD 16,000 (medium-income levels). High-technology-intensive industries contribute to a larger share of the economy when income levels are more than USD 16,000. These different sub-sectors of manufacturing are mapped to the different technology intensity levels as illustrated in Table 2.

TABLE 2: CLASSIFICATION OF MANUFACTURING SECTORS BY TECHNOLOGY UTILISATION

Technology Group	Manufacturing Sectors
Low Technology	Food & beverages, Tobacco products, Textiles, Paper, Leathers etc.
Medium Technology	Rubber, Basic Metals, Non-Metals & Fabricated Metals
High Technology	Chemicals, Machinery, Transport Equipment, Electronics & Electrical Products

Source: Adapted from (UNIDO, 2013)

i-b) How does a rise in income lead to a structural shift in the manufacturing industry?

To understand the relationship between the income level and the composition of the industrial sector, a regression analysis was carried out between the incomes of 40 countries[14] and the corresponding value add contributions of the different sub-sectors of the industry sector over a period of 19 years.

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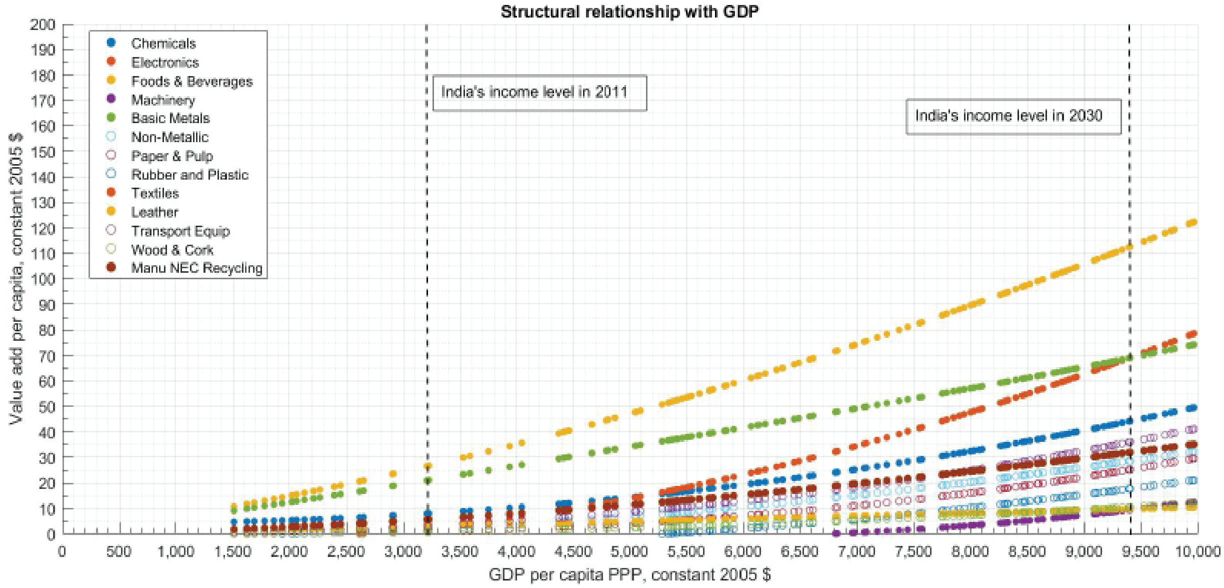
[14] The mix consists of 12 per cent low-income countries, 22 per cent middle-income countries, and the rest high-income countries (refer annexure 9).

FIGURE 6: SECTOR WISE GROWTH TRAJECTORY OF GLOBAL ECONOMIES ON THE BASIS OF THEIR PER CAPITA INCOME LEVELS



Source: CEEW Analysis

Figure 6 captures this variation across various income levels. The clear trend is that with the rise in income levels, a country's manufacturing base tends to shift towards technology- and capital-intensive sectors in the search for higher returns, moving away from labour-intensive manufacturing (UNIDO, 2013).

This macro-level relationship between structural change and rising income level globally is applicable in equal measure to India, as the country experiences economic growth (and per capita income growth). The growth trajectories suggest that low-technology-intensive sectors like textiles, wood and paper; and food and beverages have high growth rates of value add at lower income levels. Medium-technology-intensive industries like chemicals, basic metals, and non-metallic minerals have higher growth rates at medium-income levels. Similarly, high-technology-intensive industries like electronics and transport equipment show higher growth rates at higher income levels.

A NITI Aayog growth scenario (of GDP growth rates) for India is used in the analysis, and population estimate data from the World Bank (refer annexure 10) are also used. The chosen economic growth scenario suggests that India will achieve a per capita income of ~ USD 9,300 by 2030. This is approximately a threefold increase from the 2011 GDP per capita of USD 3,354.[15] As mentioned earlier, it is also assumed that India closely tracks the average development path of the basket of countries used in the analysis above (Figure 6). The future sectoral value add of the industrial sub-sectors can be inferred from Figure 6 by using the per capita GDP in 2030. The corresponding sectoral value adds at the specific per capita income level give the future structural mix for determining the economic importance of the mineral in the study.

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[15] GDP per capita or per capita income specified in constant 2005 PPP USD.

ii) Future consumption pattern of minerals in the Indian economy

A rise in income levels leads to a structural change in the industry—a gradual shift from low-technology-intensive industry to high-technology-intensive industry. This gradual change also leads to changes in the mineral consumption pattern. As mentioned earlier, a low-income country will have very little or negligible consumption of minerals like gallium, silicon, germanium, and tantalum. However, these minerals will be in increasing demand (as raw materials or as embedded minerals within imported ***intermediate*** products) by the high-technology-intensive electronics and ICT industry as income levels rise and consumption patterns change.

In this study, the global trends in the structural composition of industry (represented by the share of various sub-sectors) have been superimposed on India as well. Given the lag in technology adoption between India and the developed countries, it is assumed that by 2030 the structure of industry and the mineral consumption pattern would emulate those of the EU in its current economic state (as of 2011). Besides, the EU consists of a mix of low-, middle-, and high-income countries, and their average consumption pattern of minerals should be a good proxy for India in the future (refer annexure 11). Since this transition cannot happen immediately, a gradual shift from the current pattern (retained until 2022) would lead to an EU-type structure by 2030.

As described earlier, economic contribution determines the relative importance of a mineral in the manufacturing industry. For both, the base year and the future estimate, the economic contribution (importance) of a particular mineral (i) is calculated as a product-sum of the percentage share of mineral consumption in various application areas (Ais) and the value added by that application area (Qs) in India's manufacturing sector. This is then divided by India's overall GDP (GDP) to give a normalized contribution of the mineral (as a percentage share of GDP).

EQUATION 1: COMPUTING ECONOMIC IMPORTANCE

$$\text{Economic importance} = (\sum A_{is} * Q_s)/\text{GDP}$$

Source : Adapted from (European Commission Enterprise and Industry, 2010)

3.1.3 Dimension 2: Supply risk

The overall supply risk pertaining to each non-fuel mineral resource is determined on the basis of the following indicators: (i) **domestic endowment of the resource; (ii) geopolitical risk associated with trade in that resource; (iii) level of substitutability at the end-use application; and (iv) potential share of the recycled mineral in the primary manufacturing of products.** These indicators are strictly non-independent and some element of correlation (inter-relationship) exists between these. For example, the complete substitution of a scarce mineral with a suitable alternative may do away with import dependency of the mineral in question, and hence may reduce the overall supply risk. However, this draws attention to the role of other determinants associated with the substitute material in assessing the overall ‘supply risk’. Hence, this study treats each indicator as an independent metric to prevent instances of one metric overshadowing the impact of others.

Each independent metric is given equal weightage in calculating the final aggregated score. We have assumed that in the next 20 years, substitutability, recycling potential, and geopolitical risk would remain static. The future supply risk is, therefore, driven solely by the import-dependency factor. The importance of these factors, and of the indicators associated with them, is described in the subsequent sections.

i) National Resource Endowment

As per official records, India is endowed with 85 mineral resources[16] (11 metallic, 52 non-metallic, and 22 minor).[17] However, insufficient breadth of techno-economic feasibility studies and inefficient policy prescriptions for promoting exploration and mining preclude the exploitation of domestic resources. This leads to supply shortfalls, which are mitigated by imports. For those minerals where domestic manufacturing depends on imports for supply, the additional issues of concern are (a) concentration of reserves and/or monopoly of production in a few regions of the world; and (b) geopolitical stand-offs and/or poor trade relationships with countries that hold these reserves.[18] Hence, import dependency for these minerals plays a crucial role in determining the associated supply risks. The key attribute or factor for tempering expectations from national resource endowment is “**import dependency**”.

i-a) Import Dependency

The indicator import dependency is calculated as the ratio of the quantity of a mineral that is imported and the total value of its consumption (production + imports) by the industry. The calculations are presented in value terms only to avoid complications arising from the differences between ores, concentrates, and other value-added forms of a mineral when measured in quantity (physical) terms (refer annexure 7).

ii) Geopolitical risk

Globally, the production of minerals is not uniformly distributed, and is dependent on a number of factors apart from natural resource endowment. The rapid economic development of the emerging economies may have contributed to their rise as mining and mineral processing and fabrication centres. These emerging economies cannot be a source of sustained supply as they are likely to be constrained by the need to cater to domestic demand and other economic and political compulsions. The Worldwide Governance Index (WGI), which measures the geopolitical stability of a country, is used in this study as an estimate of geopolitical risk. The WGI scores are scaled between 0 and 10, and weighted with the corresponding share of concentration of production. This weighted factor ($HHI._{WGI}$) determines the overall geopolitical risk for a supplier country (refer annexure 7).

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[16] IBM, 2011.

[17] The term minor minerals refer to building stones, gravel, ordinary clay, ordinary sand, and any other mineral that the central government may declare officially as minor.

[18] CEEW analysis.

iii) Substitutability in end-use application

Today's high-end applications demand minerals with specific properties and characteristics. Tantalum's property of providing high capacitance per unit volume led to the invention of micro-capacitors, which are widely used in all electronics circuits today. Neodymium and dysprosium are used in high-performance permanent magnets, which are deployed in almost all low-maintenance motors. Due to the exclusive properties of these minerals, applications are dependent on their availability, thereby highlighting their importance owing to the absence of suitable substitutes. Substitutability plays an important role in determining the supply risk of a mineral. The presence of a substitute reduces the supplier's market influence. In addition, the availability of an abundant and cheap mineral substitute reduces the supply risk. The level of substitution of a mineral is measured by the indicator "substitution risk".

iii-a) Substitution risk

The substitution risk indicator is represented by σ. The value of this indicator ranges from zero to one where one refers to "no possible substitution" and zero refers to "full substitution possible" depending on the application area in the different sectors. In effect the indicator (σ) is defined as the complement of substitutability, where substitutability represents how substitutable a mineral is in a particular application/ area. The values are determined based on literature reviews. The overall substitution risk indicator of a mineral is a sum of the values obtained by multiplying the share of consumption of the mineral in different sectors with the substitution risk indicator values associated with those sectors. These overall substitution risk values are then scaled from zero to one to fit the 'order' of magnitude of the other indicators (refer annexure 7).

iv) Domestic Recycling Capacity

Recycling is a secondary source for any mineral, which, in turn, reduces dependency on the primary source. For instance, at current levels of extraction, known indium supplies would be able to cater to current levels of demand only for 14 years. Additional sources of supplies would be possible only through recycling (Department of Natural Resources and Mines, 2014). The presence of domestic facilities for the recycling of indium would certainly ease the pressure on primary mine production. However, it is not simple to set up domestic recycling facilities merely in anticipation of this projected demand. The recycling process should be techno-economically feasible to sustain long-term production. The indicator "recyclability risk" captures the current state of metal/mineral recycling in the world (in general) as present a best available recycling potential scenario for India.

iv-a) Recyclability risk

This study takes the global recycling rates for a mineral as the benchmark. Country-specific data are inconsistent, and are also mostly unavailable from official sources. In India, except for a few basic metals (from the machinery and automotive sector), most of the minerals coming from electrical and electronic waste (more than 17 specialty minerals) are handled by players in the unorganised sector (CPCB, 2014). The unorganised sector is highly dispersed and lacks sufficient scale for extracting specialty minerals from waste in an economical manner, and thus ends up recovering only conventional minerals. The indicator used for calculating recyclability risk indicator (ρ) is Recycled Content (RC). This is the percentage of recycled mineral content (recovered from scrap) in the overall mineral input (primary as well as secondary) for the manufacturing sector. Just like in the case of substitution risk, ρ is calculated as the complement of recycle content (1 – RC). The higher the recycled content in the primary manufacturing, the lower will be the need for primary mineral supplies, and hence the lower will be the recyclability risk indicator and concomitantly, the supply risk as well (Refer Annexure 7).

3.1.4 Calculating Future Supply Risk

To predict supply risks associated with an individual mineral, the same set of indicators is considered. However, certain parameters are difficult to foresee, such as accretion or consumption of a mineral resource across geographies, political stability of supplier countries, technological innovations for identifying substitutes of a few critical minerals, and improvements in material use and recovery potential. Such uncertainties are would increase as the time frame for the analysis goes further away from the present. Thus, a medium-term span of 20 years has been considered in this study. Additionally, indicators like geopolitical risk, substitution risk in end-use application, and recycling potential of minerals are considered to remain constant until 2030. The underlying assumptions are that there will be minimal change in the political equation (HHIWGI) between the major mineral-supplying countries and their trade partners, and that technological development (for substitute materials and resource efficiency) will have a considerable lag between the laboratory phase and the commercialisation phase (refer annexure 13).

Furthermore, intensity of mineral use across manufacturing sub-sectors or from specific new applications (refer to Section 4.1.2 (ii)) will drive mineral-specific demand. India's estimated GDP/income levels will determine the evolution of manufacturing sectors by 2030 (Figure 6), and hence mineral demand will be calculated on the basis of the proportionate growth of an individual sector at a particular income level. We are assuming that a transition from the current industry structure to the future industry structure will take place gradually, and therefore the uptake of a mineral by the current manufacturing sectors will continue until 2022. Thereafter, the transition will be to the newer industry mix (representative of the 2030 India)
The demand estimations and the corresponding import dependencies for the future have all been carried out in quantity terms as opposed to value terms. The reasons for doing this are (a) price change is hard to capture or predict; (b) all future demands are estimated to total the amounts of mineral required; and (c) greater volumes of imported low-grade ore would be required to produce the same quantity of metal demanded.

i) National Resource Endowment

India is not endowed with all of the minerals required for manufacturing products demanded today. In addition, lack of suitable technology and limited domestic demand has curbed domestic production of many such minerals, despite the presence of domestic reserves/resources. India has the potential to exploit much more of its documented/ prospected mineral wealth, but this requires a change in policy, improved infrastructure and enhanced investment in modern technology. Hence, India's future resource endowment by 2030 is estimated by tallying the "Total Reserves". This includes the "Proved-STD 111" and "Probable-STD 121 & 122" data provided by the GSI. The rationale for considering total reserves is that, going forward, further exploration will accrue proved reserves from the probable reserves that have already been identified. Domestic production, however, would depend on the amount of reserves left. This is, in turn, captured by the reserve's depletion time or R/P (R is "Total Reserves" and P is "Production Level"). Our study assumes that the mine production of minerals in 2030 will maintain a reserve depletion time of at least 20 years. For minerals having less than 20 years of reserves left, mine production will shut down. For those minerals having more than 20 years of reserves left, there can be a possible increase in the mine production rate depending on the demand. Similar to the base year, supply risk in the future is measured by (the expected) **"import dependency"** for the minerals in 2030, which is a function of the overall requirement of a mineral and the (expected) extent of domestic production that can be sustained over the next two decades. On the one hand, the extent of usage of the mineral is contingent on the growth of Indian manufacturing industry and the changing contribution from various sub-sectors. On the other hand, domestic production is contingent on maintaining a satisfactory reserve to production ratio (R/P). Import dependency is calculated as the ratio of the required amount to be imported (total consumption minus domestic production) to the total consumption (refer annexure 13).

Overall, for both the base year and for future calculations, the score of supply risks can be calculated as per the formula below:

EQUATION 2: COMPUTING SUPPLY RISK

$$\text{Mineral Supply Risk} = \text{HHI.WGI}*\text{Import Dependency} + \rho + \sum A_{is}*\sigma_i$$

HHI.WGI = Geopolitical risk

ρ = Aggregated recyclability risk of mineral from end-of-life products

A_{is} = % share of mineral consumption in various application areas

σ_i = Substitution risk in each of the individual application

Source: CEEW compilation using (European Commission Enterprise and Industry, 2010)

3.2 Data Sources

Secondary desktop research was undertaken to source much of the data required for the analysis. Consultation with government and industrial experts through stakeholder discussions supplemented the data that were made available in public data sets. Publications by IBM and MOSPI, international best practices on metal recycling rates from the International Resource Panel (United Nations Environment Programme), substitution roadmap of critical raw materials from CRM-InnoNet, among others, were the primary public data sources that were used.

