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MINISTRY OF ELECTRONICS AND INFORMATION TECHNOLOGY

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Report on Critical Raw Materials & Secondary Raw Materials in Electrical and Electronics Sector in India

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EU-India Joint Study

Toxics Link
for a toxics-free world

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Authors
Toxics Link
Dr Kalyan Bhaskar, Mr. Satish Sinha

Reviewers
WEEE Forum
Mr Pascal Leroy, Ms Lucía Herreras Martínez

Project Consortium Lead and Review
Dr Rachna Arora, Dr Reva Prakash, Dr Katharina Paterok, Ms Mehar Kaur

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Report on Critical Raw Materials & Secondary Raw Materials in Electrical and Electronics Sector in India

एस. कृष्णन, आई.ए.एस.
सचिव
S. Krishnan, I.A.S.
Secretary

सत्यमेव जयते

इलेक्ट्रॉनिकी और सूचना प्रौद्योगिकी मंत्रालय
भारत सरकार
Ministry of Electronics &
Information Technology (MeitY)
Government of India

Foreword

'*Circular Economy*' is the new 'Mantra' for future development and growth. Circular economy approach is imperative to fulfill the need of resources for the growing economy, like India. It minimizes the wastage at each life-cycle stage and promotes 4Rs (i.e. reuse, repair, recover, re-manufacture) and also ensures regeneration of products and materials.

India is the third largest consumer of raw materials produced globally. If current economic trends persist, then India's material consumption would reach nearly 15 billion tonnes by 2030 and above 25 billion tonnes by 2050. In order to fulfill the resources need, it is essential to follow circular economy approach rather than the current linear economy principle of take-make-dispose.

This study report prepared under European Union – Resource Efficiency Initiative (EU-REI), India on circular economy in E-waste provides an international scenario on global best practices to be adopted by Indian Manufacturer and Recyclers. Promotion of eco-design & Green products, scientific extraction and reuse of SRM & CRM in manufacturing value chain would be a forthcoming step in the country. This report ensures an India-centric approach to understand the preparedness of circular economy business models, identify gaps and opportunities, as also to formulate evidence-based policy recommendations.

I compliment EU-REI team for this comprehensive well-researched report on Global best practices in circular economy in E-waste.

Best Wishes,

(S. Krishnan)

Dated: 22.9.2023
Place: New Delhi

आज़ादी का अमृत महोत्सव

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इलेक्ट्रॉनिक्स निकेतन, 6, सी.जी.ओ. कॉम्पलेक्स, नई दिल्ली–110003 / Electronics Niketan, 6, C.G.O. Complex, New Delhi-110003
Tel. : 011-24364041 • email : secretary@meity.gov.in

CONTENTS

LIST OF ABBREVIATIONS

BRSR	Business Responsibility and Sustainability Reporting
CPCB	Central Pollution Control Board
CMIE	Centre for Monitoring of Indian Economy
CRM	Critical Raw Materials
EEE	Electrical and Electronic Equipment
EMC	Electronics Manufacturing Clusters
ELV	End-of-Life Vehicles
EU	European Union
EPR	Extended Producer Responsibility
FutuRaM	Future Availability of Secondary Raw Materials
GPN	Global Production Networks
GST	Goods and Services Tax
GDP	Gross Domestic Product
INDC	Intended Nationally Determined Contributions
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KABIL	KhanijBidesh India Limited
LCA	Life Cycle Assessment
LiFE	Lifestyle for Environment
MeitY	Ministry of Electronics & Information Technology
MoM	Ministry of Mines
Mt	Million tonnes
MSP	Minerals Security Partnership
M-SIPS	Modified Special Incentive Package Scheme
NPE	National Policy for Electronics
PGM	Platinum Group of Metals
ProSUM	Prospecting Secondary Raw Materials in the Urban Mine and Mining Wastes
REE	Rare Earth Elements
SPECS	Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors
SRM	Secondary Raw Materials
SEZ	Special Economic Zone
SDG	Sustainable Development Goals
TCFD	Taskforce on Climate Related Financial Disclosures
TNFD	Taskforce on Nature Related Financial Disclosures
UMKDP	Urban Mine Knowledge Data Platform

1. INTRODUCTION

Driven by various global, regional, national, and local concerns, policies, and market mechanisms, sustainability has become one of the most pressing agendas for organisations in the public and private sector today. The adoption of the 17 Sustainable Development Goals (SDGs) by the United Nations in 2015 was one of the most important global initiatives in recent times. Inspired by SDGs, the Indian government has introduced Mission Life (Lifestyle for Environment) as an India-led global mass movement to nudge individuals and community action to protect the environment. Among other things, initiatives like SDGs and Mission Life highlight the need to bring about a change in global production and consumption patterns so as to transition from a linear economy to a circular economy.

SDG 12 on responsible consumption and production has eight main targets and three sub-targets. These include ensuring the sustainable management and efficient use of natural resources, substantially reducing waste generation through technological and behavioural changes (prevention, reduction, reuse, recycling), encouraging companies to adopt sustainable practices and adopt sustainability reporting, promoting sustainable public procurement, and achieving environmentally sound management of waste throughout their life cycle. Achievement of these targets could also help in meeting other SDGs, in particular SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities and communities), and SDG 13 (climate action).

The adoption of the 17 Sustainable Development Goals (SDGs) by the United Nations in 2015 was one of the most important global initiatives in recent times.

A number of policies, market mechanisms, and approaches have been adopted and introduced by governments and companies to promote responsible consumption and production. These include using a life cycle assessment (LCA) approach for evaluating products and services, adopting circular economy initiatives, making the supply chain sustainable, and publishing sustainability reports. While these are relevant for all industries and sectors, these become particularly more important for the global electrical and electronics equipment (EEE) sector.

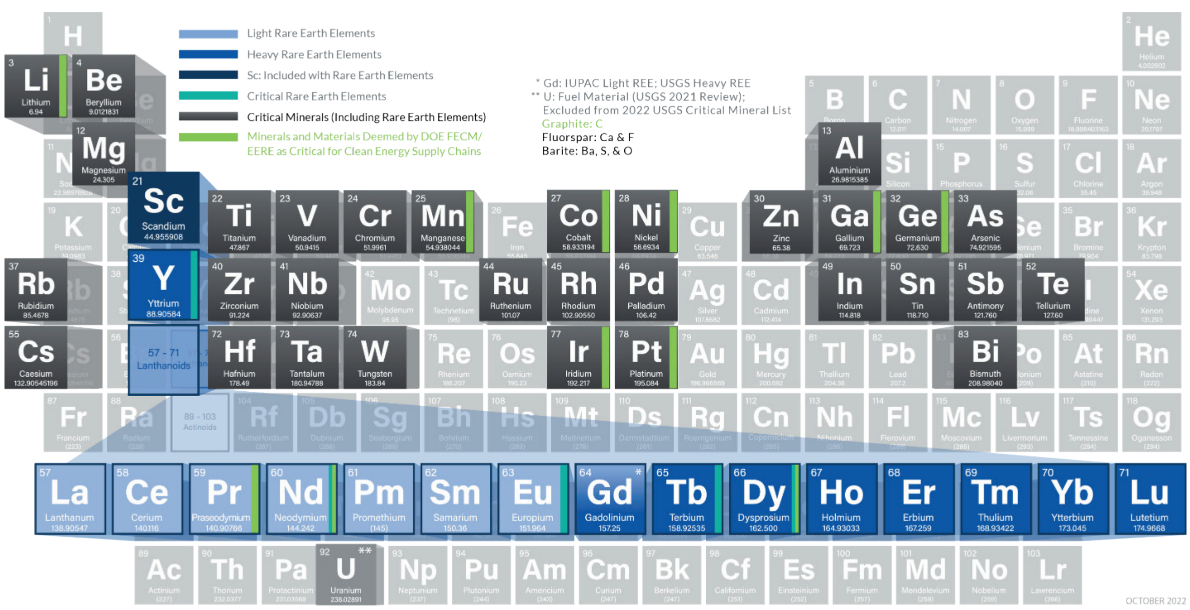
The global EEE sector plays a vital role in today's technology-enabled interconnected world. It encompasses a wide range of industries, including consumer electronics, telecommunications, automotive, and industrial equipment. The sector is of paramount importance to the global economy, contributing significantly to GDP and employment. As per a recent estimate[1], the current size of the EEE sector is around US$ 3.7 trillion in 2023 and is estimated to grow to US$ 5 trillion by 2027. In terms of the consumer electronics segment, the total global market was estimated to be around US$ 1 trillion in 2022[2]. The major manufacturing locations for EEE products are primarily concentrated in China, the United States, Japan, South Korea, Germany, and Taiwan, countries that possess advanced manufacturing capabilities and the necessary infrastructure. In terms of consumption, developed economies such as the United States, European countries, and Japan are the major consuming locations.

Three distinguishing features of the EEE sector make SDG 12 on responsible consumption and production more relevant and challenging. The first is the nature of production and consumption in the EEE sector. The EEE sector operates through complex Global Production Networks (GPNs), with supply chains spanning across multiple countries and often continents, involving raw material extraction, material processing and refining, component manufacturing, product assembly, product sales, and waste generation, resulting in truly global production and consumption. In many other sectors, much of production and consumption is restricted to a particular geographic cluster and, thereby, it is relatively easier, effective, and efficient for the governments and companies to adopt and implement sustainable policies and practices. However, the global production network (GPN) nature of the EEE sector makes it harder for any domestic policies or practices to have a tangible and sustainable impact.