3.3 Key Assumptions

1. Assessment of future criticality is based on the important assumption that India's manufacturing sector will mimic the developed world average.

2. The extent of usage of minerals across the different sectors varies according to a country's manufacturing industry and its production basket. Based on our assumption, if India's industrial growth is to follow the global trajectory, it needs to produce a set of goods that is also being produced globally along that trajectory. Hence, for our study, the mineral pattern of the EU[19] has been taken as a benchmark.

3. To determine future resource endowment, it is assumed that the entire stock of reserves (proved, probable, and inferred) will be available for extraction and that the extraction would be done by maintaining a constant depletion time (R/P) of 20 years.

4. Since it is difficult to predict the distribution of global mineral production 15 years into the future, it is assumed to remain constant. Similarly, the quality of governance across these countries, indicated by WGI, is assumed to remain constant for the purpose of evaluating future criticality.

5. Keeping in mind the status of technology penetration in India, and the time taken for commercialisation of technologies that are still under development, it is assumed that the level of substitutability of non-fuel minerals in the industrial production process will remain constant.

6. Similarly, the extent of recyclability is assumed to remain unchanged for the Indian manufacturing industry.

3.4 Limitations

1. Data inconsistency both at the global and national levels and lack of a national inventory on mineral consumption and reserves/resources of non-fuel minerals are major limitations.

2. The effect of price changes, driven either by shortage of supply or oversupply, is difficult to capture.

3. The impact of environmental factors and the need for a sustainable production process of a mineral are (yet) not included in the determination of criticality.

4. India often imports intermediate products or semi-finished products, and subsequently adds value for exports. The embedded minerals in these products are ignored, and hence their criticality may not be reflected fairly.

5. It is a top-down analysis, and as a result, the impact of specific technologies (whether in the research stage or in the commercialisation stage) is not explicitly accounted for in future estimations. The estimations are assumed to be built in. A separate bottom-up estimation[20] provides a more technology- (or product-) specific outcome, but this depends largely on the breadth of the technologies considered for evaluation. In certain sectors like electron-

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[19] The European Union consists of 28 countries, which exhibit significant diversity in their economic structure and GDP (per capita).

[20] The methodology for this is discussed in the results section.

ics, where the categorisation of products and technologies is done more easily (based on an identification of the building blocks of electronic components), the demands for the various intermediate components and materials that are needed for manufacturing the different end-use products are accounted for in a comprehensive manner.

4. Results and Discussion

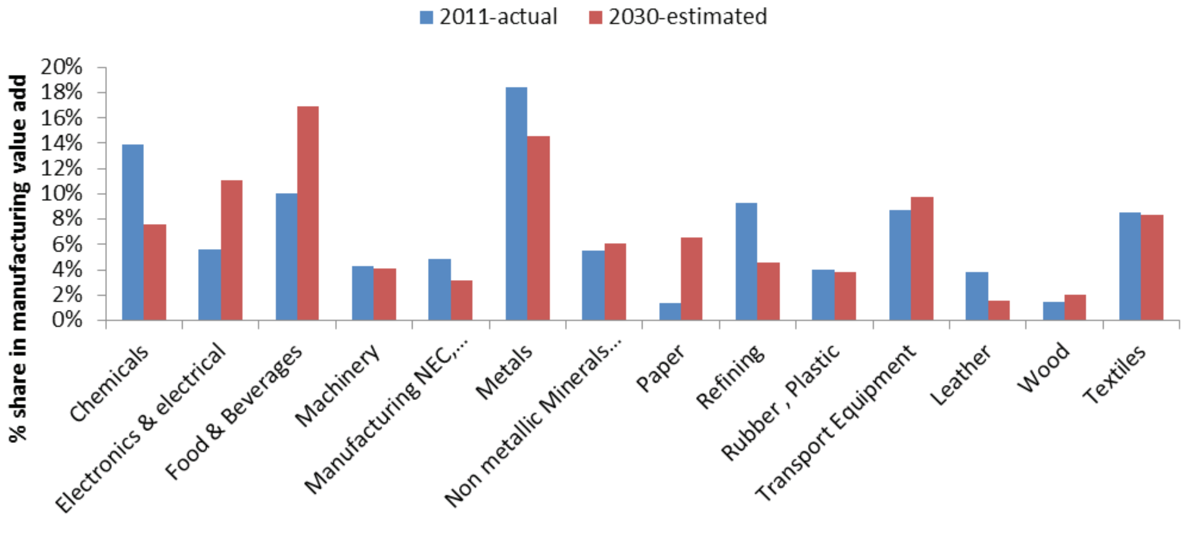
The framework defined in Section 3 helps characterise critical minerals from a set of pre-identified minerals that find use in the manufacturing sector. As illustrated in previous sections, the objective is to emphasise the relative difference between various minerals along the two dimensions (economic importance and supply risk) and to categorise those that score higher on both dimensions as being ‘critical’. Neither of the two dimensions is intended to provide an absolute view on the criticality of the various minerals.

The overall framework is flexible and allows for a scenario-based interpretation of criticality. Significantly, the results are subject to assumptions about the structural make-up of Indian manufacturing. The other variations that could be captured in the scenarios include (a) the growth rate of individual sub-sectors; (b) the overall contribution of manufacturing to the Indian economy; and (c) the extent of technology-driven value addition across these sub-sectors.

4.1 Review of the critical minerals

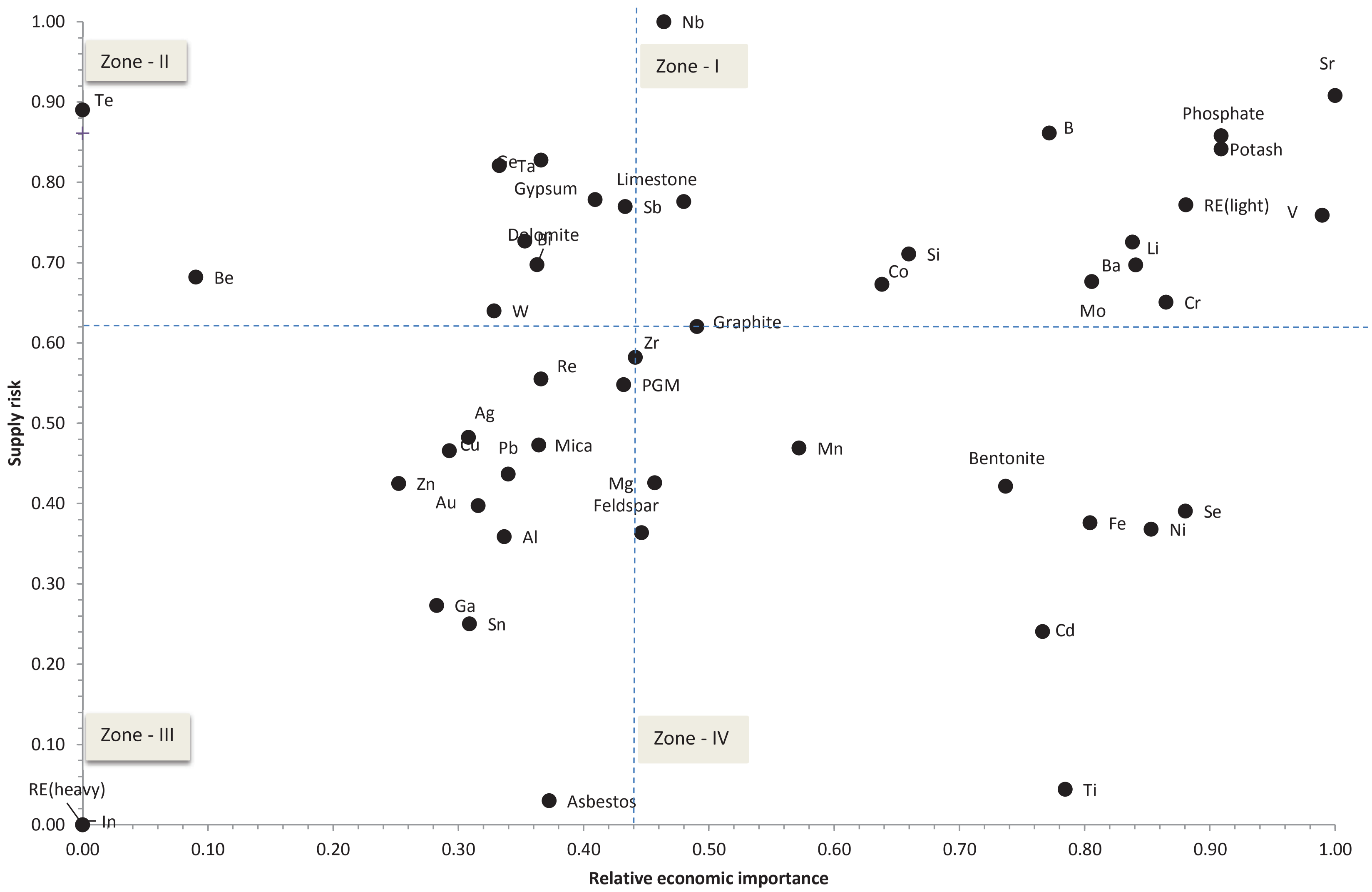
The manufacturing sub-sectors are grouped into 16 mega sectors, and nearly half of the manufacturing value add in India is represented by the manufacturing of metals (18 per cent), chemicals and fertilisers (13 per cent), food and beverages (10 per cent), and textiles and apparel (9 per cent). CEEW’s analysis, which superimposes global growth patterns on India, suggests that by 2030 sectors like food and beverages and electronics will register a steep jump in their respective growth rates. Figure 7 compares the share of each mega-sector in 2011 versus that in 2030.

FIGURE 7: RELATIVE SHIFT IN MANUFACTURING STRUCTURE UNDER A MODERATE GROWTH SCENARIO



Source: CEEW analysis

FIGURE 8: CRITICAL MINERALS FOR THE REFERENCE YEAR 2011



Source: *CEEW analysis*

Figure 8 illustrates the scores (for 2011) attributed to 49 minerals that are used in the manufacturing sector in India. The median scores of each axis (on a scale of 0 to 1, 0.44 for economic importance and 0.62 for supply risk) are taken as indicative reference points to determine the level of criticality associated with the minerals and to categorise them into four zones as follows:

a) **Zone I:** high economic importance and high supply risk (most critical)

b) **Zone II:** low economic importance and high supply risk (moderately critical)

c) **Zone III:** low economic importance and low supply risk (least critical)

d) **Zone IV:** high economic importance and low supply risk (moderately critical)

In the reference year, 14 minerals fall into the most critical category, i.e. Zone I; 20 minerals were categorised in the moderately critical regions (Zone II and Zone IV); and only 15 minerals were assigned to Zone III (annexure 8).

It is useful to reiterate that economic importance is sensitive to the consumption pattern of a mineral across the industrial sub-sectors as well as to the contribution of that sub-sector to the overall economy. Similarly, supply risk is determined based on (a) domestic demand and import dependency; (b) geopolitical stability of global suppliers; and (c) level of substitution and (d) recycling possible for each mineral in the relevant application.

Table 3 provides a detailed breakdown and interpretation of the reference-year results.

TABLE 3: KEY FACTORS INFLUENCING CRITICALITY OF THE IDENTIFIED SET OF MINERALS

Mineral	Key application areas/sectors (in 2011)	Measure of Supply risk
Rare earths (light)	a) Major use of light rare earth elements as an alloying material to impart pyrophoricity property to the steel b) Modern day applications in electronics manufacturing is yet to begin in India	a) Highest geopolitical risk (~ 94% of global supplies coming from China, while India is 100% import dependent) b) Low or no recyclability from the end of life products c) Moderately substitutable in current set of applications
Strontium	a) As per ASI statistics, it is solely used in manufacturing of products of aluminium and its alloy.	a) High geopolitical risk with India exposed to 100% import dependency b) No declared resource available in India c) Although substitutes are available easily for the current applications
Vanadium	a) Chiefly used in manufacturing of ferro- alloys. Although the share of specialised steel production in very low in India, but overall value addition from the sector is considerably high	a) Worldwide demand is associated with demand of Steel (essential component of specialised steels). India is 100% import dependent for its primary supplies. b) Associated with titaniferous magnetite, already proved reserves with a high R/C of 360 years. Yet no primary production in India. c) Minor recovery from alumina industries takes place owing to low vanadium content in east coast Bauxite grade. d) Substitutes available at higher costs or low performance

Mineral	Key application areas/sectors (in 2011)	Measure of Supply risk
Phosphate	a) Single largest use in manufacturing of fertilisers which has substantial contribution to economic value add	a) More than 80% of supplies came through imports b) Nothing can substitute its utility as a nutrient provider c) Apart from natural mechanisms, not recyclable in true sense after its use
Lithium	a) Majorly used in manufacturing of chemical compounds (high value add sector) whereas globally its major application area is in manufacturing of Li-ion batteries. b) Slight amount of total consumption goes towards refineries and secondary fuel manufacturing	a) India is 100% import dependent. Though supply risk is marginally above the threshold, the moment demand is battery space will get realized, it will be highly critical. Energy storage application makes it a strategic mineral as well
Potash	a) Single largest use in manufacturing of chemical fertilizers, which accounts for a substantial contribution in economic value add	a) India is 100% import dependent b) Nothing can substitute its utility as a nutrient provider c) Apart from natural mechanisms, not recyclable in true sense after its use
Boron	a) Mainly used in manufacturing of wide range of chemicals	a) India has significant resources but exploration activities are required to establish the economic viability in terms of proved reserves. That will certainly reduce the supply risk moving forward
Barium	a) Almost 75% of total usage is in the chemical sector (major usage is in imparting green colour in firecrackers as barium nitrate) b) Used as a drilling fluid in Oil & Gas wells	a) Due to its end use applications, recycling is very difficult. b) Absence of suitable substitutes for its applications in the chemical sector c) Barium is produced from barytes and is exported significantly
Molybdenum	a) Major consumption is in the metals sector to produce alloys	a) 100% import dependency; 70% of global production coming from a single country (Dem. Republic of Congo) b) It is used in specialty alloys, and is difficult to substitute without compromising the quality
Silicon	a) Wide usage across metals (40%), electronics (38%) and transport equipment (17%)	a) India is at a moderate supply risk owing to difficulty in substitution and low recycling potential from the end of life products
Chromium	a) Used extensively within the metals sector (80%). Mostly in the production of stainless steel.	a) Chromium has no substitutes in the production of stainless steel, hence has a high substitutability risk. b) Extraction rate of chromium is very high due to rising demand of ferro-alloys (which is also exported significantly). b) India very limited amount of chromium is recycled and reused.
Cobalt	a) Major uses of cobalt are in chemicals (paints and dyes) and in corrosion resistant alloys	a) 100% import dependency; 70% of global production coming from a single country (Dem. Republic of Congo. b) Difficult to substitute from its application in special alloys, magnets, chemicals (paint and dyes), cutting tools etc.
Niobium	Majorly used as an alloying agent in steel industry	100% import dependency; No reserve/resource declared by ministry of mines
Limestone	96% of total production goes into cement manufacturing. Huge potential of cement industry growth from current per capita consumption of 150 kilograms to a global average of 300kilograms	a) No substitute is available at present for its use in cement manufacturing. b) Recovery/recycling from cement is less likely, as construction work has a high lock-in period. c) Import dependency would rise from 0% to 20% if no accretion of reserves happens in coming 20 years.

Source: CEEW analysis

Some minerals said to be ‘strategic’ or ‘critical’ in common discourse or deemed to be so by national agencies (e.g. the Planning Commission/NITI Aayog or the Ministry of Mines) do not find a place in the critical zone that is identified in this analysis. The major base metals (iron, aluminium, copper, lead, nickel, zinc), precious metals (gold, silver, platinum), and strategic minerals identified in the Planning Commission report (beryllium, germanium, gallium, indium, tantalum, niobium, bismuth, tin) are notable omissions from the list given in Table 3: Key factors influencing criticality of the identified set of minerals.