The second distinguishing feature of the EEE sector that makes SDG 12 more relevant and challenging is the nature and volume of waste generated from the consumption of EEE. Waste EEE, also known as e-waste, contains many toxic and non-toxic components, including plastics, wood, metallic and non-metallic components, precious metals, rare earth, etc. This combination of different types of components in e-waste with varying physical and chemical properties makes managing e-waste daunting for local agencies. The rapid rise in e-waste compounds this problem. As per Global E-waste Monitor 2020[3], the total global e-waste generation is expected to increase from 53.6 million tonnes (Mt) in 2019 to 74.7 Mt by 2030.

The third, and somewhat connected with the second, feature of the EEE sector deals with the composition of materials required for manufacturing EEE. EEE requires several rare-earth metals and other critical minerals, some of which are found in relatively limited quantities, and many which are difficult to extract and process and are in the hands of just a few countries (see Figure 1 for a description of light and heavy rare earths, and critical minerals). The economic importance of these materials in combination with their risky supply make adoption of responsible consumption and production even more important for the EEE sector.

FIGURE 1: CRITICAL MINERALS (INCLUDING RARE EARTH ELEMENTS)[4]



In addition to these distinguishing features of the EEE sector, there have been many recent developments in the last few weeks in 2023 that have brought global and domestic attention to the sector and the materials used as inputs in the sector. In the first week of July 2023, China announced imposing restrictions on the exports of Gallium and Germanium products used in the EEE sector, especially computer chips and other components. This rather unexpected move is being seen as response to other global developments, particular the U.S. curbs on sale of technologies to China[5]. Earlier in August 2022, the U.S. President had signed the CHIPS and Science Act of 2022 that aims to boost domestic research, development, and production of semiconductors and reduce dependence on foreign countries[6]. These, and other related, developments are likely to have an impact on Indian economy in general, and the EEE sector in particular, as well[7].

Given this backdrop, the different chapters of this report provide an overview of the policies and practices related to the circular economy and resource efficiency in the EEE sector. The chapters focus on topics like critical raw materials (CRM) and secondary raw materials (SRM), recycling, eco-design, and circular economy indicators.

These chapters aim to provide a detailed overview of the policies and practices for critical raw materials (CRMs) and secondary raw materials (SRMs) used in the EEE sector in both the global and the Indian context. Furthermore, it delves into the primary and secondary raw materials essential for the Electronics and Electrical sector in India. It encompasses the methodology and data analysis for both CRMs and SRMs, while also exploring the technology and approaches for recycling at a global level, including platforms such as ProSUM and the urban mine platform.

1.1 EEE Sector in the Indian Context

The EEE sector plays a significant role in India's industrial landscape and contributes a substantial portion to the country's GDP. India has emerged as a popular manufacturing hub in this sector, witnessing remarkable growth in domestic electronics production. According to IBEF India[8], the production of electronics in India has increased from US$ 29 billion in 2014-15 to US$ 67 billion in 2020-21. This growth has positioned the electronics sector as a key contributor, accounting for approximately 3.4% of India's GDP. Exports have been on a rising trend for the last five years but have lagged imports every year in this period. Table 1 provides an overview of the trade in the EEE sector in India in the last decade.

TABLE 1: TRADE IN EEE SECTOR: INDIAN CONTEXT[9][10][11]

Year	Exports (US$ bn)	Imports (US$)	Deficit (US$)
2014-15	6.0	36.9	- 30.8
2015-16	5.7	40.0	- 34.3
2016-17	5.7	41.9	- 36.2
2017-18	6.1	51.5	- 45.5
2018-19	8.4	55.5	- 47.1
2019-20	11.2	49.3	- 38.1
2020-21	10.6	52.4	- 41.8
2021-22	15.0	70.8	- 56.0
2022-23	25.3	73.4	- 48.1

On the policy front, the Indian government has taken several initiatives to promote the EEE sector in India. In 2012, the Modified Special Incentive Package Scheme (M-SIPS)[12] was introduced to promote large-scale electronics manufacturing in India. The scheme provided a capital subsidy of 25% for the electronics industry in non-SEZ areas and 20% for those in SEZ areas. At the time of the revision of this scheme in December 2018, 197 applications (proposed investment of approximately INR 41,791 Crores) out of the 419 investment proposals received had been approved. Among the 197 approved units, 134 units had commenced commercial production. These units reported a total capital investment of INR 9,961 Crores and total sales of INR 74,921 Crores, with exports worth INR 16,418 Crores. In June 2022, the Indian government approved further proposals worth INR 86,824 Crores under the revised M-SIPS.

In 2019, the National Policy for Electronics 2019 (NPE 2019)[13] was introduced as a comprehensive framework with the aim of making India a global hub for electronics manufacturing. It focused on increasing domestic value addition, promoting innovation and R&D, and creating a favourable business environment through initiatives like the Electronics Manufacturing Clusters (EMCs). In April 2020, another scheme called the Scheme for Promotion of Manufacturing of Electronic Components & Semiconductors (SPECS)[14] was launched to strengthen electronics manufacturing by targeting the downstream value chain comprising digital parts, semiconductor/display fabrication units, specialised sub-assemblies, and capital goods for the manufacture of these components. In April 2023, the scheme was extended by one more year[15].

The global shortage of semiconductor chips, observed during the 2020 pandemic, created a need for taking strategic measures and the Indian Government directed its attention toward the domestic manufacturing of semiconductor chips, recognizing their significance in electrical and electronic equipment Last year (2022), the Ministry of Electronics & Information Technology released the second volume of the Vision document on Electronics Manufacturing in India[16]. The vision document predicts continued expansion of electronics manufacturing and exports from India, with the manufacturing estimated to reach US$ 300 billion by 2025-26.

During the recent visit of the Indian PM Modi to the USA in June 2023, the Indian government invited Micron Technology, one of the leading chip makers in the world, to set up its manufacturing base in India[17]. Later in the same month, the Indian Cabinet approved Micron's US$2.7 billion plan and further authorised production-linked incentives amounting to US$ 1.34 billion (INR 110 billion) for the establishment of Micron's plant in Gujarat. The Indian Government also released a list of 30 'critical minerals' in the report titled Critical Minerals for India[18].It has also, since then, announced plans to boost exploration and mining of these 'critical minerals' in India. These different policy initiatives reflect India's commitment to nurturing the EEE sector and attracting investments in electronics manufacturing. The ambitious targets reflect the commitment of the Indian government to position India as a global manufacturing powerhouse in EEE.

These policies and ambitious targets warned India to ensure steps to strategically manage access to materials required for electronics manufacturing. Understanding the significance of the different raw materials is crucial, as they form the foundation for not just the EEE sector but associated sectors like automobile, auto-components, and cleantech among others. Raw materials can be classified as either primary (extracted directly from nature) or secondary (retrieved or derived from recycling or reprocessing waste materials) based upon the source and manner of extraction. Based on some dimensions like scarcity or supply risk and economic importance, some raw materials can become critical, and the next chapter provides a discussion on such critical raw materials (CRM). On the other hand, if raw materials are available from secondary resources, it will reduce the environmental and social costs associated with mining, reduce reliance on primary raw materials, conserve existing resources, and also improve material security for materials with high import dependence. Such materials, also known as secondary raw materials (SRM) are discussed in the third chapter.

Analysing the global context of CRM and SRM will provide valuable insights into the dimensions of criticality associated with specific raw materials and the policies implemented by countries to ensure their sustainable supply. Additionally, examining the Indian context is crucial, as it highlights the predominant role played by the informal sector in both raw material extraction and recycling. To effectively address the challenges posed by CRMs and SRMs, efficient and effective recycling approaches are essential. Later in this report, different recycling technologies and approaches adopted globally are explored, with a specific focus on platforms like the Urban Mine Platform, a deliverable of ProSUM (Prospecting the Secondary Raw Materials in the Urban Mine and Mining Wastes), an EU grant funded project[19], which facilitates the data collection, analysis, and information - based decision-making. The Indian context is also examined, shedding light on the recycling practices prevalent in the country.

Considering the insights gained from the global and Indian perspectives, this report concludes with policy recommendations tailored specifically for India. These recommendations aim to enhance the sustainable management of CRMs and SRMs, promote responsible extraction and recycling practices, and foster a more circular economy in the EEE sector.

In summary, this report endeavours to provide a comprehensive understanding of CRMs and SRMs, encompassing their criticality, global and Indian contexts, recycling approaches, and policy implications. By offering data-driven insights and policy recommendations, this report aims to contribute to the sustainable management of raw materials, fostering economic growth and environmental preservation in India.

2. CRITICAL RAW MATERIALS

2.1 Methodology

There is no single globally acceptable definition of critical minerals or critical raw materials (CRM) yet. The term has been defined in different ways in various national policies, strategies, technical reports, and published literature. As such, the first few steps in our methodology involve understanding the different definitions and dimensions of criticality and then drawing insights from those for our report. This is done by an extensive review of a) various national policies and strategies, b) different technical reports published by policy thinktanks and research institutions, and c) academic papers published in peer-reviewed journals. The key insights from these tables are analysed and discussed next.

This is then followed by a discussion on the insights that emerged from an analysis of primary data and secondary data. For the former, a stakeholder mapping was first carried out to identify the relevant stakeholders for CRM and secondary raw materials (SRM) in the EEE sector. The stakeholder mapping process is described in the next sub-section. After that mapping, primary data was collected through various interviews, one seminar (conducted in December 2022), one webinar (conducted in June 2023), and two workshops (conducted in April 2023). Industry experts, researchers, and policymakers participated in these discussions, providing valuable perspectives on CRM, supply chain vulnerabilities, and potential solutions. The data on latter involved figures for mineral production, imports, and consumption and was collected through governmental and industry databases.

Following these, we identify the appropriate definition and dimensions of critical raw materials (CRM) and then distil it further by identifying the CRM for EEE sector in India. In doing so, we use a combination of data and expert judgement for assessing criticality, a practice common in criticality studies. Import-export data from the Indian Government specifically focused on the EEE sector CRM, was analysed to examine trade dynamics. This analysis aimed to identify the key Critical Minerals on which India relied and assess the country's import dependency, helping to identify areas requiring a sustainable and diversified supply of Critical Minerals.

2.1.1 Stakeholder Mapping

A crucial aspect of our report on CRM assessment for the EEE sector is the understanding of the various stakeholders involved in the domain. Through stakeholder mapping, we identified key actors who have a significant interest or influence in the management of CRM and SRM. These included industry associations, Policy makers for CRM, subject matter experts, environmentalists, and recyclers.

Industry and Industry associations: This group included electrical and electronic goods manufacturers and other producers who are key stakeholders in the critical minerals landscape. These industries heavily rely on critical minerals for their manufacturing process, products development, and technological advancements. Such engagement provided us insights into their specific mineral requirements, challenges they face due to scarcity or supply chain vulnerabilities, and potential strategies for securing a sustainable supply. We engaged with various producers' representatives, such as HP and Dell. We also engaged with Tata Steel, the pioneer iron and steel manufacturer in India, that has also recently started expanding in urban mines and recycling of ferrous and no-ferrous minerals.

Policymakers: Policymakers play a crucial role in shaping regulations, policies, and frameworks concerning critical minerals. Engaging with policymakers, such as government officials and regulatory agencies helped us understand existing policies, identify gaps, and propose recommendations for the effective management of critical minerals. We also engaged with the senior officials from the central regulatory agency (Central Pollution Control Board, New Delhi) as well as those from the government.

Recyclers: Recyclers form an important stakeholder group in the context of critical minerals. With the increasing emphasis on circular economy principles, recycling critical minerals from end-of-life products and waste streams is gaining significance. Collaborating with recyclers and understanding their capabilities, challenges, and potential for scaling up recycling efforts helped deepen our understanding of sustainable supply chains. We engaged with both Indian (e.g., Karo Sambhav, RLG, Greenscape) and foreign-origin recyclers (e.g., Umicore).

Subject Matter Experts: Subject matter experts specialising in critical minerals, possess in-depth knowledge and expertise in the field. Engaging with these domestic and global experts provided valuable insights into mineral deposits, extraction techniques, processing methods, and substitution possibilities. Their expertise also helped us assess the availability, accessibility, and potential risks associated with CRM (and SRM also), enabling us to develop informed recommendations. We engaged with several such experts, including three from India- one with multiple patents and years of experience in critical minerals (working in National Metallurgical Laboratory, Jamshedpur), the second with vast experience of working on policies and strategies for CRM (working in Council of Energy, Environment, and Water, New Delhi), and the third withmore than two decades of global experience working on e-waste and circular economy policies and strategies, along with others from Europe (e.g., WEEE Forum).

Environmental organisations: Environmental organisations, policy think tanks, and activists are important stakeholders concerned with the environmental impact of critical mineral extraction, processing, and disposal. Collaborating with environmentalists helped us understand the ecological consequences and potential mitigation measures associated with critical minerals' lifecycle.

2.2 Criticality Definitions & Dimensions: Analysis & Insights

We present two tables below that provide an overview of the definitions included in various national policies and strategies (Table 1), various technical reports published by policy thinktanks and research institutions, and academic papers published in peer-reviewed journals (Table 2).

TABLE 2: NATIONAL POLICIES AND STRATEGIES FOR CRITICAL MATERIALS

Country/Region	Policy/Strategy Name	Year	Definition
European Union	Critical Raw Materials Act[20]	2023	Economic Importance and Supply Risk
United Kingdom (UK)	Resilience for the Future: The United Kingdom's Critical Minerals Strategy	2022	Minerals with high economic vulnerability and high global supply risk

Country/Region	Policy/Strategy Name	Year	Definition
United States of America (USA)	Critical Minerals Policy Act[21] National Critical Materials Act Strategic and Critical Materials Stockpiling Act[22]	2013 1984 1939 1979 (revised)	Materials subject to potential supply restrictions and important in use Strategic and Critical Materials mean materials that would be a) needed to supply the military, industrial, and civilian needs, and b) are not found or produced in the US in sufficient quantities to meet such need
Australia	Critical Minerals Strategy 2023-2030 Australia's Critical Minerals Strategy	2023 2019	Metallic or non-metallic materials that are essential to modern technologies, economies and national security, and whose supply chains are vulnerable to disruptions Minerals that are scarce and considered essential for the economic and industrial development of major and emerging economies
Canada	The Canadian Critical Minerals Strategy[23]	2022	Materials having few or no substitutes, are strategic and somewhat limited commodities, and are increasingly concentrated in terms of extraction and, even more, in terms of processing location.
South Korea	Strategy for Securing Reliable Supply of Critical Minerals[24]	2023	Economic Importance and Supply Risk
India	Critical Minerals for India[xviii]	2023	Economic Importance and Supply Risk

Note: Quotes in italics are used verbatim in the respective policy/strategy

TABLE 3: DEFINITION OF CRITICAL MATERIALS IN SELECT TECHNICAL REPORTS AND ACADEMIC ARTICLES

Reference	Definitions
National Science and Technology Council (NSTC), 2016[25]	Indicators of minerals criticality include a) low substitutability with other minerals, b) dependence on imports for raw materials and refined products, and c) single versus multiple supplies of raw materials
U.S. National Research Council (NRC), 2008[26]	Criticality defined on the basis of a criticality matrix where the horizontal axis is the availability and reliability of the mineral supply and the vertical axis is importance of minerals in use
Brookings India, 2020[27]	Two dimensions of criticality- economic importance and supply-side risks
OECD, 2015[28]	Minerals for which the risk of disruptions in supply is relatively high and for which supply disruptions will be associated with large economic impacts
International Renewable Energy Agency (IRENA), 2021[xli]	Minerals that a) require significant extraction effort, b) where the production is concentrated in a few countries, c) where the quality of natural resources is declining, d) where a massive ramp-up of supply would be needed, and e) where prices have shown large fluctuations that reflect supply-demand imbalances
World Energy Outlook, 2022[xlvii]	Minerals whose extraction and processing are highly concentrated geographically and whose use and importance are increasing

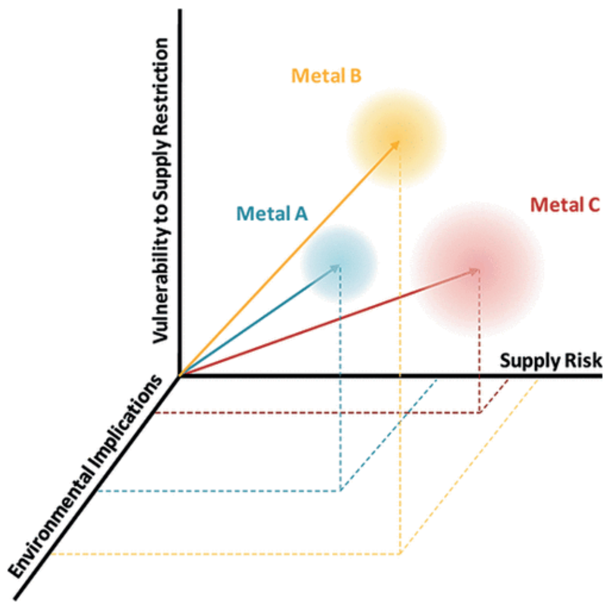
Reference	Definitions
CriticalMetals Handbook[29]	The degree of criticality of a metal is related to the physical and chemical properties of the metal itself, to a number of factors influencing supply and demand, and to the questioners themselves
European Commission[30]	Three dimensions of criticality: a) economic importance, b) supply risk, and c) environmental country risk
CEEW, 2016[31]	Economic importance and supply risk
CSEP, 2022[32]	Economic importance and supply risk
Kalantzakos, 2020[33]	Minerals that are essential to the production of high-tech, renewable energy, and defence applications
Lapko, Trucco, and Nuur, 2016[34]	Materials criticality is characterized by a high probability of supply constraints and the high impact of supply destruction
Russett, 1984[35]	Criticalness of material for an economy or a state is a related, but separable, concept from minerals dependence. It includes high ratio of import relative to consumption, high concentration of import suppliers, inelastic supply from additional sources, and unreliable foreign suppliers
Goe and Gaustad, 2014[36]	Material criticality, as described in this context, is a concept that involves comparing different materials to identify those that possess the highest risks of supply disruptions. It is a relative assessment that aims to determine the level of vulnerability for each material in relation to others.
Gloser et al., 2015[37]	Supply risk (in the context of likelihood of supply disruptions) and vulnerability (economic importance with consideration of substitution potentials)
Graedel et al., 2012[38]	Three dimensions of criticality- supply risk, economic importance, and environmental implications

There are several key insights that emerge from the above tables. The first is that the terms critical minerals, critical materials, critical raw materials (CRM) have been used interchangeably in these various government policies and strategies. The terms'criticality' and 'critical materials' were first used more than 80 years ago, in 1939,[39] in the Strategic and Critical Materials Stockpiling Act, the first such Act passed in the US and anywhere else in the world. The Act was later amended in 1939 and was later followed by the National Critical Minerals Act in 1984[40] and that Act also used the term 'critical materials'. The EU's 2023 Act used the expression 'critical raw materials' (CRM).However, in the policy and strategy documents of UK, Australia, Canada, South Korea, and the recent ones from USA, the term critical minerals, and not critical materials, has been used. It is important to point out these so as not to get confused with these different terms. Technically minerals refer to the mined commodities while materials refer to the output obtained after processed minerals.[41] Therefore, both the terms are correct in a way that minerals and materials both can be critical. However, it is the material that goes into the production process and not the minerals per se. Therefore, in this report, we use the expressions critical materials and critical raw materials (CRM) interchangeably.