In interpreting this difference, it is useful to remember the following:

a) The economic importance of all the base metals is significant, but the supply risk for India is low. A major advantage comes from the domestic availability of considerable resources for many base metals, barring a few exceptions (e.g., 100% import dependency for nickel). In addition, geopolitical risk is minimal in cases where India is exceedingly import dependent, and many minerals exhibit high recycling potential (although they are not easily substitutable), thereby reducing risk on the supply side.

b) Import of precious metals such as gold and silver is largely a result of cultural bias and their view as investment options. Although India is highly import dependent for the raw ores of these metals, most of the trade takes place in the form of finished products (jewellery and ornaments). Thus, they correspond to the low contribution from the manufacturing sector value addition, and hence to the low economic importance from the perspective of manufacturing value addition.

c) Selective focus on ensuring the sustained supply of strategic minerals is imperative for India, as rightly pointed out by the Planning Commission working group report and several other independent studies. However, in the context of the present manufacturing basket of India, most of these minerals are not used directly by industry. An inadequate technology base, uncertain price of raw materials (especially mineral ores), power deficit, and lack of a skilled workforce, among many other factors, render the manufacture of high-technology products uncompetitive and significantly reduce the demand for materials consumed by these sectors.

A forward-looking scenario (Figure 5 and Figure 6) suggests that the food and beverages sector, among the traditional industries, is likely to see an impressive growth rate over the next two decades and to play a dominant role in manufacturing value addition. Another important sector could be transport equipment manufacturing. The remaining conventional contributors (such as metals and chemicals), while exhibiting growth, do not play as central a role as they do in the economy today. Electronics and electrical products manufacturing is estimated to nearly double its share in the manufacturing value addition by 2030.

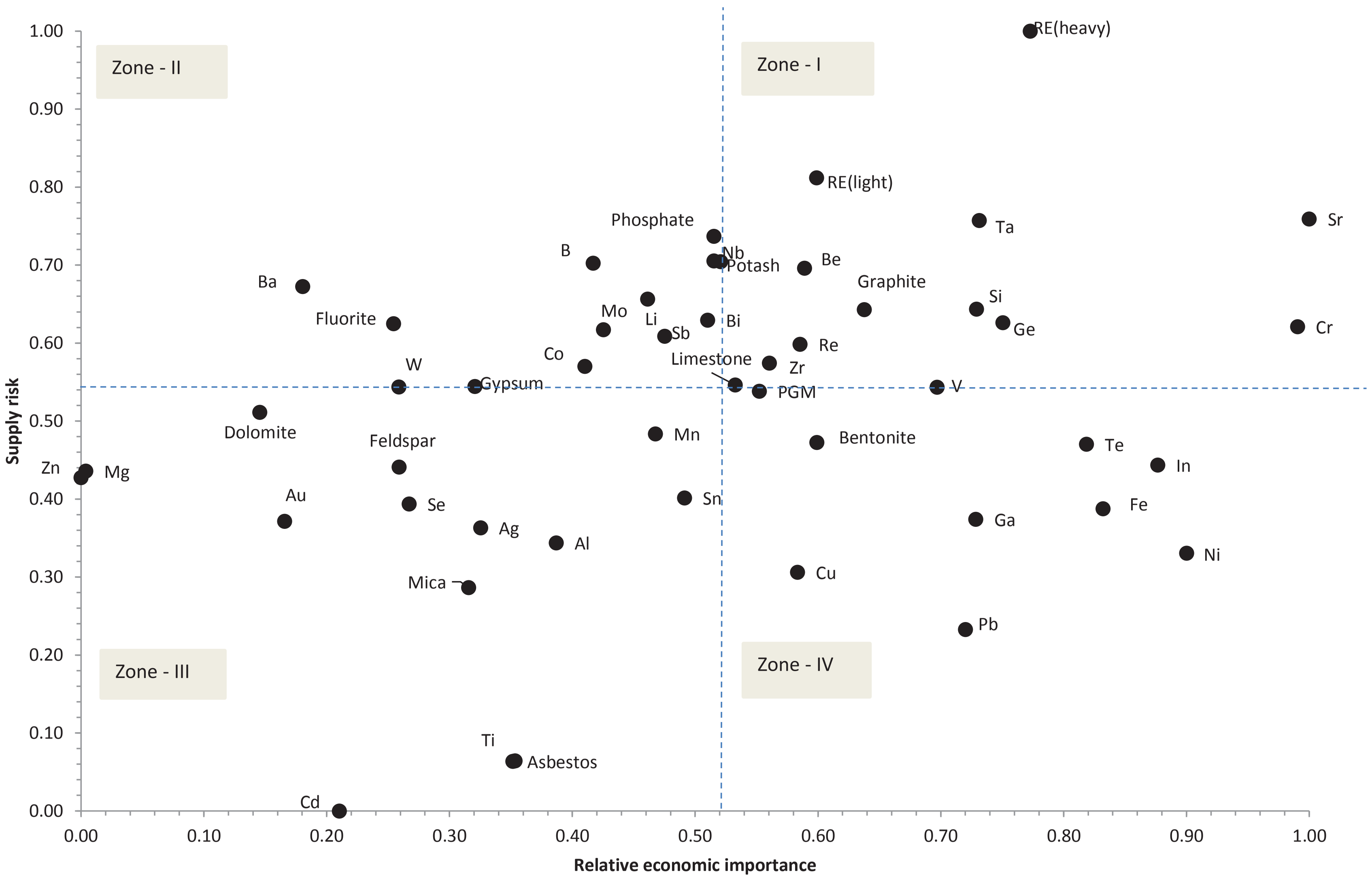


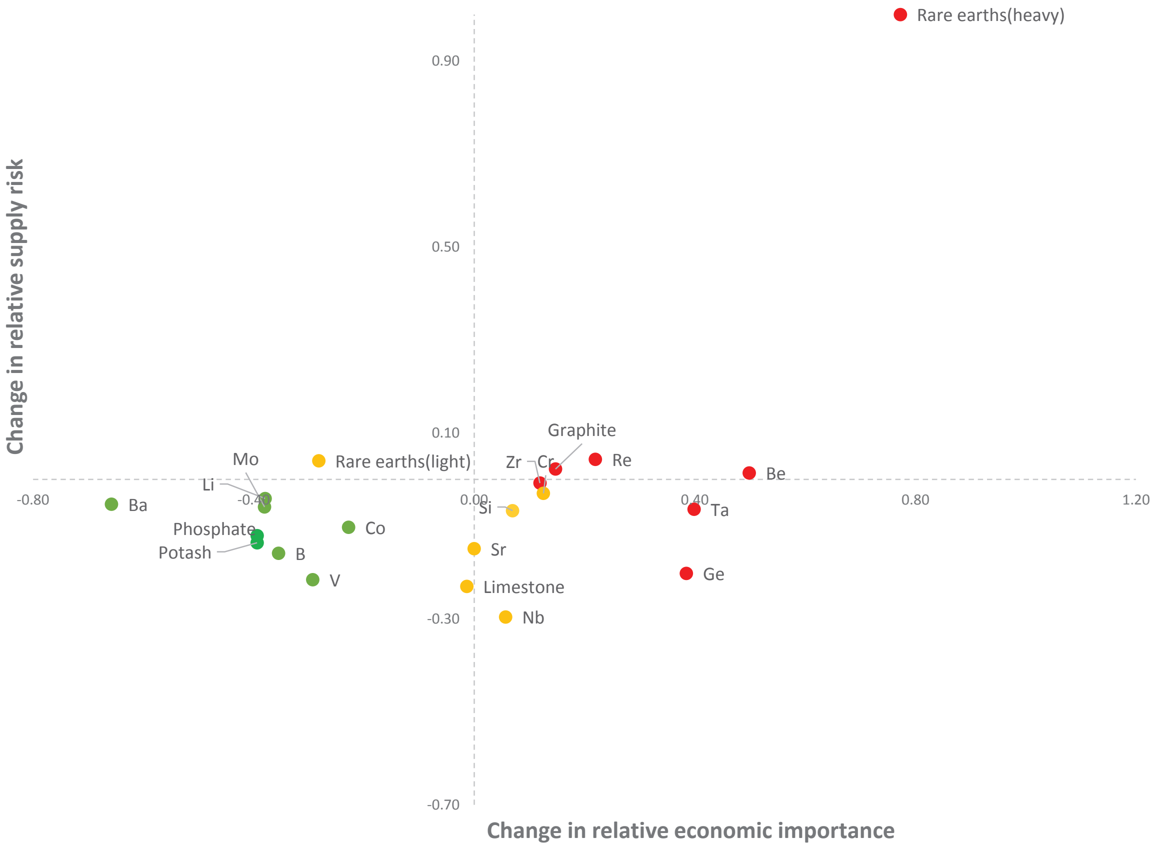
FIGURE 9: SNAPSHOT OF CRITICAL MINERALS FOR THE YEAR 2030

Source: CEEW analysis

It can be seen from Figure 9 that over the period of analysis in this study, a change in the overall manufacturing structure has an impact on the level of criticality associated with the concerned mineral. Here, we have considered a pragmatic timeframe (20 years from the reference year) to provide a future perspective on critical mineral resources, the reason being that any measurable impact of the current policies on the manufacturing and mineral sector (mining and processing) is visible only over such a period. The structure of the manufacturing sector, mining output, geo-political risks will be visible only in the medium to short-term while technology has impact only in the medium to long term. This analysis focuses on the medium term – an intersection where the impact of multiple factors can be seen.

More importantly, the transition that is evident between the two periods is noteworthy. This is of more interest because risk mitigation (associated with supply) enters hitherto unchartered territory. From the policymaker's perspective, it is important to track the key drivers influencing such developments. Figure 10 provides a comparison of the two snapshots (2011 and 2030) and indicates the transition of minerals from 2011 (reference point) to 2030 along the two dimensions that define criticality.

FIGURE 10: TRANSITION OF MINERALS INTO THE CRITICAL ZONE FROM 2011 TILL 2030



Red: Minerals which will become critical in 2030; **yellow:** minerals which are critical both in reference year and future year; **green:** minerals which will are only critical in the reference year

Source: CEEW analysis

Over the analysis period of 20 years, the importance of many of the minerals (indicated in yellow) that were in the 'critical' zone in 2011 has diminished marginally, but they continue to retain their status of 'critical minerals' (refer annexure 14).

Furthermore, seven new minerals (indicated in red) have been added to the most critical zone by 2030. This transition can largely be attributed to their increased economic importance (movement along the X-axis), and, to a lesser extent, to the heightened overall supply risk.

Table 4 summarises the main drivers for this transition.

TABLE 4: KEY DETERMINANTS OF THE TRANSITION OF MINERALS TO THE MOST-CRITICAL QUADRANT

S.No	Critical minerals – 2030	Key parameters to impact economic importance	Key parameters to impact Supply risk
1	Rhenium	Super-alloys in aerospace and machinery uses rhenium as a principal alloying element	India is currently 100% import dependent, with no declared resource/reserve so far, as it is mainly obtained as a by-product of copper/molybdenite ores.
2	Beryllium	Current use is exclusively in the paper sector (very low value add), in future finds its use in a diversified group of sectors	Complete import dependency with 99% of global supplies controlled by US and China only. For most of the applications, substitutes are difficult to find.
3	Rare earths (Heavy)	a) All the major green technologies depend on heavy rare earths imparting the special properties to them b) Extensive applications within the defense industry	India is 100% import dependent, with 94% of global supplies controlled by China. India bears mainly deposits for lighter rare-earth elements (in form of monazite).
4	Germanium	Decline in its consumption from steadily growing machine manufacturing, while gaining demand from high value sectors (electronics and metals)	India is likely to continue with 100% import dependency. It is a secondary mineral. recovered mainly as a by-product of Zinc (also from silver, lead and copper). Recyclability is low and alternative substitutes are a difficult find.
5	Graphite	Diversification of its use from electronics alone into other value add sectors as well	Majority of the resources of graphite are unexplored and those identified are of poor grade. Only 5% of declared resource have been translated into viable reserves. India can minimise future risk by carrying out survey and exploration activities to open new mines.
6	Tantalum	Decline in its consumption from steadily growing machine manufacturing, while gaining demand from high value sectors (electronics and metals)	No declared resource available in India, while 95% of global supplies are controlled by a single country Brazil. Substitutes are difficult to find, whereas recycling potential is also low.
7	Zirconium	Rising demand from the high value chemical manufacturing and electronics sector	75% of domestic resource is already identified as a viable reserve. Although R/P is very high (53 years), but lesser options for substitutes and difficulty in recycling makes it susceptible to high risk.
8	Chromium	All were identified critical in the reference year (2011) as well.	Major application is in manufacturing of stainless steel for which nearly no substitutes are available at prevailing cost and efficiency. Potential environmental hazard, and has low R/P
9	Limestone		a) No substitute is available at present for its use in cement manufacturing. b) Recovery/recycling from cement is less likely, as construction work has a high lock-in period. c) Import dependency would rise from 0% to 20% if no accretion of reserves happens in coming 20 years.

S.No	Critical minerals – 2030	Key parameters to impact economic importance	Key parameters to impact Supply risk
10	Niobium		100% import dependency; No reserve/resource declared by ministry of mines
11	Rare earths (light)		India is 100% import dependent, Its reserves are associated with coastal beach sands of India, but its mining is not open for private sector till date
12	Silicon		Obtained from sand, which is abundantly available. However, processing of specific grade of sand into Silicon is highly energy intensive. Much of the silicon grade resource is yet to get translated into reserve category.
13	Strontium		India has not declared any resource for them and is 100% import dependent. 90% of global supplies are controlled by China and Spain. Hence, there are higher chances of supply side monopoly in global trade.

Source: CEEW compilation

4.2 Bottom-up analysis: An alternative approach to determine mineral criticality

In this study, the economic importance of minerals so far has been determined through a top-down approach taking into consideration macroeconomic parameters such as income level and structure of the industrial (manufacturing) sector. As the economy grows, changes in the industrial structure and the resultant shifts in raw material consumption become the key driving factors in determining economic importance. Alternatively, economic importance can also be determined by a framework that uses a bottom-up assessment that relies on technological progression as an indicator for mineral consumption.

However, our limited understanding of (plausible) future technologies is a significant barrier in carrying out such an exercise for all sectors and in making this a comprehensive assessment. In certain sectors like electronics, which are comparatively well organised and where the categorisation of products and technologies is done more easily, the demands for the various intermediate components and materials needed for manufacturing different end-use products are accounted for in a comprehensive manner (Figure 11).

The bottom-up analysis (illustrated below) estimates the mineral requirement for manufacturing high-value electronic components (Figure 11) by assuming that ***20 per cent of the overall demand would be served by domestic manufacturing***. However, the resulting raw material demand by the manufacturing industry in the future does raise concerns for raw material security and sustained growth of this sector (refer annexure 15). For example, minerals like indium and gallium, which are used principally in the manufacturing of display screens and semiconductors, the demand could easily become as large as 500 times the current domestic consumption. Although India has these minerals locked away (as secondary sources) within the large reserves of zinc and aluminium ores, the country does not possess enough technical capacity to enable production within reasonable cost considerations. Hence, both these minerals are exposed to future supply risks because of low substitutability in application fields and low production in selected countries. This is more so in the case of indium because its known resources could be depleted within 20 years.[21]

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[21] CEEW analysis.

FIGURE 11: KEY COMPONENTS CONSIDERED FOR MICRO-ECONOMIC ANALYSIS

				PCB	LCD & OLED	LED	Permanent Magnets	Batteries	Optics
Telecommunications Sector	Services - 83%								
	Equipment- 17%	Mobile Handsets		🟩	🟩	🟩		🟩	
		Other Equipments		🟩	🟩	🟩	🟩	🟩	
Automotive Sector	Carriers - 8.4%, Passenger cars - 16.8%, Two Wheelers - 74.8%	Mechanical Components							
		Electronic Components	Core Components	🟩	🟩	🟩	🟩	🟩	🟩
			Safety & Security	🟩	🟩	🟩	🟩	🟩	🟩
			Accessories	🟩	🟩	🟩	🟩	🟩	🟩
		Electrical Components							
		Other Components							
Consumer Electronics	Appliances - 39%, Air Conditioners, Refridgerators , Washing Machine etc.			🟩	🟩	🟩		🟩	
	Electronics- 61%, Televisions, Music Systems, Cameras, Accessories			🟩	🟩	🟩	🟩	🟩	🟩
IT & Office Automation	Hardware	Computer & Allied Products		🟩	🟩			🟩	
		Networking & Allied Components		🟩	🟩			🟩	
	Software								
Medical & Health	Health Care Services - 72%								
	Medical Equipment - 1.4%	Medical Electronics Market	Imaging Equipments- 57%	🟩	🟩		🟩	🟩	🟩
	Healthcare IT - 1.3%		Homecare Equipments-8%	🟩	🟩	🟩	🟩	🟩	
	Pharma Components - 20%		Patient Monitoring Systems-9%	🟩	🟩	🟩	🟩	🟩	
			Therapeutic Products- 26%	🟩	🟩	🟩	🟩	🟩	
	3rd Party Insurance Providers-5%								
Lighting Sector	Incandescent Lamps								
	Flouroscent Lamps								
	Compact Flouroscent Lamps								
	Light Emitting Diodes			🟩		🟩		🟩	
Industrial Electronics Sector	Process Control Equipments	Sensors, Indicators, PCBs, Ics		🟩	🟩	🟩	🟩	🟩	🟩
	Test & Measuring Equipments	Electronic Meters, Recorders, Printers, Testers, Indicators		🟩	🟩	🟩	🟩	🟩	
	Power Electronic Equipments	Rectifiers, Invertors, Wound Components, UPS, Regulators, Grid Storage Systems		🟩	🟩	🟩		🟩	
	Industrial Electronics & Automation	Solar, Wind, Hydro, Nuclear Appliances, PV modules, etc.		🟩	🟩		🟩	🟩	
	Analytical Equipments	Agricultural Electronic Instruments, Environmental Monitoring Systems etc.		🟩	🟩			🟩	
Strategic Electronics	Satellite Based Communications			🟩	🟩		🟩	🟩	🟩
	Navigation & Surveillence			🟩	🟩	🟩		🟩	🟩
	Underwater Electronics			🟩	🟩	🟩		🟩	🟩
	IR- based Detection			🟩	🟩			🟩	🟩
	GPS based Monitoring			🟩	🟩			🟩	🟩
	Disaster Management Sytems			🟩	🟩	🟩		🟩	🟩

PCB: Printed Circuit Board, LCD: Liquid Crystal Display, LED: Light Emitting Diodes, OLED: Organic Light Emitting Display

Source: CEEW compilation

REEs find use in green technologies such as energy-efficient display screens, LED lights, permanent magnets, and infrared-active fibres. Although India has 2.8 per cent (IBM, 2014a) of the world's REE reserves, it is constrained by a lack of technical expertise in processing the reserves in a cost-effective manner. As a result, future demand that is 120 times the current consumption will render India entirely import dependent for the supplies. Further, future supply may be affected, as China, the single largest producer (accounting for more than 97 per cent production), is planning to limit the production of REEs on account of the environmental stresses resulting from the mining process. Certain minerals such as tantalum do not have any official declared resource within India, although its presence has been reported in tantalite-bearing tin ores (IBM, 2014a). The Indian electronics manufacturing industry would require nine times the current consumption of tantalum to produce high-performance micro-capacitors. In light of the need for sustainable supply of tantalum for the growth of the industry, the indigenous reserve base needs to be clearly defined to under the evolving import dependency. Palladium is also an important metal, which is used in printed circuit boards and display screens. Its concentration in ores, found in India, precludes economical extraction (IBM, 2014a). With the future demand estimated at eight times the current consumption, and scarce global production, India would do well to secure future supplies by initiating discussions with current suppliers.

FIGURE 12: CONCORDANCE BETWEEN MICRO AND MACRO ANALYSIS

	Micro Analysis	Macro Analysis
In	CRITICAL	CRITICAL
Ga	CRITICAL	CRITICAL
REEs	CRITICAL	CRITICAL
Ta	CRITICAL	CRITICAL
PGM	CRITICAL	NOT CRITICAL
Graphite	NOT CRITICAL	CRITICAL
Se	NOT CRITICAL	NOT CRITICAL
Au	NOT CRITICAL	NOT CRITICAL
Sb	CRITICAL	CRITICAL
Pb	NOT CRITICAL	NOT CRITICAL
Ag	NOT CRITICAL	NOT CRITICAL
Ba	NOT CRITICAL	NOT CRITICAL
Cu	NOT CRITICAL	NOT CRITICAL
Ge	CRITICAL	CRITICAL
Te	CRITICAL	CRITICAL

Source: CEEW analysis

CEEW analysis identifies indium, gallium, REEs, platinum group of metals (PGM), and tantalum as major contributors to the growth of the electronics manufacturing sector. This estimate is based on the projected increased demand for these minerals due to additional manufacturing capacity (a purported scenario), which is in sharp contrast to the business as usual (BAU) scenario (where no or insignificant increase in manufacturing of electronic components is expected). It is worth noting that a majority of minerals identified here as *"important"* for the growth of the electronics industry are also labelled as critical in the top-down analysis framework described earlier for 2030 (Figure 12: Concordance between Micro and Macro analysis).

5. Takeaways and Recommendations

The two-dimensional framework adopted to evaluate criticality, and the methodology used to arrive at measures of economic importance and supply risk, constitute a large portion of the value of this first of a kind exercise that CEEW has undertaken. It has the potential to be a strategic tool in the hands of Indian policy makers, industry leaders, researchers, and investors in the mining and mineral sector for identifying and anticipating the potential supply bottlenecks for minerals crucial to the manufacturing sector. Our recommendations, stemming from our experience in carrying out this study and based on the results emerging from the criticality framework employed, can be categorised under three broad heads as below:

a. Legislative and institutional reforms to aid better analysis

b. Domestic interventions: Enhanced exploration and R&D in mining and mineral processing) technologies

c. International interventions: Strategic acquisition of mines and signing of diplomatic and trade agreements

5.1 Institutional reforms to aid better analysis

In India, one of the key barriers is the lack of capacity and coordination between existing institutions to plan for the supply of (and to anticipate the demand for) the mineral inputs required for the manufacturing sector. As highlighted in Chapter 1, an institutional arrangement that links the requirements of the manufacturing sector with a concomitant strategy for mineral development is vital.

The Ministry of Mines regulates the mining and mineral sector through its principal law, the Mines and Minerals (Development and Regulation) Act (MMDR), 1957. The Act lays down a set of rules that define various processes related to the exploration, concession, and regulation of the mining and mineral sector. It has been amended in recent years, with the last formal amendment in 2015.

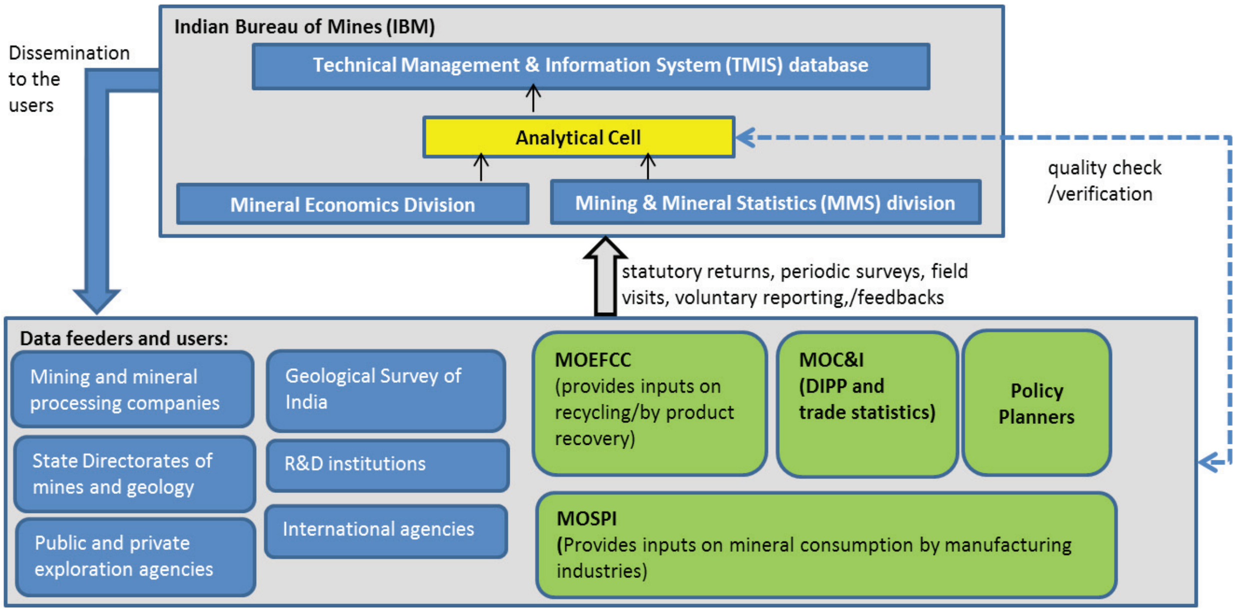
The MMDR Act prescribes the provisions for conducting exploration activity, as well as the process of granting permits (at various stages) for exploration and mining. The recent amendment to the MMDR Act 1957 (amended in 2015) is noteworthy and has been lauded for introducing a transparent regime for the granting of exploration and mining licences. However, it has been equally criticised for a few debatable provisions that act as deterrents to entry of private sector mining companies. The provision of additional taxes (in the form of *District Mineral Foundation* and *National Mineral Exploration Trust*) would be an extra burden on mining entities. Similarly, the *non-exclusive reconnaissance permit* prohibits the permit holder from making any claim to the grant of prospecting or mining licenses. This dynamic is often difficult to manage for any government, as a gain by one party is a lost opportunity for another party. Nevertheless, an appropriate balance is essential for guaranteeing the risk associated with such activities and for encouraging public and private agencies to realise the associated gains. **GSI has an important role to play here**, as it can advance the progress of surveying and exploration through strategically planning for OGP areas (low risk), as well as for terrains that are likely to possess critical minerals. Certainly, downstream exploration companies will show increased interest after gaining useful baseline information (and that too for strategic business opportunities), perhaps even taking risks in their search for higher returns. Nevertheless, the foundational support has to come through the legislative route.

One of the prime objectives of the Ministry of Mines is *"to promote systematic and scientific development and optimum utilisation of mineral resources of the country (both on-shore and off-shore)"*. Being a regulator and an agency tasked with information dissemination, **the role of IBM is equally crucial in connecting the end-use business or manufacturing sector with the mining and mineral processing industry**.

In the due course of this study, most recently the Ministry of Mines has announced NMEP (4, July, 2016), which also recognises "*critical minerals for industry and strategic minerals vital for national security,*" and recommends priority based exploration from GSI. IBM is designated entity to develop a mechanism for setting these priorities on a periodic basis.

IBM already collects, processes, and disseminates a wide range of information gathered from various agencies. However, in order to set a mechanism to identify and act on critical minerals, we recommend that IBM must also carry out the all-important analysis that combines information on demands of the manufacturing sector with the prospects of the mining sector. At the upstream level, information on the country's potential reserves/resources for many advanced-technology-related minerals is essential (through the inputs from GSI and other public or private exploration agencies). On the other hand, updated information on the consumption patterns of even the relatively less important minerals is equally essential. To efficiently meet these expectations (both on the supply and demand sides), extensive inter-ministerial coordination is also required. Figure 13 details some departments and coordination arrangements that could enhance and improve the efficiency of its functioning. NMEP (2016) also prescribes formation of a not-for-profit autonomous body National Centre for Mineral Targeting (NCMT) solely to focus on optimising mineral exploration efforts. Our recommendations provide essential steps that need to be taken, either to support NCMT, or to augment the current capacity within IBM.

FIGURE 13: PROPOSED CAPACITY ENHANCEMENT OF IBM FOR BETTER INTER-AGENCY COORDINATION



Note:
Blue Blocks: Current information flow system within the IBM
Green blocks: Existing entities with whom IBM needs to develop a close and enhanced coordination
Yellow block: A new department within IBM
Abbreviations: MOEFCC = Ministry of Environment, Forest and Climate Change; MOSPI = Ministry of Statistics and Program Implementation; MOC&I = Ministry of Commerce and Industries; MOPNG = Ministry of Petroleum and Natural Gas; MOC = Ministry of Coal

Source: CEEW illustrative

a) Coordination with the Ministry of Environment, Forest and Climate Change (MOEFCC) is necessary to get regular inputs on the actual material recovered or the potential available from the end-of-life recycling of products. CPCB and SPCB have a mandate to regulate waste recovery from industrial, domestic, and other resources. The India Resource Panel (InRP) constituted recently within the MOEFCC, is expected prepare a roadmap for the utilisation of secondary resources for meeting the material inputs required by the economy.

b) Establishing closer ties with the Ministry of Commerce and Industries (MOCI) is proposed to enable a flow of information on the structural changes that are expected in the Indian manufacturing sector, and to anticipate the changing material requirements in the future. Further, this linkage will also help track global developments (in terms of resource pricing, trade policies, India's acquisition of resources overseas, demand–supply trends, etc.)

c) A linkage with MOSPI presumably already exists. However, the inconsistencies between MOSPI data (as evinced in the ASI) and IBM data are quite stark in many cases. The ASI dataset, which represents the nationwide industrial consumption (of fuels and raw material), is a good indicator of mineral-use intensity. A process that enables periodic flow of industry-specific data, in a structured manner, from MOSPI to IBM is essential to enable better planning.

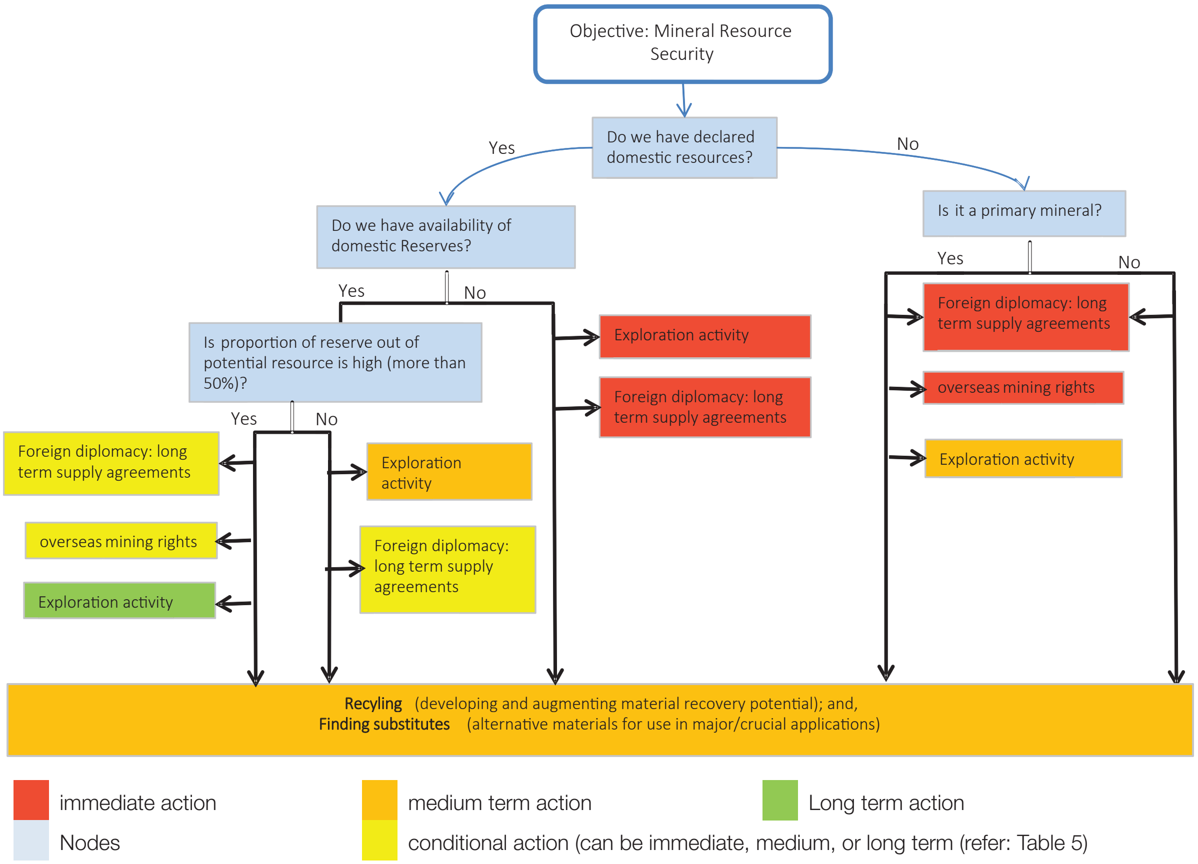
Constant feedback between supply drivers (mining and mineral processing companies, environmental clearances, diplomatic ties, overseas acquisitions) and demand drivers (manufacturers, investors in new businesses, technology developers) is necessary to meet the demand for cost-effective resources. By incorporating and implementing some of these proposed recommendations, the Ministry of Mines could help in sustaining manufacturing as it enters unchartered territory where mineral-use intensity is higher and more diverse. The importance of empowering IBM and GSI to fulfil their respective stated mandates cannot be overstated.

5.2 Domestic interventions: Enhanced exploration and R&D in mining and mineral processing technologies

We have classified the criticality of minerals by considering supply risk as one of two important determinants. The most important response to a perceived supply risk is through domestic action—to tap resources available within India. The mining industry in India can make major gains by focusing on domestic exploration and by exploiting reserves that pose a lower risk. However, the pace of development on this front is slow for various reasons, including a paucity of investment (stemming from a mineral policy that has not incentivised private sector investment), delayed regulatory clearances, and social resistance to the diversion of land in mineral-rich areas.