The second insight is that even though there is no universal consensus on the definitions and the dimensions of criticality, economic importance and supply risk are the two most common dimensions considered for criticality. The constituents (components) of these dimensions vary in published work and are discussed later in this chapter. The EU defines criticality along two dimensions, economic importance and supply risk, and materials that reach or cross the defined thresholds in each of these dimensions are referred to as critical raw materials. There is an elaborated methodology for calculating the two scores of materials on these two dimensions and are described in the Annexures with the Act. For now, the threshold is 1 for supply risk and 2.8 for economic importance. In the US, supply restrictions also consider factors such as foreign political risk, military conflict, and anti-competitive or protectionist behaviours. The importance in use considers sectors such as energy technology, defence, agriculture, consumer electronics and healthcare related applications.

The Australian definition of economic importance is slightly different and is rooted in the context of resource and energy commodity exports accounting for more than two-thirds of goods exports from Australia. The first Australian strategy for critical minerals, that came out in 2019, defined economic importance not just for Australia but also for other major and emerging economies. The dimension of scarcity was linked to potential supply constraints and challenges. The strategy was later revised in 2022 first and then later in 2023. The most recent revision considers additional dimensions of domestic and regional energy security, national security, defence and domestic economic security.

FIGURE 2: THREE DIMENSIONS OF CRITICALITY



One significant framework that differs from these two-dimensional views of criticality was put up by Graedel et al. (2012[xxxviii]. According to this three-dimensional framework (Figure 2), the third dimension is that of environmental implications related with utilizing a particular material. The authors adopt a cradle-to-gate life cycle approach and consider environmental implications from the mining to producing ingots or their equivalent stage. The associated environmental implications include issues related to toxicity and climate impact (related to energy use in extracting and processing the materials). Similarly, in the report of the Ad-hoc Working Group in defining critical raw materials in the EU, published in 2010, recycling rate was one of the three parameters constituting the supply risk dimension. It is important to note here that several other works have considered the environmental dimension, if not directly then as a constituent of supply risk. Figure 3 provides an overview of the typical components constituting the three dimensions of criticality. Table 4, an adaptation from Lapko et al. (2016)[xxxiv], provides a more detailed description of supply risk dimension by dividing into two sub-dimensions- supply chain risk and supplier risk.

FIGURE 3: TYPICAL COMPONENTS OF CRITICALITY-DIMENSIONS (ADAPTED FROM TABLES 2 AND 3)

Dimension of Criticality

Supply risk

Geological scarcity,
Geopolitics
Trade policy vulnerability
Political Stability
Demand and supply issue
Manufacturing needs
Resources and availability
Sensitivity to price fluctuation
Substitutability
Trade exposure
High concentration in producing countries

Economic importance

Value to Economy
Economic resilience
Economic vulnerability

Environmental effect

Environmental standards
Recycling options and possibility
Life-cycle impact
Toxicity, Energy use,
Damage to health and ecosystems

TABLE 4: SUPPLY RISK CATEGORY[xxxiv]

Supply chain risk category	Examples
Supply	• Supply market: ○ Price fluctuations ○ Small number of available suppliers ○ Lack of the purchased items on the market ○ Supplier strength at the market ○ High geographical concentration of suppliers • Sourcing strategy ○ Small number of suppliers in supply base ○ Single sourcing ○ Global sourcing
Demand	• Small customer base, customer dependency • Demand growth • Demand variability • Order variability • Meeting requirements of customers (design, quality, delivery time) • Relationship with customers: reputation, liability risks, opportunistic behaviour
Internal Operations	• Lack of technical capability • Lack of design capability • Lack of manufacturing capability, manufacturing breakdown • Inability to adapt to changes (capacity, technology, design, legislation etc.) • Inability to anticipate changes
Information	• Lack of visibility • Lack of transparency • Lack of information exchange (delay, lack) • Lack of information security • Lack of information accuracy
Competition	• Rivalry among existing firms (for product and/or material) – high competition in the market • Lack of a possibility to differentiate the product from the competitors • New entrants
Regulatory/ Policy	• Environmental regulations • Trade policy (export quotas) • Resource nationalism
Geopolitical	• Political uncertainty and instability
Sustainability	• Impact on environment, health and safety

Supplier risk categories.

Supplier risk category	Examples
Business	Financial and ownership instability of a supplier
Performance	Failure to meet buyer's requirements in relation to: • Delivery time, • Quality of purchased items, • Quantity of purchased items, • price (increase, volatility, competitive pricing), • Flexibility (order variability)
Capabilities	• Lack of technical capability • Lack of design capability • Lack of manufacturing capability • Inability to adapt to changes (capacity, technology, design, legislation etc.) • Inability to anticipate changes • Low level of supplier certification
Relationship	• Lack of information exchange, information asymmetry • Opportunistic behaviour • Reputation risk • Liability risk • Wrong supplier segmentation, selection
Sustainability	• Hazardous materials in product

A comprehensive review of literature has also helped in preparing Figure 4 where the different dimensions (indicators) of criticality mentioned in different studies have been depicted.

FIGURE 4: CRITICAL ASSESSMENT STUDIES

Study/Methodology	Criticality indicators					Modelling assumptions			
	Supply risk					Importance of/Vulnerability to supply risk			
	Geological availability		Geopolitical availability		Environmental risk	Importance "(economic, product specific, import dependency, impact" on revenue)	Specific focus on substitutability	Recycling	Expected future demand growth
	Geological availability	Co-Production Risk	Political risk	Global Supply share					
Critical Minerals Consortium 29 June 2020				*	*	*		*	
Critical Minerals current science in India CURRENT SCIENCE, VOL. 119, NO. 6, 25 SEPTEMBER 2020	*	*	*						
Nieto et al. (2013)	*			*	*	*			*
Graedel et al. (2012)	*	*	*	*	*	*	*	*	
British Geological Survey (2012)	*		*	*			*	*	
U.S Department of Energy (Bauer et al, 2011)	*	*	*	*		*	*	*	*

Study/Methodology	Criticality indicators					Modelling assumptions			
U.S Department of Energy (Bauer et al, 2010)	*	*	*	*		*	*	*	*
European Commision (2010)			*	*	*	*	*	*	
Oakdene Hollins (Kara et al 2010)	*		*	*			*	*	
Oeko Institut (Buchert et al 2009)	*			*		*		*	*
National Research Council (2008)	*	*	*	*	*	*	*	*	*

The indicated asterisk (*) signifies the inclusion of specific indicators in various studies. Here is an overview of selected criticality assessment studies, their scope, basic concept, and choice of indicators. It is important to note that the classification of indicators into supply risk, importance/vulnerability to supply risk, and other categories may differ among these studies. The information provided has been adapted from Erdmann and Graedel (2011) and Speirs et al. (2013) and other studies.

The third key insight on the blurring of boundaries between critical minerals and strategic minerals.The 2023 revisions in Australian strategy reflect strategic dimensions (e.g., defence, national security) being combined with the dimensions of criticality. This is not too dissimilar from the Executive Order passed by President Trump in September 2020 in the USA[42]. This order directs the relevant agencies in the US to prioritise the expansion and protection of domestic supply chain for minerals and establishment of secure critical minerals supply chains to reduce dependency on foreign adversaries. The order outlines the context of US depending on imports for meeting more than half of its annual consumption for 31 out of the 35 identified critical minerals. Forrare earths, the dependency of US on one country (China) is more than 80%. Even the first such Act in the USA, passed initially in 1939 and revised later in 1979, uses both the terms strategic and critical materials, with the latter being defined in terms of availability and the former in terms of use in key sectors.

The EU's Act, on the other hand,clearly distinguishes between critical minerals and strategic minerals and defines a new category called strategic raw materials (SRM). The latter is a subset of critical raw materials and are distinguished with their use on strategic technologies underpinning the green and digital transitions, defence and space sectors. Of the 34 materials identified as critical raw materials in the EU list, 16 are identified as strategic raw materials. Several of these policy and strategy documents describe the need for relook at the criticality in the changing context of recent global geopolitical issues (e.g., Russia-Ukraine war, Covid-19 lockdowns in China).

The fourth key insight is on the increased focus on the interlinkages between critical materials and energy transition, especially in recent months. The International Energy Agency (IEA) came out with its first such report[43], titled 'The Role of Critical Minerals in Clean Energy Transitions, in May 2021. Its flagship annual publication, World Energy Outlook, had no mention of critical minerals or CRM in 2019[44]. The count (including references and annexures) was 4 in 2020[45] and has since gone up from 52 in 2021[46] to 132 in 2022[47]. IEA now has a dedicated policy tracker dashboard[48] for tracking domestic and global policies on critical minerals. Later in the same year (2021), the International Renewable Energy Agency (IRENA) also came out with a report titled 'Critical Materials for the Energy Transition'. The revised policy documents and strategies released by several governments in 2022 and 2023 also point out the significance of critical materials for energy transition in their respective countries.

The fifth key insight is on the dynamic nature of criticality. Most of the frameworks for assessing criticality are based on a combination of data (e.g., on reserves, consumption, imports etc.) and expert judgement. The dynamic nature of criticality means that criticality could differ (change) with time and degree. For the former, consider the Canadian Strategy that explicitly mentions that criticality can change with time based on supply and demand, technological development, and shifting societal needs. Similarly in the EU, before 34 materials were identified as being CRM in 2023, there were 4 other such lists that had come out in 2011, 2014, 2017, and 2020. The 2011 list had identified 14 materials, the 2014 had identified 20, the 2017 had identified 27, and the 2020 had identified 30 such materials as being critical[49]. The EU's

Critical Raw Materials Act stipulates reviewing the list every four years to keep into account the evolution in economic importance and supply risks associated with those materials. As for the dynamic nature arising due to degree, consider the same EU's Critical Raw Materials calculates a score on two dimensions (supply risk and economic importance), for each material. Based on the scores of each material and identified thresholds for both the dimensions, metals are deemed to be critical or not critical. It means that criticality is not a binary construct but rather a continuum, a point also made in the Critical Minerals Handbook.

The sixth and the final insight in on the role of recycling in these domestic policies and strategies. The last two of the seven steps outlined in the South Korean strategy for critical minerals focus on boosting the ecosystem and infrastructure for recycling in the country. The strategy outlines a goal of improving critical minerals recycling percentage from current 2% to 20%. Similarly, the Canadian strategy also highlights the need for growing domestic expertise across the value chain, from mining to manufacturing to recycling. It also talks about incentives for domestic stakeholders for recycling. The EU's Critical Raw Materials Act sets out a goal for having domestic recycling capacities equivalent to at least 15% of annual consumption. The USA's Critical Minerals Policy Act of 2013 and the subsequent also emphasize the role of recycling in reducing supply risk. Following that Act, in 2021, the Department of Energy (USA) came out with a strategy document titled 'Critical Minerals and Materials' that outlined four strategic goals, one of which is to build an ecosystem for long-term minerals and materials innovation to mitigate future supply chain challenges related to critical minerals and materials. Recycling has been mentioned as one of the key approaches for meeting that goal. .

2.3 CRM for EEE sector: Analysis of other Data

We now move on to consider analysis of other primary and secondary data. But before we do that, we need to describe the framework used for ascertaining criticality of materials for this study. We do not use the more common two-dimensional criticality framework, we rather use a modified version of the three-dimensional framework proposed by Graedel et al. (2012)[xxxviii]. Economic importance, supply risk, and sustainability implications are the three dimensions of this modified framework. The first two have also been used for identifying the 30 critical materials by the Indian Government. However, we believe sustainability implications should also be used for ascertaining criticality, especially considering the EEE sector in the Indian context. We propose to use this in a two-stage process. In the first, we identify the critical materials based on the economic importance and supply risk dimensions. Since the Indian government has adopted that approach to assess criticality, we do not propose a modification for now.

In the second stage, those critical materials are assessed on the third dimension of sustainability implications. The latter would have two main sub-dimensions, environmental implications and social implications. Environmental implications would include criteria like toxicity and climate impact along the entire life cycle from mining, processing, to recycling. The approach followed would be based on the established environmental life-cycle assessment (LCA). Social implications would follow the social LCA approach and consider the social implications along the entire life cycle from mining, processing, to recycling. This approach, we believe, is important in the EEE sector in the Indian context essentially because of the large dominance of the informal sector in various stages of the life-cycle and the multiple social and environmental externalities occurring across the entire value-chain. Various studies have estimated that more than 90% of the e-waste in India is managed by the informal sector. The practices adopted by the informal sector are often unscientific and cause multiple social, economic, and environmental externalities. Accounting for these social and environmental externalities then become important.

In terms of CRM required for electronics production, India still faces supply risks for several materials including lithium, nickel, cobalt, indium, tungsten, silicon, scandium, and germanium. These materials are predominantly sourced from global producers in countries such as Australia, Congo, China, and Germany. India is among the largest importers of these materials globally, as indicated by import and export data. India's import dependency on critical materials highlights the need for strategic measures to ensure a secure and sustainable supply chain for electronics production.

Table 5 has been prepared after an extensive review of government documents (Annual report of the Ministry of Mines, Government of India), relevant literature (published academic papers), archival documents (other reports, media articles, and documents of other government agencies), and feedback from the sectoral experts. It contains data on reserves, production, imports, and exports of different minerals that have been referred to as critical minerals in one or more of the reviewed works. The data on production, imports, and exports, expressed in tonnes are an average for the five-year period between 2017-18 and 2022-23. The corresponding value figures are expressed in INR '000. Minerals for which there was no data available in the government documents and other databases are indicated as blank (--). The last column of the table contains a brief overview of the use of those minerals in different electrical and electronic products and components. It is done to help one understand the significance of a particular mineral for the EEE sector.

TABLE 5: DATA ON RESERVES, AND AVERAGE PRODUCTION, IMPORT, AND EXPORT OF MINERALS IN INDIA FOR THE FIVE-YEAR PERIOD 2017-18 TO 2022-23[50]

Minerals	Production		Import		Export		Reserves	Uses
	Production	Value	Quantity	Value	Quantity	Value		
Bauxite	126,422,351	109,565,408	12,005,890	64,581,770	4,182,197	9,128,304	4,958,248	electrical wiring
Cerium	--	--	299,451	--	132,552	--	--	production of capacitors and catalytic converters
Chromium	19,943,687	197,153,559	849,781	14,691,547	160,503	4,110,307	331,685	corrosion-resistant coatings for electrical equipment
Cobalt	--	--	1,708	8,187,119	319	4,484,148	45	production of rechargeable batteries
Copper	21,283,038	59,470,393	1,488,163	278,344,776	572,596	52,537,952	1,673,067	Essential for electrical wiring, conductors, and printed circuit boards
Graphite	243,842	390,551	222,523	10,139,909	3,396	223,113	211,623,587	Used as a conductive material in electrodes and electrical contacts.
Indium	--	--	1,383.24.	--		--	--	essential for transparent conductive coatings in touch screens and flat-panel displays.
Iron	157,065,983	3,260,494,973	30,207	154,675,018	161,195	977,656,630	35,285,519	Used in magnetic cores for transformers, inductors, and motors in electrical systems.
Lead	2,003,492	102,661,879	17,800	981,890	61	4,932	12,870	Used in lead-acid batteries for various applications in the electrical industry.
Limestone	262,411,602	512,219,539	121,244,943	185,037,908	26,145,727	61,196,973	227,589,259	Used as a flux in the production of electrical components such as glass and ceramics
Lithium	--	--	229,012	63,672,724	--	--	5,900,000	Essential for lithium-ion batteries used in portable electronics and electric vehicles.
Manganese	15,388,592	113,876,018	21,287,525	292,067,514	354,179	2,464,676	--	Used in the production of alkaline batteries and as an alloying element in electrical components
Molybdenum	--	--	46,389	55,885,424	61	48,327	27,203,398	Utilized in electrical contacts, heat sinks, and thin film transistors.
Nickel	--	--	143	22,942	70	6,821	189	Used in the production of batteries, electrical contacts, and resistors.
Niobium	--	--	10,938,301	--	11,008,853	--	--	Utilized in capacitors and superconducting magnets for electronic and electrical applications.
Scandium and yttrium	--	--	1,116	279,466	21	8,464	6,900	Used in the production of solid-state lighting devices and high-temperature superconductors.
Silicon			290,923	1,860,893	52,174	132,820	3,907,819	Essential for semiconductors and integrated circuits used in electronic systems
Silver	3,438,500	171,947,070	--	11,759,941,054		534,600,000	568,643,752	Utilized in electrical contacts, connectors, and printed circuit boards due to its high conductivity.