To break down the process of arriving at the required interventions in mining and mineral processing, a decision tree approach (Figure 14) has been adopted. The primary driver of the decision tree is enhanced resource security in the country. The determinants of the interventions (at the domestic and international levels) are provided in Table 5, and specific recommendations are detailed subsequently.

FIGURE 14: DECISION TREE TO ARRIVE AT APPROPRIATE ACTIONS FOR SECURING MINERAL RESOURCE SUPPLY



Source: CEEW illustrative

TABLE 5: DETERMINANTS OF INTERVENTION

Action required	Priority Level	Key determinants
Exploration	Immediate	Domestic reserves have not been identified from a known resource base. Investment risk will be relatively low
	Medium term	Unavailability of resources. Here, associated risk with investments in exploration activities will be high. Hence, suggested as a medium term priority. Reserve to resource ratio is less than 50%, and reserve is slowly depleting (proxy: estimated R/P in 2030 less than 50)
	Long term	Proportion of reserve to resource is high. To conserve balance resource, exploration is needed as a long-term action.
Long term trade agreements	Immediate	If there is no resource or no reserve base If reserve to resource ratio is low, import dependency is high (>50%), i.e. either we are unable to explore or unable to produce more. If reserve to resource ratio is high, import dependency is high (>50%), and R/P is less than 20
	Medium term	If reserve to resource ratio is low, and import dependency is also low (<50%), but balance reserves (R/P) are estimated to be less than 20 years If reserve to resource ratio is high, import dependency is low (<50%), and R/P is less than 20 If reserve to resource ratio is high, import dependency is high (>50%), and R/P is more than 20
	Long term	If reserve to resource ratio is low, and import dependency is also low (<50%), but balance reserves (R/P) are estimated to be more than 20 years If reserve to resource ratio is high, import dependency is low (<50%), and R/P is more than 20
Overseas mining rights	Immediate	No clarity on resource, and all should be of primary origin
	Medium term	Reserve to resource ratio is high, but rapidly depleting (R/P less than 20)
	Long term	Reserve to resource ratio is high, but R/P is high (greater than 20)

Source: CEEW analysis

Specifically, domestic exploration is needed when any of the following four conditions is met:

a. **No resource is available**: There is not sufficient clarity on the resource base for many minerals.[22]

b. **Resource is available but there are no declared reserves**: Due to lack of effort and other obstructive factors, we have failed to identify economically viable extractable reserves for many of the minerals where a resource base has been established.

c. **Reserves are a small share of resources**: In this case, rapidly depleting (low R/P) mineral reserves need interventions on a priority basis.

d. **A high percentage of resources is already converted to reserves**: In this case, since much of the mineral wealth has been explored already, further exploration activities can be delayed and we can look for alternative ways to meet our demands.

A primary geological survey has been undertaken across the entire landmass of India. However, a detailed geophysical and geochemical mapping forms the basis for a more accurate classification of resources and reserves. Making data and analyses (resulting from such a mapping) accessible to investors who are interested in undertaking reconnaissance surveys and other exploration activities will help incentivise more investors to

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[22] Many minerals discussed in this study have only secondary sources, that is, they are found only as by-products of the processing of other primary minerals. Exploration is discussed only in the context of primary minerals. Actions to address the supply of secondary minerals are detailed in later sections.

come forward and reduce the overall perception of risk associated with exploration in India.

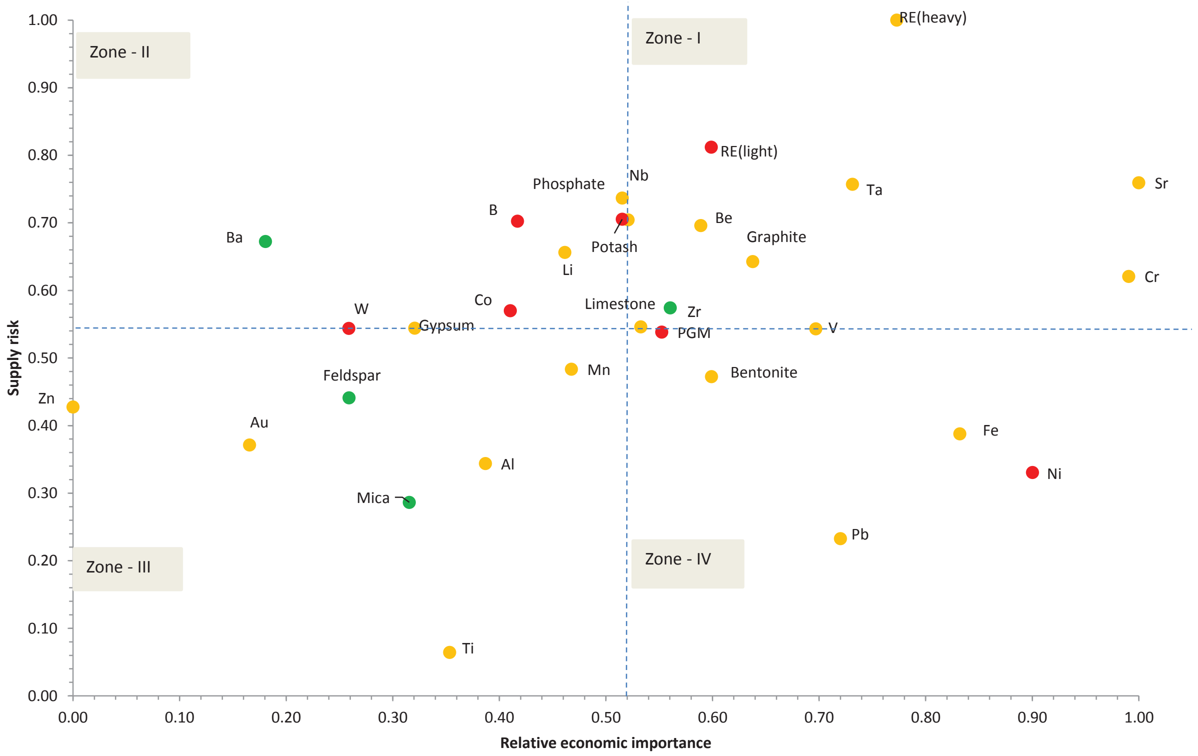
The decision tree and the determinants only provide a rule of thumb for driving action. However, setting priority among the various minerals will require this to be linked with the criticality metrics proposed earlier. Combining the criticality ratings in 2030 (Figure 9) with the priority of action (Figure 14), we arrive at an actionable list (Figure 15). The interpretation of Figure 15 is provided below:

a. The minerals marked in 'red' need immediate action (short term), compared to those marked as 'orange' (medium term) and 'green' (long term).[23]

b. Among those minerals that were identified as being critical (in 2030), only REEs (light) need priority action, while others do not warrant any immediate action as a result of the present status of mining and reserve utilisation. For example, zirconium (although identified as critical) needs long-term action, because already 75 per cent of the resource has been categorised as reserves, and India needs to look into other alternative options to secure supplies.

c. Similarly, some minerals need immediate exploration efforts, but these are not classified as being critical (relative to others). However, in the event of supply shortages arising for any of these, we can prioritise action against them accordingly.

FIGURE 15 : PRIORITISATION OF EXPLORATION ACTIVITY ASSOCIATED WITH MINERALS



Red = immediate attention; **Orange** = medium term; **Green** = Long term

Source: CEEW analysis

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[23] This is not to be confused with the colouring scheme given in Figure 10, which only highlights the transition in criticality between 2011 and 2030.

5.3 Promoting R&D on enhancing recyclability and finding substitutes for critical minerals

Keeping in mind the fundamental requirements of improving resource efficiency and increasing resource conservation, India needs to build strong R&D capacity in the following areas:

(a) resource recovery/recycling from waste products;

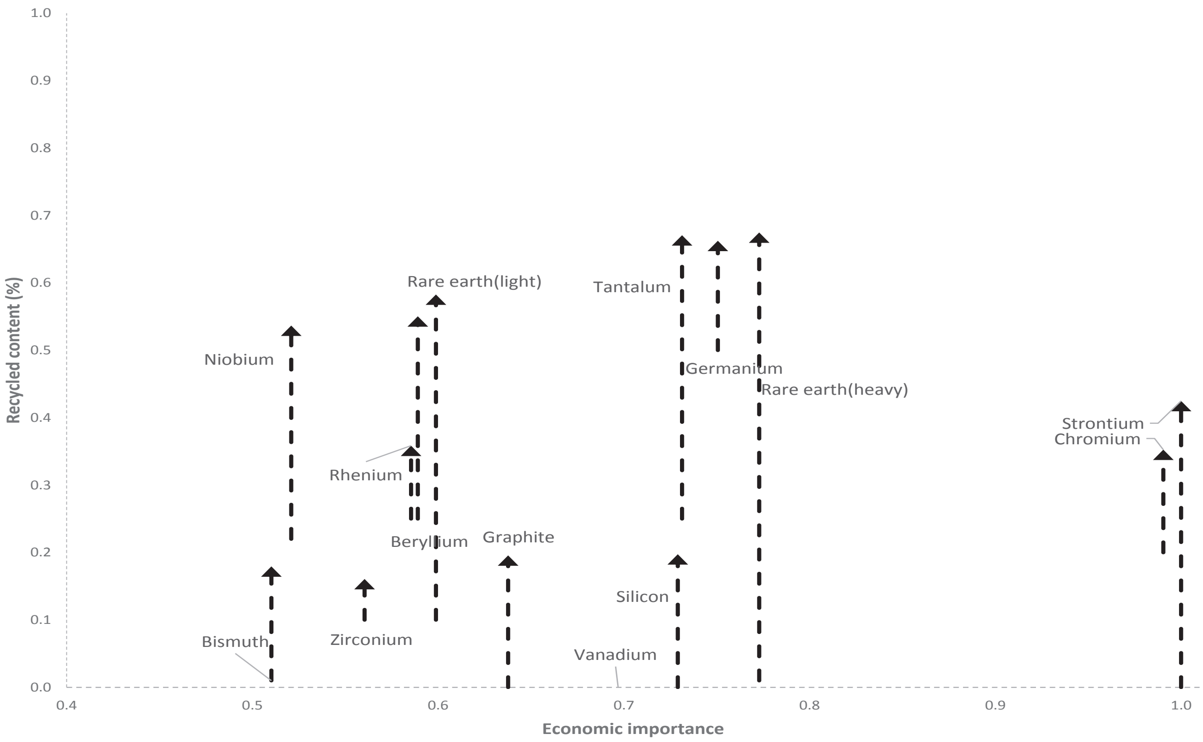
(b) technologies for recovering secondary minerals from primary mineral processing activities;

(c) technologies in mining and mineral processing that will have minimal impact on the environment; and, most importantly,

(d) developing mineral substitutes for those minerals that have scarce supplies or low recovery potential through recycling.

Again, it is important to prioritise action as the R&D ecosystem in India is still at a nascent stage and may not be able to handle the challenges posed by these different requirements. Figure 16 presents the incremental level of recycling (as a percentage) that has to be achieved for various minerals (*ceteris paribus*)[24] to move out of the critical zone as per the evaluation presented in the section 5.

FIGURE 16: IMPROVEMENTS REQUIRED IN RECYCLING LEVELS FOR CRITICAL MINERALS



Source: CEEW analysis

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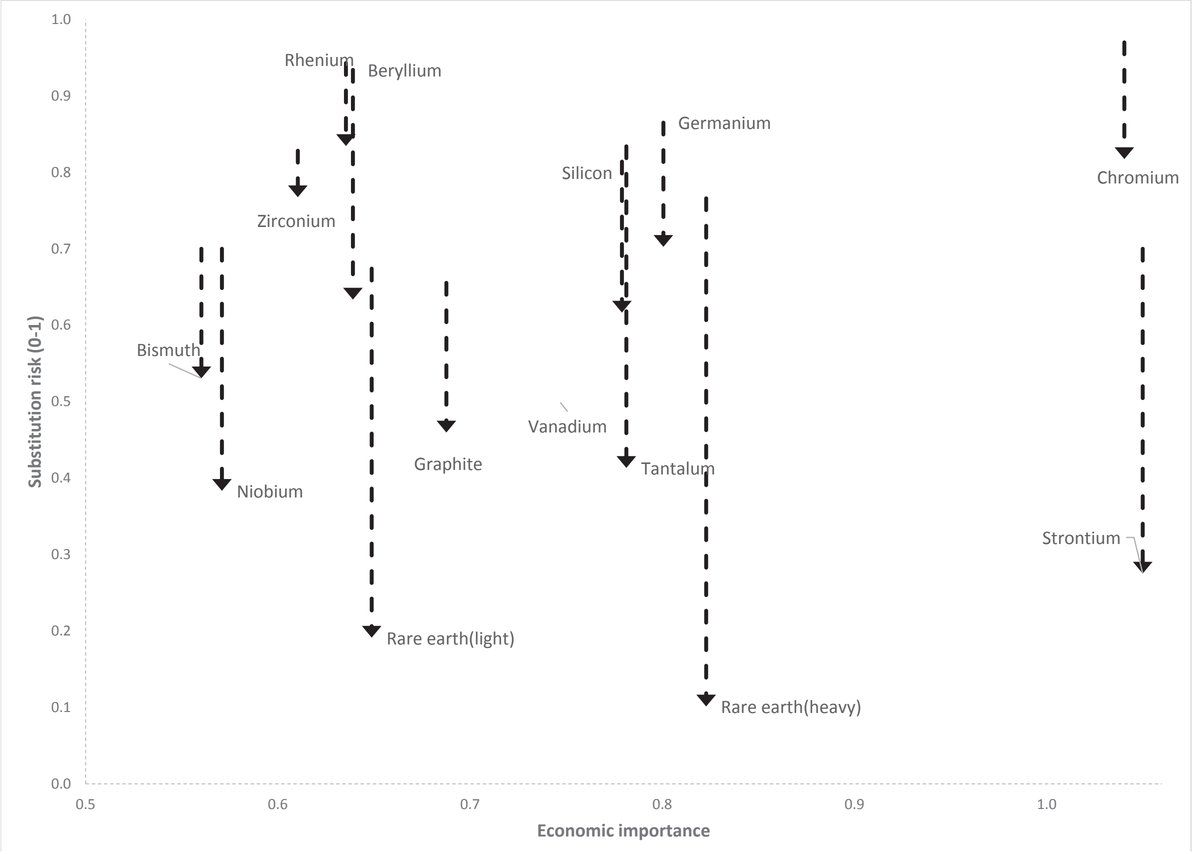
[24] Keeping all other factors in the framework—geopolitical risk, substitution, unchanged domestic production.

Similarly, the incremental substitutability that is needed for various minerals to move out of the critical zone (while keeping all other attributes the same) is shown is Figure 17.[25]

FIGURE 17: IMPROVEMENTS NEEDED IN SUBSTITUTABILITY TO MOVE AWAY FROM CRITICAL ZONE



Source: CEEW analysis

Current developments in the area of substitutability in many parts of the world are presented in Table 6. It provides details of minerals that can be substituted in specific applications. These technologies have been proven and are likely to be pursued over the period under review in this study. ***Although there are no drivers (economic or technical) for this substitution in India, even in the best-case scenario (where India matches global benchmarks in using substitutes in various applications), we find that supply risk will not be mitigated by pursuing substitutes alone.*** While technical research on recycling and finding cheaper and more readily available substitutes is a worthy cause, resource efficiency and conservation must be pursued in equal measure.

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[25] This is a purely theoretical exercise, and is not intended to suggest that this level of technical substitutability actually exists or is possible to achieve for these minerals.

TABLE 6: COMPARISON OF SUBSTITUTABILITY INDICES

Mineral	Baseline Substitutability Index	Possible Technological Innovations (Globally) by 2030	Substitutability limit of existing technologies	Required Substitutability to move out of critical zone (< median)
Niobium	0.70	Niobium in steel can be substituted with quite a few carbide forming metals like Ti	0.44	0.38
Zirconium	0.82	Only a small proportion of Zirconium used in Vaccum Tubes will be phased out	0.82	0.77
Rhenium	0.94	Usage of Yttrium oxide and Ti as coatings in turbine parts will reduce the consumption of Rhenium	0.68	0.83
Beryllium	0.93	Subsitution by Aluminium Nitride and Boron Nitride as electrical contacts	0.70	0.63
Rare Earth(light)	0.66	Gradual phasing out of NiMH batteries will reduce consumption of rare earths ReO free FCC catalysts substituted by Ni and V	0.52	0.19
Graphite	0.65	Susbtitution by synthetic graphite in all application areas except in foundries and refractory applications Graphite can also susbtituted by anthracite coal in foundry applications	0.61	0.46
Silicon	0.81	Usage of Graphene as a substitute of Si based components	0.78	0.62
Tantalum	0.83	Introduction of Multilayer Ceramic Capacitors (MLCC) as a replacement to Tantalum based capacitors	0.55	0.41
Germanium	0.86	Usage of antimony acetate, aluminium & titanium based catalysts for PET production	0.63	0.70
Rare Earth(heavy)	0.76	Possible susbstitutes of Organic LEDs in display technology rather than lighting	0.67	0.10
Chromium	0.97	Chromium is essential for stainless steel. But there has been a gradual reduction in demand for stainless steel as corrosion resistant coatings for ordinary steel have been improved	0.35	0.82
Strontium	0.70	Current research promotes more use of strontium as aluminium and magnesium casting alloys	0.70	0.28

For the minerals marked in red, current innovations cannot move them out of the critical zone

*Source: CEEW compilation using #: (CRM_InnoNet, 2015) ; ^: (USGS, 2013); *: (MRC; GRACE, 2012)[2]; $: (CRM Alliance, 2016); @: (ESTEP, 2012)*

5.4 International interventions: Strategic acquisition of mines and signing of diplomatic and trade agreements

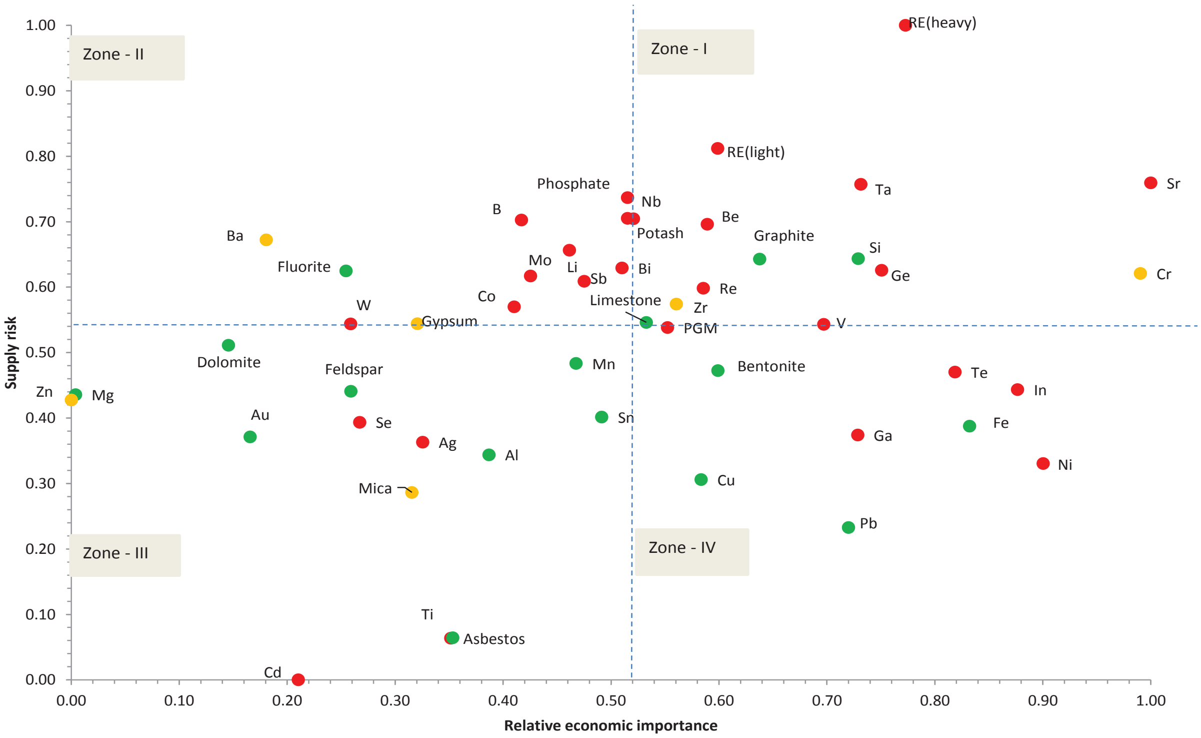
Across the world, countries are developing strategies to secure raw materials required for various economic activities. Diplomatic ties between countries play a crucial role in international trade relations, specifically in the acquisition of overseas mining rights and their development, and can have a telling impact on long-term security of resource supply. Strategic diplomatic efforts help to mitigate risks on the supply side.

India is highly dependent on imports for more than half of the minerals covered in this study. The reasons, as stated before, are (a) lack of clarity on resource availability; (b) lack of recovery of secondary/by-product minerals; (c) non-establishment of commercial and technical viability of resources (proven reserves); and (d) rapid depletion of existing (proven) reserves and the fact that they constitute a small share of estimated reserves. While India is in a similar position when it comes to energy minerals (coal, oil, and natural gas), there is a much better understanding of the country's long-term demands, and as a result efforts have been made to sign trade agreements with global suppliers.

However, in the case of non-fuel minerals, thinking at the level of long-term trade agreements is not commonplace. At the level of the individual organisation, some examples of mergers and acquisition (M&As) are visible, but that too largely for coal and conventional non-fuel minerals, primarily iron, copper, aluminium, zinc, and chrome (Ministry of Mines, 2015). India is still far from registering its presence, as none of the top 10 global mining deals suggests that India has an active strategy to get involved in the global mining scene (PWC, 2011).

Policy planners and manufacturing firms need to assign priority to actions when it comes to *developing long-term trade agreements or acquiring overseas mining rights* in order to secure future supplies. Figure 18 (like Figure 15) provides details on the priority level for action required (on the international front) for various minerals. Not all minerals identified as critical require immediate action on the international front, and India can delay action for a few minerals, as other actions (such as exploration, recycling, and substitution) are more relevant for them.

FIGURE 18: PRIORITISATION OF ACTION IN DEVELOPING LONG TERM TRADE AGREEMENTS WITH GLOBAL SUPPLIERS



Red = immediate attention; **Orange** = medium term; **Green** = Long term

Source: CEEW analysis

Table 7 lists the top three countries with which establishing effective trade ties must be pursued on a priority basis (immediate action) for some of the critical minerals identified in the study.

TABLE 7: DEVELOPMENT OF INTERNATIONAL TRADE AGREEMENTS FOR THE LONG TERM

Mineral	Category	Primary/ Secondary	Source Mineral (S)	Major supplier countries		
				Country -1	Country -2	Country -3
Germanium	No resources	secondary	Zinc, Copper, Lead	China (85%)	Finland (10%)	USA (3%)
Niobium		primary	--	Brazil (95%)	Canada (4%)	Rest of world (1%)
Rhenium		secondary	Copper	Chile (57%)	USA (19%)	Poland (11%)
Strontium		Primary	--	China (79%)	Spain (11%)	Mexico (5%)
Tantalum		primary	--	Brazil (95%)	Canada (4%)	Rest of world (1%)
Rare earths(heavy)		primary	--	China (94%)	Russia (5%)	Malaysia (1%)
Rare earths(light)	Resource: Yes Reserve: No	primary	--	China (94%)	Russia (5%)	Malaysia (1%)
Beryllium	Resource: Yes Reserve/Resource < 50%	Primary	--	USA (88%)	China (11%)	Mozambique (1%)

Source: CEEW compilation using IBM (IBM, 2014a) and World Mineral Statistics (BGS, World Mineral Statistics, 2016)[26]

Similarly, Table 8 lists the specific minerals for which Indian investors, manufacturers, and mining companies must look to acquire overseas mining assets or invest in joint ventures to ensure sustained supplies for the long term. Given India's nascent mining industry and limited expertise, the government may not be able to pursue this option aggressively. Instead, India can strategically develop joint partnerships with existing global players (private firms or governments) in these countries.

TABLE 8: RECOMMENDED MINERALS FOR ACQUIRING OVERSEAS ASSETS

Mineral	Category	Name of major reserve/resource bearing Countries
Lithium	No resources	Chile; China, Argentina, Australia
Niobium		Brazil
Strontium		China
Tantalum		Brazil, Australia, Mozambique
Rare earths(heavy)		China, Brazil, Australia
Barium	Domestic reserve more than 50% of resource	China, Kazakhstan, Turkey, Thailand
Feldspar		Portugal, Poland, Czech Republic
Zirconium		China, South Africa, Mozambique

Source: CEEW compilation using (IBM, 2014a)

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[26] BGS: British Geological Survey

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Annexures

Annexure 1: List of Minerals

Mineral	Symbol	Mineral	Symbol
Aluminium	Sb	Manganese	Mica
Antimony	Asbestos	Mica	Mo
Asbestos	Ba	Molybdenum	Ni
Barium	Bentonite	Nickel	Nb
Bentonite	Be	Platinum group of metals	PGM
Beryllium	Bi	Rare Earth(light)	REE (light)
Bismuth	B	Rhenium	Se
Boron	Cd	Selenium	Si
Cadmium	Cr	Silicon	Ag
Chromium	Co	Silver	Sr
Cobalt	Cu	Strontium	Ta
Copper	Feldspar	Tantalum	Te
Feldspar	Flourite	Tellurium	Sn
Fluorite	Ga	Tin	Ti
Gallium	Ge	Titanium	W
Germanium	Graphite	Tungsten	V
Graphite	Gypsum	Vanadium	Zn
Gypsum	In	Zinc	Zr
Indium	Fe	Zirconium	Potash
Iron	Pb	Gold	Au
Lead	Limestone	Dolomite	Dolomite
Limestone	Li	Phosphate	Phosphate
Lithium	Mg	Rare earth(heavy)	REE (heavy)
Magnesium	Mn		

Source: CEEW analysis

Annexure 2: Concordance of mega-sectors with NIC 2008

Megasector code	Megasector	NIC Mfg Sectors codes included
1	Chemicals and chemical products	20 & 21
2	Electronics and Optical products	26 & 27
3	Food & Beverages	10 & 11
4	Machinery	28
5	Manufacturing NEC, Recycling	32
6	Metals	24 & 25
7	Other non metallic Minerals (including glass)	23
8	Paper	17
9	Refining	19
10	Rubber , Plastic	22
11	Transport Equipment	29 & 30
12	Wood	16 & 31
13	Publishing & Printing	18
14	Textiles and Apparels	13 & 14
15	Leather	15
16	Tobacco	12

Source: CEEW analysis

Annexure 3: Value addition distribution among the manufacturing sectors

		value addition (USD million) - Qs									
Megasector code	Megasector	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
1	Chemicals and chemical products	13454	15044	16843	20882	19039	20539	23281	23771	21168	18906
2	Electronics and Optical products	5415	6055	6779	8405	7663	8267	9370	9568	8520	7609
3	Food & Beverages	9731	10882	12182	15104	13771	14856	16839	17194	15311	13675
4	Machinery	4182	4676	5235	6491	5918	6384	7236	7389	6579	5876
5	Manufacturing NEC, Recycling	4713	5271	5901	7316	6670	7196	8156	8328	7416	6623
6	Metals	17832	19940	22323	27677	25234	27223	30857	31507	28056	25058
7	Other non metallic Minerals (including glass)	5352	5984	6700	8306	7573	8170	9261	9456	8420	7520
8	Paper	1336	1494	1673	2074	1891	2040	2312	2361	2103	1878
9	Refining	8982	10044	11244	13941	12710	13712	15542	15870	14132	12621
10	Rubber , Plastic	3877	4336	4854	6018	5487	5919	6709	6851	6101	5448
11	Transport Equipment	8452	9451	10581	13119	11961	12903	14626	14934	13298	11877
12	Wood	1406	1572	1760	2182	1989	2146	2432	2484	2212	1975
13	Publishing & Printing	1442	1613	1806	2239	2041	2202	2496	2549	2269	2027
14	Textiles and Apparels	9022	10089	11295	14004	12768	13774	15613	15942	14196	12678
15	Leather	3721	4161	4658	5776	5266	5681	6439	6575	5855	5229
16	Tobacco	2100	2349	2629	3260	2972	3206	3634	3711	3305	2951

Source: CEEW analysis

Annexure 4: Resource/Reserve and production statistics of minerals in 2011

Minerals	Unit	Mine Production	Production (all in Tonnes) 2011-12	Proved Reserve	Proved Reserve - corrected for units (Tonne)	Total Reserve	Total Reserve - corrected for units (2011-12), in Tonne	Total Resource
Aluminium	000 tonnes	12877	12877394	321258	321258000	592938	592938000	3479620
Antimony	tonne	0	0	0	0	0	0	10588
Asbestos	tonne	280	280	1700152	1700152	2510841	2510841	22166603
Barium	tonne	1722804	1722804	29557972	29557972	31584128	31584128	72733874
Bentonite	tonne	996	996000	0	0	25060508	25060508	568367346
Beryllium	tonne	0	0	0	0	0	0	0
Bismuth	tonne	0	0	0	0	0	0	0
Boron	tonne	0	0	0	0	0	0	74204
Cadmium	tonne	449	0	0	0	0	0	0
Chromium	000 tonnes	3764	3764120	31652	31652000	53970	53970000	203346
clays	000 tonnes	744561	744561	150787	150786820	224098	224098042	3758772
Cobalt	mill.tonnes	0	0	0	0	0	0	45
Copper	000 tonnes	3478	3478189	133388	133388000	394372	394372000	1558458
Dolomite	000 tonnes	5417	5416817	431567	431567000	738185	738185000	7730557
Feldspar	tonne	660371	660371	24545334	24545334	44503240	44503240	132335451
Fluorite	tonne	4856	4856	4566234	4566234	4712316	4712316	18213904
Gallium	tonne	55	0	0	0	0	0	0
Germanium	tonne	0	0	0	0	0	0	0
Gold	tonne	492192	492192	16045673	16045673	24124537	24124537	493694918
Graphite	tonne	148974	148974	3685172	3685172	8031864	8031864	174849645
Gypsum	000 tonnes	3189	3189229	22494	22494000	39096	39096000	1286498
Indium	tonne	0	0	0	0	0	0	0
Iron	000 tonnes	167289	167289000	5998015	5998015000	8115301	8115301000	28526158
Lead	mill.tonnes	92100	92100	0	398000	2	2245000	12
Limestone	000 tonnes	256669	256669000	8978583	8978583000	14926392	14926392000	184935112

Minerals	Unit	Mine Production	Production (all in Tonnes) 2011-12	Proved Reserve	Proved Reserve - corrected for units (Tonne)	Total Reserve	Total Reserve - corrected for units (2011-12), in Tonne	Total Resource
Lithium	tonne	0	0	0	0	0	0	0
Magnesium	000 tonnes	217662	217662	20851	20851000	41950	41950000	335172
Manganese	000 tonnes	2349	2349300	97425	97425000	141977	141977000	429980
Marble	000 tonnes			103736	103736000	276495	276495000	1931463
Mercury	tonne	0	0	0	0	0	0	0
Mica	kg	1807430	1807	169840721	169841	190741448	190741	532236979
Molybdenum	tonne	0	0	0	0	0	0	19286732
Nickel	mill.tonnes	0	0	0	0	0	0	189
Niobium	tonne	0	0	0	0	0	0	0
PGM	tonne	0	0	0	0	0	0	16
Rare earths	mill.tonnes	0	0	0	0	0	0	11
Rhenium	tonne	0	0	0	0	0	0	0
Selenium	tonne	0	0	0	0	0	0	0
Silicon	000 tonnes	68	68000	4889	4889000	11464	11464000	179317
Silver	tonne	207142	207	46109414	46109414	187558668	187558668	466984959
Strontium	tonne	0	0	0	0	0	0	0
Talc	000 tonnes	11398	11398400	54615	54615000	90026	90026000	269023
Tantalum	tonne	0	0	0	0	0	0	0
Tellurium	tonne	0	0	0	0	0	0	0
Tin	tonne	48971	49	4404	4404	7131	7131	83726197
Titanium	tonne	767761	767761	15271219	15271219	22030223	22030223	393995917
Tungsten	tonne	0	0	0	0	0	0	87387464
Vanadium	tonne	0	0	293539	293539	410955	410955	24718888
Zinc	mill.tonnes	1	783647	2	1938000	12	12453000	37
Zirconium	tonne	25996	25996	1025942	1025942	1347470	1347470	3133953