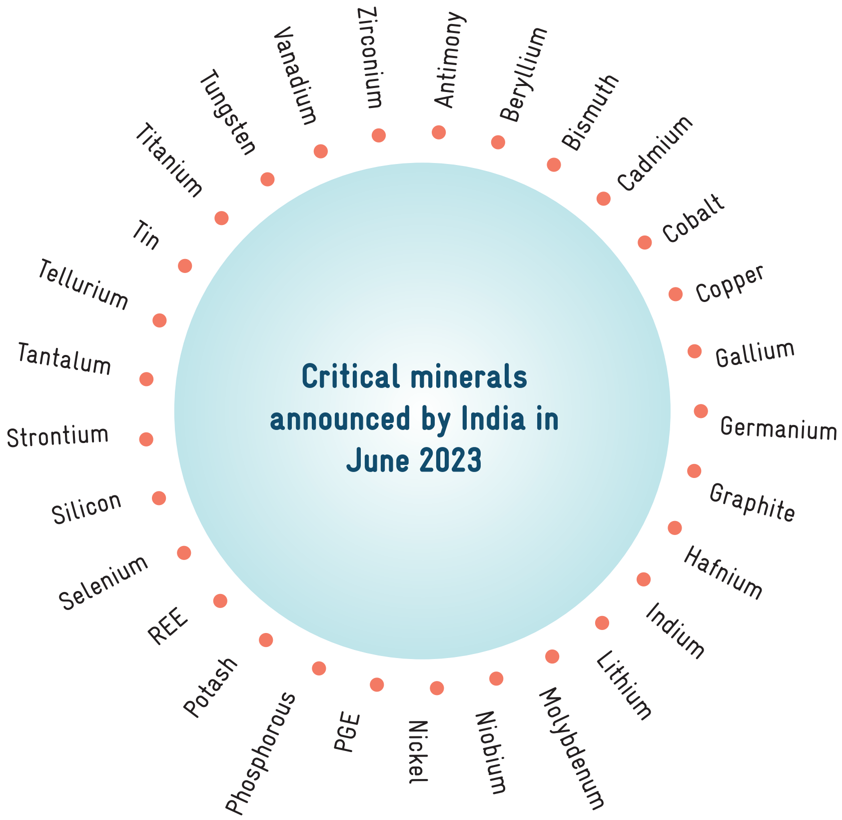
Minerals	Production		Import		Export		Reserves	Uses
	Production	Value	Quantity	Value	Quantity	Value		
Strontium	--	--	3,912,958	--	42,984.32.	--	--	Used in the production of cathode ray tubes (CRTs) for display devices.
Titanium	772,000	--	589,439	19,008,609	1,424,092	29,076,409	427,107,150	Utilized in electrical connectors, high-temperature applications, and corrosion-resistant coatings.
Tungsten	--	--	1,530	181,267	77	80,199	89,432,464	Used in electrical contacts, heating elements, and high-temperature applications.
Vanadium	1,242,000	--	17,023	1,405,385	20	13,121	24,633,855	Used in rechargeable batteries and as an alloying element in electrical components.
Zinc	1,539,657	49,799,273	3,047	75,745	5,762	185,930	--	essential for galvanizing steel, batteries, and as a protective coating for electrical components.
Dysprosium	--	--	136,763		120,441	--	--	Used in the production of high-performance magnets for electric motors and generators
Erbium	--	--	--	--	--	--	--	Utilized in optical amplifiers for fiber-optic communication systems
Europium	--	--	--	--	--	--	--	Used in phosphors for the production of color displays in electronic devices
Gadolinium	--	--	--	--	--	--	--	Used in magnetostrictive materials for electronic sensors and actuators.
Germanium	--	--	--	--	--	--	--	Utilized in semiconductors for diodes, transistors, and infrared optical devices.
Holmium	--	--	--	--	--	--	--	used in laser systems for various applications in electronics and telecommunications.
Lanthanum	--	--	--	--	--	--	--	Utilized in nickel-metal hydride (NiMH) batteries for hybrid and electric vehicles.
Lutetium	--	--	--	--	--	--	--	Utilized in lighting applications such as high-intensity discharge lamps.
Neodymium	--	--	1,330,745.28.	--	--	--	--	essential for high-performance magnets used in motors and speakers.
Praseodymium	--	--	--	--	--	--	--	Used in magnets and lasers for various electronic and optical devices.
Promethium	--	--	--	--	--	--	--	utilized in nuclear batteries for long-lasting power sources in electronic systems.
Samarium	--	--	--	--	--	--	--	Used in magnets and lasers for various electronic and optical applications.
Terbium	--	--	--	--	--	--	--	Utilized in phosphors for fluorescent lamps and color display technologies.
Thulium	--	--	--	--	--	--	--	Used in lasers and fiber-optic communication systems.
Ytterbium	--	--	--	--	--	--	--	Utilized in lasers and optical amplifiers for telecommunications and laser processing.

Data on reserves, production, import, and export of minerals in India (Source: Mines_AR_22-2023, Statista, Indian Bureau of Mines, Volza crow global import & export data)

Figure 5 below has been developed based on an adaptation of Hayes & McCullough (2018) work. In their paper, they had prepared a summary of criticality study results, listed by publication year, and indicated materials identified as 1.

FIGURE 5: CRITICAL MINERALS IN DIFFERENT STUDIES FOR THE EEE SECTOR

criticality study	He	Li	Be	B	C	F	Na	Mg	Al	Si	P	S	Cl	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ce	As	Se	Br	Sr	Y	Zr	Nb	Mo	Ag	Cd	In	Sn	Sb	Te	I	Cs	Ba	Hr	Ta	W	Re	Au	Hg	Tl	Pb	Bi	Th	U	PGM	REE	considered	critical	geographic
NREL, 2005									0	0														0		0	0		1						0	1	0	1			1																	11	4	United States
NEDO, 2005																			0	1		0	0											0	0			1								1	J									1	1	11	6	Japan
NRC, 2008		0															0	0		1				0		0								1				1								0										1	1	11	5	United States
Morley & Eatherley, 2008			0	0	0	0		0		0								0	0		0	0	0	0	0	0	0	0	0	0	1		0	0	0	1		0	1	1	0	0		0			0	0	1	1		0	0			1		36	7	United Kingdo
NEDO, 2008																			0	0		1	0											1	1			1								1	1									1	1	11	8	Japan
Buchert et. al., 2009		1																				1				1	1											1			1					1										1	1	9	9	
EC, 2010		0	1	0	1	0		1	0								0	0	0	0	0	1	0	0	0	1	1							1	0	0		1		1	0			0		1	1	0								1	1	30	13	European Unic
Bae, 2010		1						1		1							1						1			1							1					1									1									1	1	11	11	Korea
DLA, 2011		0	1	0		0			0								0	0	1	0		1	0	0	1	0	1					0	0	1	0	0	0	0	0	0	0				0	1	1	0		0		0	0			1	0	34	9	United States
EC, 2011		0	1	0	1	1		1	0								0	0	0	0	0	1	0	0	0	1	1							1	0	0		1		1						1	1	0								1	1	28	14	European Unic
Moss et. al., 2011																		1					0			1			1					1	0	0	0	1	1		1																1	12	8	European Unic
BGS, 2011	1	1	1	0	1	0	0	1	0		0	0	0	0	1		0	0	0	1	0	1	0	0	0	0	1	1	0	1	1		0	1	1	1	1	1	1	1		1		0		1	1	1	1	1		0	1	1	0	1	1	50	29	United Kingdo
BGS, 2012		0	1		1	0		1	0								0	0	0	0	0	1	0	0	0	1	1	1	1		1		0	1	1	0	0	1	0	1				1		1	1	0	0	1		0	1	1	0	1	1	40	21	United Kingdo
METI, 2012		1			1	1		1		1							1	1	1	1	1	1	1		1	1	1				1		1	1	1			1	1	1						1	1	1								1	1	27	27	Japan
Willis & Chapman, 2012		1	1	0		1		1	0	1							1	0	1	1		1	1	0	1	1	1		0				1	1	0	1	0	1	1	1	1					1	1	1				1	1			1	1	34	27	
DLA, 2013		0	1	0		1		0	1	0							0	0	1	1		0	0	0	0	1	1		0		0		0	0	0		0	0	1	1	0				0	1	1			0		0	1			0	1	35	13	United States
Moss et. al., 2013		0			1													1	1			1	0	0		1	1		0					1	0	0	0	1	1		1				1	1		1	1			0				1	1	24	16	European Unic
Skirrow et. al., 2013											1			1																																												2	2	Australia
EC, 2014		0	1	1	1	1		1	0	1	1			0		0	0	0	1	0	0	1	0	0	0	1	1		0					1	0	0		1	0	1	0			0	0	0	1	0	0							1	1	38	17	European Unic
METI, 2014		1																1	1			1	1			1						1		1	1			1		1				1		1	1									1	1	16	16	Japan
Zepf et. al., 2014		1									1			1				1	1			1	1	1		1	1							1	1	1	1	1			1						1	1							1	1	1	21	21	
DLA, 2015		0	1	0	0	0		1	1							0		0	0	1		0	0		0	0	1				0	0		0				0	0	1	0					0	1	0				0	0			0	1	30	8	United States
BGS, 2015		1	1		1	1		1	0								0	1	0	0	0	1	0	0	0	1	1	1	1		1		0	0	1	1	1	1	0	1				1		1	1	1	0	1		0	1	0	0	1	1	40	25	United Kniador
Bastein et. al., 2015		0	0	0	0	0		0	1	0	0						0	0		0	1	0	0	1	0	1	1		0		0		1	0	0	0		1	0	1	0			0		0	0	0	0						0	1	1	37	10	The Netherlan
Hatayama & Tahara, 2015									0										1	1	1	1	0	1	1									1	1	1		1	1							1	1		1			1				1	1	19	17	Japan
Graedel et. al., 2015		0	0	0				0	0							1	0	0	0	0	0	0	0	0	0	0	0	1	1		0	0	1	0	0	1	1	1	0	1	0			0	0	0	0	1	1	1	1	0	1	0	0	1	0	44	14	
Bortnikov et. al., 2016		1	1													1						1				1	1		1		1	1		1			1	1			1					1		1			1		1				1	18	18	Russia
NSTC, 2016	0	0	0	0	0			1	0	0	0	0		0			0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0		0		0	1	0	0	1		0	1			1	l	47	11	
Schulz et. al., 2017		1	1		1	1											1	1		1		1				1	1		1				1	1				1	1	1	1			1	1	1		1								1	1	23	23	United States
EC, 2017	1	0	1	1	1	1		1	0	1	1	0		0		1	0	1	0	0	0	1	0	0	0	1	1		0			1		1	0	0		1	0	1	0			1	1	1	1	0	0			0	1			1	1	43	24	Eurpoean Unic
McCullough & Nassar, 2017	0	0	0	0	1	0		1	0	0	1	0		0			0	1	0	0	0	1	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	1	0	1		0		0		1	1	1	0	1		0	1			1	1	47	19	
Fortier et. al., 2017	1	1	1	0	1	1		1	1	0	0	0		1		1	1	1	1	1	0	1	0	0	0	1	1	1	0	0	1	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	n	1		0	1		1	1	1	52	34	United States
evaluated by study	5	25	19	15	16	17	1	18	18	12	9	5	1	8	1	6	19	24	23	22	15	27	26	21	19	28	24	8	18	5	13	9	15	28	25	20	15	31	20	20	19	5	1	14	8	26	24	21	13	10	2	15	14	4	7	28	29			
Identified as critical	3	11	14	2	12	9	0	14	4	5	5	0	0	3	1	4	5	11	10	10	3	21	5	3	4	20	21	5	7	1	8	5	7	20	8	8	5	26	10	19	9	1	1	6	4	20	21	11	5	7	2	2	11	2	2	26	27			
percent criticality- all	60	44	74	13	75	53	0	78	22	42	56	0	0	38	100	67	26	46	43	45	20	78	19	14	21	71	88	63	39	20	62	56	47	71	32	40	33	84	50	95	47	20	100	43	50	77	88	52	38	70	100	13	79	50	29	93	93			
percent critical- post-201	50	40	60	14	63	57		75	33	20	40	0		25		80	25	67	25	40	25	73	0	25	11	70	90	60	44	0	50	57	57	55	25	38	50	82	30	100	38	0	100	50	75	64	78	60	25	80	100	13	88	0	25	90	91			
Critical for EEE		1			1					1						1	1	1				1	1			1					1			1				1									1									1	1			