Source: IBM mineral yearbook

Annexure 5: Consumption pattern of minerals within the Industry in 2011

Minerals/ Megasector	Chemicals and chemical products	Electronics and Optical products	Food & Beverages	Machinery	Manufacturing NEC, Recycling	Metals	Other non metallic Minerals (including glass)	Paper	Refining	Rubber & Plastic	Transport Equipment	Wood	Publishing & Printing	Textiles and Apparels	Leather	Tobacco
Aluminium	2.69%	24.34%	0.01%	4.48%	0.22%	47.15%	3.04%	0.54%	0.10%	1.24%	15.03%	0.26%	0.57%	0.02%	0.00%	0.07%
Antimony	4.23%	82.34%	0.04%	0.17%	0.00%	0.00%	0.41%	0.00%	0.00%	0.78%	0.92%	0.00%	0.00%	11.12%	0.00%	0.00%
Asbestos	0.13%	0.59%	0.00%	0.25%	0.00%	0.70%	96.27%	0.00%	0.00%	0.00%	2.02%	0.00%	0.00%	0.04%	0.00%	0.00%
Barium	74.29%	7.55%	0.26%	0.04%	0.00%	7.49%	9.61%	0.00%	0.00%	0.48%	0.25%	0.00%	0.00%	0.00%	0.03%	0.00%
Bentonite	34.64%	0.00%	1.01%	0.00%	0.00%	28.40%	35.15%	0.00%	0.00%	0.00%	0.74%	0.00%	0.00%	0.00%	0.03%	0.00%
Beryllium	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	99.98%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bismuth	0.00%	79.25%	0.00%	0.00%	0.00%	12.78%	0.00%	0.00%	0.00%	7.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Boron	80.74%	0.00%	0.00%	0.00%	0.00%	1.71%	1.32%	0.00%	0.00%	0.17%	0.00%	0.06%	16.01%	0.00%	0.00%	0.00%
cadmium	0.00%	13.45%	0.00%	0.01%	0.00%	62.93%	22.93%	0.00%	0.00%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
chromium	17.00%	1.03%	0.02%	0.00%	0.00%	79.27%	1.37%	0.00%	0.08%	0.05%	0.94%	0.00%	0.00%	0.01%	0.22%	0.00%
clays	19.45%	5.88%	0.06%	3.36%	0.33%	0.61%	66.45%	1.39%	0.01%	1.58%	0.12%	0.27%	0.00%	0.08%	0.40%	0.00%
Cobalt	46.63%	4.93%	0.03%	13.89%	0.03%	10.93%	18.63%	0.00%	0.00%	1.02%	2.79%	0.00%	0.00%	1.13%	0.00%	0.00%
Copper	0.47%	36.42%	0.01%	4.57%	0.09%	54.68%	0.03%	0.00%	0.00%	0.18%	3.35%	0.09%	0.00%	0.03%	0.00%	0.00%
Dolomite	15.81%	0.11%	0.12%	0.01%	0.08%	58.53%	25.19%	0.00%	0.01%	0.05%	0.01%	0.01%	0.00%	0.06%	0.00%	0.00%
Feldspar	11.15%	2.23%	0.00%	0.00%	0.00%	0.00%	86.62%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Gallium	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
germanium	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Gold	0.21%	0.09%	0.00%	0.00%	96.69%	3.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Graphite	0.04%	4.93%	0.00%	6.98%	3.98%	28.69%	42.57%	0.00%	0.00%	11.20%	1.61%	0.00%	0.00%	0.00%	0.00%	0.00%
Gypsum	1.15%	0.00%	0.15%	0.00%	0.00%	6.41%	92.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Iron	0.10%	4.07%	0.00%	7.58%	0.39%	63.92%	0.44%	0.01%	0.02%	0.25%	21.99%	1.01%	0.00%	0.00%	0.00%	0.00%
Indium	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Minerals/ Megasector	Chemicals and chemical products	Electronics and Optical products	Food & Beverages	Machinery	Manufacturing NEC, Recycling	Metals	Other non metallic Minerals (including glass)	Paper	Refining	Rubber & Plastic	Transport Equipment	Wood	Publishing & Printing	Textiles and Apparels	Leather	Tobacco
Lead	1.04%	70.46%	0.00%	0.06%	0.01%	27.88%	0.07%	0.00%	0.00%	0.03%	0.45%	0.00%	0.00%	0.00%	0.00%	0.00%
Limestone	5.80%	0.00%	0.18%	0.00%	0.00%	35.96%	57.93%	0.10%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Lithium	84.39%	0.00%	0.00%	0.00%	0.00%	0.00%	2.78%	0.00%	8.72%	4.04%	0.00%	0.00%	0.07%	0.00%	0.00%	0.00%
Magnesium	18.15%	14.43%	0.34%	1.50%	0.04%	32.09%	31.48%	0.00%	0.00%	1.41%	0.47%	0.01%	0.00%	0.00%	0.00%	0.00%
Manganese	4.85%	9.52%	0.01%	0.44%	0.01%	84.93%	0.23%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Marble	0.22%	0.00%	0.09%	0.00%	0.05%	0.00%	99.35%	0.00%	0.00%	0.00%	0.00%	0.30%	0.00%	0.00%	0.00%	0.00%
Mica	7.78%	67.73%	0.00%	1.03%	0.25%	0.50%	21.55%	0.00%	0.00%	0.00%	0.68%	0.44%	0.00%	0.02%	0.00%	0.00%
Molybdenum	2.08%	13.79%	0.00%	0.51%	0.00%	71.77%	0.08%	0.00%	1.08%	0.00%	8.62%	0.00%	0.00%	2.09%	0.00%	0.00%
Nickel	7.83%	5.38%	0.40%	7.04%	1.05%	68.11%	0.68%	0.00%	0.00%	0.39%	8.99%	0.00%	0.01%	0.00%	0.00%	0.00%
Niobium	0.00%	84.51%	0.00%	0.00%	0.00%	15.49%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PGM	15.84%	42.19%	0.00%	0.00%	41.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Rare earth(light)	1.89%	13.39%	0.00%	0.28%	0.00%	79.55%	3.65%	0.00%	0.00%	1.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Rhenium	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Selenium	66.91%	1.68%	0.00%	0.00%	0.00%	9.02%	22.39%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Silicon	0.45%	38.46%	0.00%	0.17%	0.10%	40.17%	0.97%	0.78%	0.00%	0.43%	17.41%	1.02%	0.00%	0.00%	0.00%	0.00%
Silver	0.23%	33.52%	0.09%	0.01%	61.04%	2.20%	0.54%	0.00%	0.00%	0.00%	0.39%	0.00%	0.00%	0.00%	0.00%	1.97%
Strontium	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tantalum	0.00%	19.54%	0.00%	59.98%	16.61%	3.87%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tin	7.66%	21.34%	0.00%	3.50%	0.51%	62.88%	0.00%	0.55%	0.00%	0.01%	3.55%	0.01%	0.00%	0.00%	0.00%	0.00%
Titanium	84.67%	0.45%	0.03%	1.66%	0.77%	2.47%	0.77%	1.62%	0.00%	4.39%	0.03%	0.00%	0.00%	1.87%	1.26%	0.00%
Tungsten	0.00%	44.81%	0.00%	28.69%	0.02%	21.35%	0.00%	0.00%	0.00%	0.00%	5.04%	0.00%	0.00%	0.00%	0.00%	0.00%
Vanadium	2.89%	0.55%	0.00%	0.16%	0.54%	95.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Zinc	3.67%	3.72%	2.39%	0.31%	0.03%	85.65%	1.73%	0.00%	0.04%	0.41%	1.68%	0.00%	0.00%	0.04%	0.12%	0.00%
Zirconium	12.85%	0.02%	0.00%	0.05%	0.00%	0.69%	82.14%	3.22%	0.00%	0.00%	1.03%	0.00%	0.00%	0.00%	0.00%	0.00%

Source: CEEW analysis

Annexure 6: Economic importance of minerals in 2011

S.No	Mineral	Economic Importance	Economic Importance scaled
1	Aluminium	0.01	0.34
2	Antimony	0.01	0.43
3	Asbestos	0.01	0.37
4	Barium	0.02	0.84
5	Bentonite	0.01	0.74
6	Beryllium	0.00	0.09
7	Bismuth	0.01	0.35
8	Boron	0.01	0.77
9	Cadmium	0.01	0.77
10	Chromium	0.02	0.86
11	Cobalt	0.01	0.64
12	Copper	0.01	0.29
13	Dolomite	0.01	0.36
14	Feldspar	0.01	0.45
15	Fluorite	0.00	0.00
16	Gallium	0.01	0.28
17	Germanium	0.01	0.37
18	Gold	0.01	0.32
19	Graphite	0.01	0.49
20	Gypsum	0.01	0.41
21	Indium	0.00	0.00
22	Iron	0.02	0.80
23	Lead	0.01	0.34
24	Limestone	0.01	0.55
25	Lithium	0.02	0.84
26	Magnesium	0.01	0.46
27	Manganese	0.01	0.57
28	Mica	0.01	0.36
29	Molybdenum	0.02	0.81
30	Nickel	0.02	0.85
31	Niobium	0.01	0.46
32	PGM	0.01	0.43
33	Rare earth(light)	0.02	0.88
34	Rhenium	0.01	0.37
35	Selenium	0.02	0.88
36	Silicon	0.01	0.66
37	Silver	0.01	0.31
38	Strontium	0.02	1.00
39	Tantalum	0.01	0.33
40	Tellurium	0.00	0.00
41	Tin	0.01	0.31
42	Titanium	0.02	0.78
43	Tungsten	0.01	0.33

S.No	Mineral	Economic Importance	Economic Importance scaled
44	Vanadium	0.02	0.99
45	Zinc	0.00	0.25
46	Zirconium	0.01	0.44
47	Potash	0.02	0.91
48	Phosphate	0.02	0.91
49	Rare earth(heavy)	0.00	0.00

Source: CEEW analysis

Annexure 7: Supply risks of minerals in 2011

S.No	Mineral	Economic Importance	Supply risk	Criticality score	Position
1	Aluminium	0.34	0.36	0.12	Zone-III
2	Antimony	0.43	0.77	0.33	Zone-II
3	Asbestos	0.37	0.03	0.01	Zone-III
4	Barium	0.84	0.73	0.61	Zone-I
5	Bentonite	0.74	0.42	0.31	Zone-IV
6	Beryllium	0.09	0.68	0.06	Zone-II
7	Bismuth	0.35	0.73	0.26	Zone-II
8	Boron	0.77	0.86	0.67	Zone-I
9	Cadmium	0.77	0.24	0.18	Zone-IV
10	Chromium	0.86	0.65	0.56	Zone-I
11	Cobalt	0.64	0.67	0.43	Zone-I
12	Copper	0.29	0.47	0.14	Zone-III
13	Feldspar	0.45	0.36	0.16	Zone-IV
14	Fluorite	0.00	0.86	0.00	Zone-II
15	Gallium	0.28	0.27	0.08	Zone-III
16	Germanium	0.37	0.83	0.30	Zone-II
17	Graphite	0.49	0.62	0.30	Zone-IV
18	Gypsum	0.41	0.78	0.32	Zone-II
19	Indium	0.00	0.00	0.00	Zone-III
20	Iron	0.80	0.38	0.30	Zone-IV
21	Lead	0.34	0.44	0.15	Zone-III
22	Limestone	0.48	0.78	0.37	Zone-I
23	Lithium	0.84	0.70	0.59	Zone-I
24	Magnesium	0.46	0.43	0.19	Zone-IV
25	Manganese	0.57	0.47	0.27	Zone-IV
26	Mica	0.36	0.47	0.17	Zone-III
27	Molybdenum	0.81	0.68	0.54	Zone-I
28	Nickel	0.85	0.37	0.31	Zone-IV
29	Niobium	0.46	1.00	0.46	Zone-I
30	PGM	0.43	0.55	0.24	Zone-III
31	Rare Earth(light)	0.88	0.77	0.68	Zone-I
32	Rhenium	0.37	0.56	0.20	Zone-III
33	Selenium	0.88	0.39	0.34	Zone-IV
34	Silicon	0.66	0.71	0.47	Zone-I
35	Silver	0.31	0.48	0.15	Zone-III
36	Strontium	1.00	0.91	0.91	Zone-I
37	Tantalum	0.33	0.82	0.27	Zone-II
38	Tellurium	0.00	0.89	0.00	Zone-II
39	Tin	0.31	0.25	0.08	Zone-III
40	Titanium	0.78	0.04	0.03	Zone-IV
41	Tungsten	0.33	0.64	0.21	Zone-II
42	Vanadium	0.99	0.76	0.75	Zone-I
43	Zinc	0.25	0.42	0.11	Zone-III

S.No	Mineral	Economic Importance	Supply risk	Criticality score	Position
44	Zirconium	0.44	0.58	0.26	Zone-IV
45	Potash	0.91	0.84	0.76	Zone-I
46	Gold	0.32	0.40	0.13	Zone-III
47	Dolomite	0.36	0.70	0.25	Zone-II
48	Phosphate	0.91	0.86	0.78	Zone-I
49	Rare earth(heavy)	0.00	0.00	0.00	Zone-III

Source: CEEW analysis

Annexure 8: Criticality score of minerals in 2011

S.No	Mineral	Economic Importance	Supply risk	Criticality score	Position
1	Aluminium	0.34	0.36	0.12	Zone-III
2	Antimony	0.43	0.77	0.33	Zone-II
3	Asbestos	0.37	0.03	0.01	Zone-III
4	Barium	0.84	0.73	0.61	Zone-I
5	Bentonite	0.74	0.42	0.31	Zone-IV
6	Beryllium	0.09	0.68	0.06	Zone-II
7	Bismuth	0.35	0.73	0.26	Zone-II
8	Boron	0.77	0.86	0.67	Zone-I
9	Cadmium	0.77	0.24	0.18	Zone-IV
10	Chromium	0.86	0.65	0.56	Zone-I
11	Cobalt	0.64	0.67	0.43	Zone-I
12	Copper	0.29	0.47	0.14	Zone-III
13	Feldspar	0.45	0.36	0.16	Zone-IV
14	Fluorite	0.00	0.86	0.00	Zone-II
15	Gallium	0.28	0.27	0.08	Zone-III
16	Germanium	0.37	0.83	0.30	Zone-II
17	Graphite	0.49	0.62	0.30	Zone-IV
18	Gypsum	0.41	0.78	0.32	Zone-II
19	Indium	0.00	0.00	0.00	Zone-III
20	Iron	0.80	0.38	0.30	Zone-IV
21	Lead	0.34	0.44	0.15	Zone-III
22	Limestone	0.48	0.78	0.37	Zone-I
23	Lithium	0.84	0.70	0.59	Zone-I
24	Magnesium	0.46	0.43	0.19	Zone-IV
25	Manganese	0.57	0.47	0.27	Zone-IV
26	Mica	0.36	0.47	0.17	Zone-III
27	Molybdenum	0.81	0.68	0.54	Zone-I
28	Nickel	0.85	0.37	0.31	Zone-IV
29	Niobium	0.46	1.00	0.46	Zone-I
30	PGM	0.43	0.55	0.24	Zone-III
31	Rare Earth(light)	0.88	0.77	0.68	Zone-I
32	Rhenium	0.37	0.56	0.20	Zone-III
33	Selenium	0.88	0.39	0.34	Zone-IV
34	Silicon	0.66	0.71	0.47	Zone-I
35	Silver	0.31	0.48	0.15	Zone-III
36	Strontium	1.00	0.91	0.91	Zone-I
37	Tantalum	0.33	0.82	0.27	Zone-II
38	Tellurium	0.00	0.89	0.00	Zone-II
39	Tin	0.31	0.25	0.08	Zone-III
40	Titanium	0.78	0.04	0.03	Zone-IV
41	Tungsten	0.33	0.64	0.21	Zone-II
42	Vanadium	0.99	0.76	0.75	Zone-I
43	Zinc	0.25	0.42	0.11	Zone-III

S.No	Mineral	Economic Importance	Supply risk	Criticality score	Position
44	Zirconium	0.44	0.58	0.26	Zone-IV
45	Potash	0.91	0.84	0.76	Zone-I
46	Gold	0.32	0.40	0.13	Zone-III
47	Dolomite	0.36	0.70	0.25	Zone-II
48	Phosphate	0.91	0.86	0.78	Zone-I
49	Rare earth(heavy)	0.00	0.00	0.00	Zone-III

Source: CEEW analysis

Annexure 9: List of countries used in regression analysis

Name	Acronym	Name	Acronym
Australia	AUS	Japan	JPN
Austria	AUT	Korea, Republic of	KOR
Belgium	BEL	Latvia	LVA
Brazil	BRA	Lithuania	LTU
Bulgaria	BGR	Luxembourg	LUX
Canada	CAN	Malta	MLT
China	CHN	Mexico	MEX
Cyprus	CYP	Netherlands	NLD
Czech Republic	CZE	Poland	POL
Denmark	DNK	Portugal	PRT
Estonia	EST	Romania	ROU
Finland	FIN	Russia	RUS
France	FRA	Slovak Republic	SVK
Germany	DEU	Slovenia	SVN
Greece	GRC	Spain	ESP
Hungary	HUN	Sweden	SWE
India	IND	Taiwan	TWN
Indonesia	IDN	Turkey	TUR
Ireland	IRL	United Kingdom	GBR
Italy	ITA	United States	USA

Source: World Input Output Database

Annexure 10: Future sectoral value adds

	Future Estimation - 2030	IESS-A	IESS-B	IESS-C	2011	Actual-2011	Compound Annual Growth Rate
Sectors(Value add per capita PPP, $)	9297	8887	8004	6990	4245	4245	
Chemicals and chemical products	98	127	113	98	60	75	1.43%
Electronics and Optical products	149	188	170	149	96	30	8.80%
Food & Beverages	235	288	264	235	157	54	8.05%
Machinery	44	67	56	44	82	23	3.40%
Manufacturing NEC, Recycling	43	54	49	43	27	26	2.61%
Metals	202	248	227	202	135	99	3.83%
Other non metallic Minerals (including glass)	86	104	96	86	58	30	5.74%
Paper	85	110	99	85	53	7	13.73%
Refining	64	77	71	64	41	50	1.29%
Rubber , Plastic	51	64	58	51	33	21	4.69%
Transport Equipment	135	167	152	135	90	47	5.73%
Leather	22	26	24	22	15	21	0.34%
Wood	27	35	31	27	16	8	6.67%
Textiles	120	143	133	120	124	46	5.21%

Source: CEEW analysis

Annexure 11: Consumption pattern of minerals within European industrial economy

Minerals	Chemicals and chemical products	Electronics and Optical products	Food & Beverages	Machinery	Manufacturing NEC, Recycling	Metals	Other non metallic Minerals (including glass)	Paper	Refining	Rubber , Plastic	Transport Equipment	Wood
Aluminium	0%	0%	0%	14%	7%	16%	26%	0%	0%	0%	37%	0%
Antimony	52%	7%	0%	0%	0%	22%	0%	0%	0%	0%	20%	0%
Asbestos	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Barium	0%	0%	0%	0%	5%	0%	0%	0%	95%	0%	0%	0%
Bentonite	4%	0%	4%	0%	29%	45%	11%	4%	2%	0%	0%	0%
Beryllium	0%	40%	0%	25%	4%	3%	3%	0%	0%	0%	25%	0%
Bismuth	67%	15%	0%	0%	0%	8%	10%	0%	0%	0%	0%	0%
Boron	24%	0%	0%	0%	2%	5%	69%	0%	0%	0%	0%	0%
Cadmium	10%	4%	0%	86%	0%	0%	0%	0%	0%	0%	0%	0%
Chromium	0%	0%	0%	0%	1%	99%	0%	0%	0%	0%	0%	0%
Clays	0%	0%	0%	0%	18%	0%	66%	17%	0%	0%	0%	0%
Cobalt	18%	37%	0%	0%	8%	37%	0%	0%	0%	0%	0%	0%
Copper	0%	47%	0%	12%	12%	0%	13%	0%	0%	0%	14%	0%
Dolomite	0%	0%	0%	92%	0%	0%	2%	0%	0%	6%	0%	0%
Feldspar	0%	0%	0%	0%	30%	0%	70%	0%	0%	0%	0%	0%
Fluorite	52%	0%	0%	0%	5%	43%	0%	0%	0%	0%	0%	0%
Gallium	0%	83%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%
Germanium	25%	70%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%
Gold	2%	13%	0%	0%	86%	0%	0%	0%	0%	0%	0%	0%
Graphite	5%	7%	0%	0%	3%	39%	46%	0%	0%	0%	0%	0%
Gypsum	0%	0%	0%	0%	10%	0%	90%	0%	0%	0%	0%	0%
Indium	0%	94%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%
Iron	0%	5%	0%	14%	0%	64%	0%	0%	0%	0%	17%	0%
Lead	9%	76%	0%	0%	8%	7%	0%	0%	0%	0%	0%	0%
Limestone	21%	0%	0%	0%	0%	21%	36%	22%	0%	0%	0%	0%

Minerals	Chemicals and chemical products	Electronics and Optical products	Food & Beverages	Machinery	Manufacturing NEC, Recycling	Metals	Other non metallic Minerals (including glass)	Paper	Refining	Rubber , Plastic	Transport Equipment	Wood
Lithium	13%	22%	0%	4%	22%	6%	0%	30%	0%	3%	0%	0%
Magnesium	5%	0%	0%	0%	11%	83%	1%	0%	0%	0%	0%	0%
Manganese	0%	6%	0%	34%	5%	16%	25%	0%	0%	0%	15%	0%
Mercury	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mica	22%	0%	0%	0%	21%	0%	54%	0%	0%	3%	0%	0%
Molybdenum	17%	8%	0%	20%	7%	0%	6%	0%	18%	0%	24%	0%
Nickel	0%	0%	0%	0%	5%	91%	0%	0%	0%	0%	0%	0%
Niobium	0%	0%	0%	3%	6%	36%	31%	0%	24%	0%	0%	0%
PGM	7%	10%	0%	0%	23%	3%	1%	0%	1%	0%	55%	0%
Rare earths	16%	11%	0%	0%	7%	15%	13%	17%	14%	0%	7%	0%
Rhenium	9%	0%	0%	15%	6%	0%	0%	0%	2%	0%	68%	0%
Selenium	20%	10%	0%	0%	5%	40%	25%	0%	0%	0%	0%	0%
Silicon	54%	8%	0%	0%	0%	38%	0%	0%	0%	0%	0%	0%
Silver	11%	28%	0%	0%	54%	7%	0%	0%	0%	0%	0%	0%
Talc	36%	0%	1%	0%	4%	0%	9%	15%	0%	35%	0%	0%
Tantalum	6%	52%	0%	21%	0%	21%	0%	0%	0%	0%	0%	0%
Tellurium	0%	70%	0%	0%	10%	15%	0%	0%	0%	5%	0%	0%
Tin	15%	45%	0%	9%	8%	21%	2%	0%	0%	0%	0%	0%
Titanium	56%	0%	0%	0%	3%	5%	0%	9%	0%	27%	0%	0%
Tungsten	0%	17%	0%	77%	0%	6%	0%	0%	0%	0%	0%	0%
Vanadium	4%	0%	0%	32%	1%	63%	0%	0%	0%	0%	0%	0%
Zinc	6%	0%	0%	0%	4%	90%	0%	0%	0%	0%	0%	0%
Zirconium	74%	13%	0%	0%	0%	0%	0%	3%	0%	0%	0%	9%

Source: Adapted from (European Commissions Enterpise and Industry, 2014)

Annexure 12: Economic Importance of minerals in 2030

S.No	Mineral	Economic Importance	Economic Importance scaled
1	Aluminium	0.01	0.39
2	Antimony	0.01	0.48
3	Asbestos	0.01	0.35
4	Barium	0.01	0.18
5	Bentonite	0.02	0.60
6	Beryllium	0.02	0.59
7	Bismuth	0.01	0.51
8	Boron	0.01	0.42
9	Cadmium	0.01	0.21
10	Chromium	0.02	0.99
11	Cobalt	0.01	0.41
12	Copper	0.02	0.58
13	Dolomite	0.01	0.15
14	Feldspar	0.01	0.26
15	Fluorite	0.01	0.25
16	Gallium	0.02	0.73
17	Germanium	0.02	0.75
18	Gold	0.01	0.17
19	Graphite	0.02	0.64
20	Gypsum	0.01	0.32
21	Indium	0.02	0.88
22	Iron	0.02	0.83
23	Lead	0.02	0.72
24	Limestone	0.01	0.53
25	Lithium	0.01	0.46
26	Magnesium	0.01	0.00
27	Manganese	0.01	0.47
28	Mica	0.01	0.32
29	Molybdenum	0.01	0.43
30	Nickel	0.02	0.90
31	Niobium	0.01	0.52
32	PGM	0.02	0.55
33	Rare Earths(light)	0.02	0.60
34	Rhenium	0.02	0.59
35	Selenium	0.01	0.27
36	Silicon	0.02	0.73
37	Silver	0.01	0.33
38	Rare Earths(Heavy)	0.02	0.77
39	Tantalum	0.02	0.73
40	Tellurium	0.02	0.82
41	Tin	0.01	0.49
42	Titanium	0.01	0.35
43	Tungsten	0.01	0.26

S.No	Mineral	Economic Importance	Economic Importance scaled
44	Vanadium	0.02	0.70
45	Zinc	0.01	0.00
46	Strontium	0.02	1.00
47	Potash	0.01	0.52
48	Phosphate	0.01	0.52
49	Zirconium	0.02	0.56

Source: CEEW analysis

Annexure 13: Supply risk of minerals in 2030

Mineral	Supply risk score	Supply risk scaled	Geopolitical risk	Substitution risk	Recyclability risk	India Import dependency
Aluminium	0.5	0.34	0.1	0.70	0.64	53%
Antimony	0.6	0.61	0.5	0.62	0.75	100%
Asbestos	0.3	0.06	0.3	0.00	0.60	91%
Barium	0.7	0.67	0.2	0.99	1.00	24%
Bentonite	0.5	0.47	0.1	0.60	1.00	45%
Beryllium	0.7	0.70	0.4	0.93	0.75	100%
Bismuth	0.7	0.63	0.3	0.70	0.99	100%
Boron	0.7	0.70	0.2	0.90	1.00	100%
Cadmium	0.2	0.00	0.1	0.36	0.25	100%
Chromium	0.6	0.62	0.2	0.97	0.80	100%
Cobalt	0.6	0.57	0.5	0.70	0.68	100%
Copper	0.4	0.31	0.1	0.63	0.63	68%
Feldspar	0.5	0.44	0.1	0.58	1.00	0%
Fluorite	0.6	0.62	0.3	0.81	1.00	41%
Gallium	0.5	0.37	0.3	0.63	0.50	100%
Germanium	0.6	0.63	0.6	0.87	0.50	100%
Graphite	0.7	0.64	0.6	0.66	1.00	58%
Gypsum	0.6	0.54	0.1	0.72	0.99	100%
Indium	0.5	0.44	0.3	0.82	0.50	100%
Iron	0.5	0.39	0.2	0.91	0.48	48%
Lead	0.4	0.23	0.2	0.62	0.37	81%
Limestone	0.6	0.55	0.0	0.79	1.00	19%
Lithium	0.7	0.66	0.2	0.82	0.99	100%
Magnesium	0.5	0.44	0.4	0.72	0.67	49%
Manganese	0.6	0.48	0.1	0.96	0.63	68%
Mica	0.4	0.29	0.2	0.14	1.00	83%
Molybdenum	0.6	0.62	0.2	1.09	0.67	100%
Nickel	0.5	0.33	0.1	0.70	0.59	100%
Niobium	0.7	0.70	0.6	0.70	0.78	100%
PGM	0.6	0.54	0.3	0.84	0.63	100%
Rare earths	0.8	0.81	0.7	0.72	0.90	100%
Rhenium	0.6	0.60	0.2	0.94	0.75	100%
Selenium	0.5	0.39	0.1	0.49	0.90	100%
Silicon	0.7	0.64	0.2	0.81	1.00	66%
Silver	0.5	0.36	0.1	0.73	0.68	26%
Strontium	0.7	0.76	0.5	0.70	1.00	100%
Tantalum	0.7	0.76	0.6	0.83	0.75	100%
Tellurium	0.5	0.47	0.2	0.46	1.00	100%
Tin	0.5	0.40	0.2	0.62	0.78	53%
Titanium	0.3	0.06	0.1	0.33	0.48	43%
Tungsten	0.6	0.54	0.5	0.70	0.54	100%
Vanadium	0.6	0.54	0.3	0.50	1.00	100%

Mineral	Supply risk score	Supply risk scaled	Geopolitical risk	Substitution risk	Recyclability risk	India Import dependency
Zinc	0.5	0.43	0.1	0.72	0.73	100%
Zirconium	0.6	0.57	0.1	0.83	0.90	82%
Marble	0.3	0.15	0.0	0.00	1.00	0%
Potash	0.7	0.71	0.1	1.00	1.00	100%
Phosphate	0.7	0.74	0.2	1.00	1.00	81%
Dolomite	0.6	0.51	0.0	0.72	1.00	49%
Clays	0.6	0.56	0.0	0.82	1.00	63%
Talc	0.5	0.40	0.1	0.40	1.00	100%
Rare Earths(Heavy)	0.9	1.00	0.7	1.00	0.99	100%
Gold	0.5	0.37	0.0	0.74	0.69	38%

Source: CEEW analysis

Annexure 14: Criticality scores of minerals for 2030

S.No	Mineral	Economic Importance	Supply risk	Criticaility Score	Position
1	Antimony	0.48	0.61	0.29	Zone-II
2	Asbestos	0.35	0.06	0.02	Zone-III
3	Barium	0.18	0.67	0.12	Zone-II
4	Aluminium	0.39	0.34	0.13	Zone-III
5	Bentonite	0.60	0.47	0.28	Zone-IV
6	Beryllium	0.59	0.70	0.41	Zone-I
7	Bismuth	0.51	0.63	0.32	Zone-II
8	Boron	0.42	0.70	0.29	Zone-II
9	Cadmium	0.21	0.00	0.00	Zone-III
10	Chromium	0.99	0.62	0.61	Zone-I
11	Cobalt	0.41	0.57	0.23	Zone-II
12	Copper	0.58	0.31	0.18	Zone-IV
13	Dolomite	0.15	0.51	0.07	Zone-III
14	Feldspar	0.26	0.44	0.11	Zone-III
15	Fluorite	0.25	0.62	0.16	Zone-II
16	Gallium	0.73	0.37	0.27	Zone-IV
17	Germanium	0.75	0.63	0.47	Zone-I
18	Gold	0.17	0.37	0.06	Zone-III
19	Graphite	0.64	0.64	0.41	Zone-I
20	Gypsum	0.32	0.54	0.17	Zone-II
21	Indium	0.88	0.44	0.39	Zone-IV
22	Iron	0.83	0.39	0.32	Zone-IV
23	Lead	0.72	0.23	0.17	Zone-IV
24	Lithium	0.46	0.66	0.30	Zone-II
25	Magnesium	0.00	0.44	0.00	Zone-III
26	Manganese	0.47	0.48	0.23	Zone-III
27	Mica	0.32	0.29	0.09	Zone-III
28	Molybdenum	0.43	0.62	0.26	Zone-II
29	Nickel	0.90	0.33	0.30	Zone-IV
30	Niobium	0.52	0.70	0.37	Zone-I
31	PGM	0.55	0.54	0.30	Zone-IV
32	Rare earths(Light)	0.60	0.81	0.49	Zone-I
33	Silver	0.33	0.36	0.12	Zone-III
34	Selenium	0.27	0.39	0.11	Zone-III
35	Tantalum	0.73	0.76	0.55	Zone-I
36	Tellurium	0.82	0.47	0.38	Zone-IV
37	Tin	0.49	0.40	0.20	Zone-III
38	Titanium	0.35	0.06	0.02	Zone-III
39	Tungsten	0.26	0.54	0.14	Zone-III
40	Vanadium	0.70	0.54	0.38	Zone-IV
41	Zinc	0.00	0.43	0.00	Zone-III
42	Zirconium	0.56	0.57	0.32	Zone-I
43	Limestone	0.53	0.55	0.29	Zone-I

S.No	Mineral	Economic Importance	Supply risk	Criticaility Score	Position
44	Rhenium	0.59	0.60	0.35	Zone-I
45	Strontium	1.00	0.76	0.76	Zone-I
46	Silicon	0.73	0.64	0.47	Zone-I
47	Rare Earths(heavy)	0.77	1.00	0.77	Zone-I
48	Potash	0.52	0.71	0.36	Zone-II
49	Phosphate	0.52	0.74	0.38	Zone-II

Source: CEEW analysis

Annexure 15: Bottom up analysis for minerals required by electronics industry

Minerals	Consumption in 2011 (tonnes)	Total Demand in 2030 (tonnes)	Times of current consumption (in log10 scale)	Import Dependency-2011
Indium	Insignificant	92	5.08	100%
Gallium	Insignificant	37	2.83	100%
Rare earths	16	1925	2.08	100%
Tantalum	57	566	0.99	100%
PGM	2	13	0.91	100%
Graphite	2522	13674	0.73	11%
Selenium	1	5	0.73	100%
Gold	34	140	0.62	0%
Antimony	355	1250	0.55	100%
Lead	24794	85409	0.54	45%
Silver	1168	4021	0.54	96%
Barium	18838	64125	0.53	1%
Copper	1262482	4288525	0.53	38%
Germanium	2	7	0.53	100%
Telllurium	7	22	0.53	100%

Source: CEEW analysis

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Citation:	The report may be cited as DST (2016): A report on 'Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030'; Vaibhav Gupta, Tirtha Biswas, Karthik Ganesan, Council on Energy, Environment and Water. New Delhi, India
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