The list of critical minerals announced by India in June 2023 include the following (in alphabetical order): Antimony, Beryllium, Bismuth, Cadmium, Cobalt, Copper, Gallium, Germanium, Graphite, Hafnium, Indium, Lithium, Molybdenum, Niobium, Nickel, PGE, Phosphorous, Potash, REE, Selenium, Silicon, Strontium, Tantalum, Tellurium, Tin, Titanium, Tungsten, Vanadium, and Zirconium.

We use the summary describe in Figure 5 and the three dimensions of criticality discussed above to identify CRM for EEE sector. The identified CRM for EEE sector are Copper, Gallium, Graphite, Indium, Lithium, Nickel, Niobium,PGM (Platinum Group of Metals), REE (Rare Earth Elements including Scandium), Silicon, Strontium, Titanium,Tungsten, and Vanadium. Of the notable exceptions from the Indian list, Copper is one of the more significant ones. Copper has been excluded because of its wide scale recycling with relatively fewer adverse environmental implications in India.

3. RAW MATERIALS (SRM)

3.1 Methodology

The methodology for analysing secondary raw materials (SRM) is similar to the one adopted for CRM. Just like it was done for CRM, we use a combination of data and expert judgement for the analysis of SRM. As such, the first few steps in our methodology involve understanding the meaning of the term and then drawing insights from those for our report. This was then followed by a discussion on the insights that emerged from an analysis of primary data and secondary data. For the former, the stakeholder mapping done for CRM was used for SRM as well. After that mapping, primary data was collected through various interviews, one seminar (conducted in December 2022), one webinar (conducted in June 2023), and two workshops (conducted in April 2023). Industry experts, researchers, and policymakers participated in these discussions, providing valuable perspectives on SRM, recycling, digital tracking, global best practices and experiences, and potential solutions.

Implemented policies and regulations related to CRM and SRM worldwide were reviewed and analysed. Successful approaches to recycling,managing and tracking SRM were examined to identify best practices and potential policy recommendations for India. Industry data related to sales, market share, and CSR for companies in the EEE sector were obtained from the ProwessIQ database of CMIE and other industry publications. Finally, firm specific data for some firms (market leaders) on key sustainability indicators, performance, and targets were obtained from the websites and annual reports (financial and sustainability) of producers identified as having significant market share (obtained from the industry level data from the ProwessIQ database of CMIE).

Based on the conducted research and global perspectives gained, policy recommendations are proposed for India and are included in the next chapter. These recommendations address challenges related to domestic production, import dependency, recycling, and international collaborations. The aim,in doing so,is to propose strategies for securing a sustainable and diversified supply of Critical Minerals, ensuring India's continued growth and development in various industries and emerging technologies.

3.2 Definition

Secondary Raw Materials (SRM) refers to raw materials that are mined from "above the ground" secondary sources, such as electronic waste, as opposed to "under the ground" mines occurring (defined as "primary"). In a circular economy, SRM are considered an important source of raw materials for producers and manufacturers from the economic viewpoint. There is a growing recognition that mining raw materials from secondary resources (recycling) is underexploited globally[xxvi]. In general mining raw materials from primary sources is more established because of relatively easier availability of resources (e.g., financial, technical, technological, human etc.). However, such processes are typically associated with multiple other challenges including resource conflicts. On the contrary, mining from secondary resources have relatively fewer challenges but face resource crunch (e.g., financial, technological, etc.)[xxvi]. .

The need for developing and securing SRM arises from several factors such as resource scarcity, environmental impacts, waste management, economic benefits etc. To effectively secure SRM these measures can be implemented such as recycling infrastructure, policies and regulations etc. By securing SRM we can reduce the pressure on primary resources extraction, and minimize waste generation, mitigate environmental impacts and foster a more sustainable and circular economy.

FIGURE 6: GLOBAL MINERAL PRODUCTION DATA OF SELECT MINERALS[XXXI]

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/Re-source < 50%	Primary	--	USA (88%)	China (11%)	Mozambique (1%)

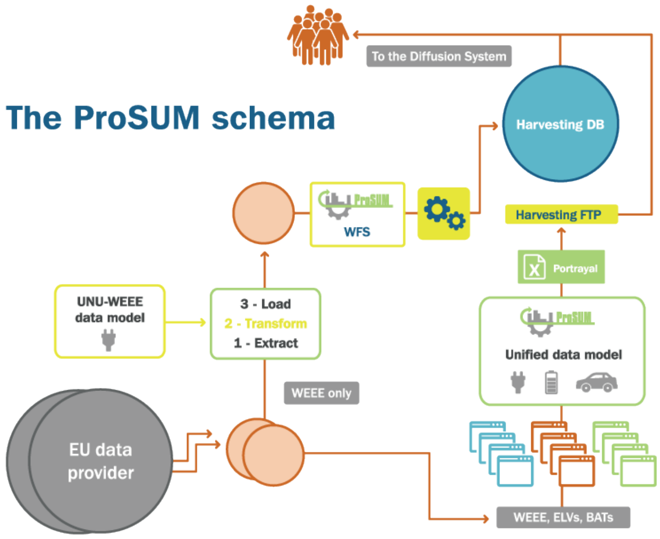
3.3 Approaches for SRM: Global Overview

There are a range of existing and evolving technologies, techniques, practices, and approaches for managing SRM in the world. A lot of these vary with context and the choice of most appropriate approach depends on multiple factors. An overview of some of these global approaches are described next.

3.3.1 ProSUM

The aim of the ProSUMproject[xix] was to provide a state-of-the-art knowledge base, using the best available data in a harmonised and editable format, which allows the recycling industry and policymakers to make more informed investment and policy decisions to increase the supply and recycling of secondary raw materials. Waste from multiple streams, viz. batteries, EVs, mining, and e-waste consist of many CRM which can be recycled to obtain SRM and therefore reduce the dependency on primary sources. If other factors favourably align, it could also reduce the manufacturing cost for the manufacturers and can be helpful to generate revenue to recyclers and implement circular economy for CRM. Figure 7 provides a schematic representation of the ProSUM project.

FIGURE 7: PROSUMSCHEME[XIX]



The key objective of ProSUM was to deliver the first Urban Mine Knowledge Data Platform (UMKDP) in the EU, and perhaps the world. This platform was meant to be a centralised database of all existing data and information on arising, stocks, flows, and treatment of waste arising from multiple streams (e.g., ELV, e-waste, batteries and mining waste). Once created, it was aimed to provide access to timely and reliable data on primary and secondary raw materials which could provide the foundation for improving Europe's position on raw material supply chain. The ProSUM project, jointly funded by the European Union and the Swiss Government, was launched in March 2015 and the UMKDP was launched in January 2018.

Urban Mine Platform:

The urban mine platform[51]consists of all the on-market, stocks in used market inputs, stocks in use, compositions, and waste flows of electrical and electronic equipment, vehicles, and batteries for all EU 28 Member States plus Switzerland and Norway. For vehicles, the data includes vehicles put on the market, in use, and scrapped each year, the composition of vehicles by vehicle type, elements, and materials, and ELVs reported as recycled through authorised treatment facilities. For batteries, the data includes batteries put on the market by cell type and product type each year, composition of batteries by cell types and elements, and waste batteries collected through producer compliance schemes versus other waste streams. In case of e-waste, the data includes EEE put on the market, in use, and generated e-waste each year, composition of products by components, materials and elements as per EU collection category, and e-waste collected through producer compliance schemes versus other waste streams.

3.3.2 FutuRaM

After the completion of ProSUM project, another project titled FutuRam (Future Availability of Secondary Raw Materials) was launched by the European Union in June 2022. The aim of the project is to develop the SRM knowledge base on the availability and recoverability of SRM within the EU, with a particular focus on CRM[52]. FutuRaM hopes to establish a methodology, reporting structure, and guidance to improve the raw materials knowledge base up to 2050 by integrating SRM and CRM data to model their current stocks and flows, and consider multiple factors to further develop, demonstrate, and align SRM recovery projects with the United Nations Framework Classification for Resources (UNFC). The multiple factors it will consider include economic, technological, geopolitical, regulatory, social, and environmental. Compared to

ProSUM, FutuRaM focuses on more waste streams, with mining, slags and ashes, and construction and demolition (C&D) being the additional waste streams.

3.3.3 Technologies for Recycling e-waste

Globally, pyrometallurgy is one of the most common methods of recycling and recovery of e-waste. Some of the known companies using pyrometallurgy for recovery of materials from e-waste include Aurubis in Germany, Noranda in Canada, Boliden Ronnskar in Sweden, Umicore in Belgium and DOWA in Japan. Umicore's Hoboken (Belgium) plant is dedicated to managing multiple waste streams with e-waste being the most dominant. The recycling operations at this facility are streamlines along two processes: the precious metals operations (PMO) and the base metals operations (BMO). Glencore Copper's Horne smelter (Noranda) is another commercial pyrometallurgical process for the recovery of metals from e-waste. The feed material for this process is composed of e-waste and mined copper concentrates. More details on the different recycling techniques are given in the separate report on recycling. .

3.4 Approaches for SRM: Indian Overview

The recycling process for e-waste involves several steps, starting with collection. Various entities, such as municipalities, retailers, producers, and non-governmental organisations, can undertake the collection of e-waste. Retailers may offer pick-up services, managed either by electronics wholesalers or the retailers themselves. Once collected, the e-waste undergoes preprocessing, which involves separating reusable components. Techniques like magnetic separation help extract ferrous materials, while eddy current separation and density separation are used to separate non-ferrous materials, plastic, and glass.

If we assess the feasibility and viability of a model like ProSUM for India, we observe a number of differences in the context and challenges arising due to those differences. The ProSUM model was designed to work with standardised data from formal sectors, which may not align well with the diverse and decentralised nature of India's informal sector. The informal sector, which contributes to a significant portion of e-waste in India, operates in various regions with different practices and challenges. Adapting the ProSUM model to account for region-specific variations and data collection methods becomes crucial. Also, India has significant disparities in terms of economic development, infrastructure, and technological advancements across different regions. These disparities can affect the availability and accuracy of data related to e-waste.

Insights obtained from one of the project coordinators of ProSUM during a webinar indicate that maintaining the urban mine platform is a costly and time-consuming affair. There are additional challenges related to obtaining high quality reliable data from producers and recyclers. This when the enabling environment and infrastructure is more developed in the EU compared to some of the other regions of the world.

In less-developed regions, the informal sector may lack access to proper facilities for data recording, making it even more challenging to gather the comprehensive information required by the ProSUM model. And as mentioned the main concern arises from gathering accurate and reliable data from the informal sector is a significant challenge in countries like India. The informal sector often operates outside formal channels, making it challenging to track and document e-waste generation, disposal, and recycling activities. The ProSUM model heavily relies on data availability and quality, and the lack of comprehensive data from the informal sector hampers its effectiveness in India.

The final step in the e-waste recycling ecosystem is end processing, where the materials are transformed into secondary materials that can be reintroduced into the supply chain. This stage is crucial for closing the loop and achieving resource recovery. End-processing significantly reduces energy consumption compared to producing metals from virgin sources. For example, steel production can require nearly 70% less energy when using recycled materials.

The policies for managing e-waste in India have undergone many revisions since those were first implemented in 2012. The underlying policy framework, however, continues to be that of extended producer responsibility (EPR). Ever since the introduction of first set of e-waste management policies based on EPR, there has been a continuous growth in the e-waste management ecosystem and a gradual increase in the number of e-waste recyclers in India. Today, there are severalglobal and domestic players involved in e-waste recycling, including Attero, E-Parisara, Exigo Recycling, Greenscape, RecyKal, and RLG. Manufacturers can also play a vital role in this ecosystem by designing products for easier recycling at the end of their life. By incorporating recyclability into product design, manufacturers can increase the recovery rates and overall profitability of the recycling ecosystem, benefiting the entire cycle of collection, pre-processing, and end-processing.

To promote recovery of materials from e-waste (and other waste streams) and recycling, three other policy frameworks have been introduced in recent years.

a. National Non-ferrous Metal Scrap Recycling Framework 2019[53] Introduced by the Ministry of Mines (MoM)

b. Steel Scrap Recycling Policy 2019[54] Introduced by the Ministry of Steel

c. National Resource Efficiency Policy 2019[55] Introduced by MeitY

In 2021, MoM came out with the National Non-ferrous Metal Scrap Recycling Framework. This framework was in alignment with one of the objectives of the National Minerals Policy 2019[56], viz. augmenting the supply of metals by developing processes for the recovery of metals through recycling. The policy, as well as the framework, are also aligned with SDG-12 on responsible production and consumption. The framework describes the social, environmental, and economic benefits of recycling. It also contains a table with figures for global benchmark and Indian recycling rates for four metals- Iron, Aluminium, Copper, and Zinc- the fourth most used metals in the world. India is the third largest consumer of Aluminium in the world with FY 2020 consumption being 3.7 MT. Recycling Aluminium requires up to 95% less energy than producing primary Aluminium.

Some other salient features of the framework are:

1. Setup a Metal Recycling Authority
2. Establish standards for the quality of scrap for recycling
3. Standard procedures for recycling and processing of scrap
4. Technology upgrade and adoption of the best available technology (BAT) for scrap recycling to be promoted
5. Set up specified metal recycling zones
6. Set up urban mines
7. Online market platform for secondary/recycled metals
8. Formalise value chains
9. Mechanisms for ranking and evaluation of recycling units- performance-based regulation
10. Recycled logo to highlight circular economy
11. Proposes a minimum recycled content requirement for certain products
12. Step-wise targets for take-back for producers/manufacturers
13. Public procurement of goods with targeted content of recycled/secondary metals
14. Online portal to be developed for aggregating central and state-level databases on identified including the number of recycling zones set up, number of recycling units in each zones, quantity and amount of metal recycled, etc.

3.4.1 Industry Analysis: Indian Overview

To achieve a sustainable approach for recycling the electrical and electronic products the industry, including brand owners, manufacturer, and component manufacturers, plays an important role. An analysis of the key players in the EEE industry in India was carried out to understand their current approaches to sustainability in general, and recycling in particular. For this analysis, we have also considered the automobile sector since a) it has emerged as a major consuming sector for EEE in recent years, and b) ELV streams could be a major source for SRM.Table 6 provides an overview of the existing strategies of the major automobile players on three aspects: a) targets or practices for use of recycled materials, b) existing data on material use, c) targets for achieving net-zero.

TABLE 6: SUSTAINABILITY STRATEGIES AND TARGETS OF SELECT INDIAN AUTOMOBILE COMPANIES

Producers (Company)	Targets or Practices for Use of Recycled Materials	Existing Data on Material Use	Net-Zero Targets
Suzuki	No	No	Yes, by 2050
Hyundai	No	No	Yes, by 2045
Tata Motors	No	No	Yes, by 2050
Mahindra & Mahindra	No	No	Yes, by 2040
Ashok Leyland	No	No	No
Volvo-Eicher	Yes	No	Yes, by 2040
Bajaj Auto	Yes	No	No
Honda	Yes	No	Yes, by 2050
Hero MotoCorp	Yes	No	Yes, by 2030
TVS Motors	Yes	Yes	Yes

The data include in Table 6 was obtained by accessing publicly available information on the websites, annual reports, annual sustainability reports, and other news articles in the popular press for these firms. This analysis could help in ascertaining the likelihood of Indian automobile firms to contribute towards policies and strategies for SRM, and to respond to associated market-based mechanisms.

A similar approach was followed to come up with Table 7 which contains similar information for major manufacturers of batteries and inverters in India. The India battery market size is expected to grow from USD 16.77 billion in 2023 to USD 27.70 billion by 2028, at a CAGR of 10.56% during 2023-28. The Indian battery market is segmented by technology and application. The market is segmented by technology into lead-acid batteries, lithium-ion batteries, and other technologies. By application, the market is segmented into automotive batteries, industrial batteries, portable batteries, and other applications.

TABLE 7: SUSTAINABILITY STRATEGIES AND TARGETS OF SELECT INDIAN BATTERIES MANUFACTURERS

Producers (Company)	Do they have recycling targets?	Do they have any data on material use?	Do they have some policy regarding net zero?
Bajaj Electronics Ltd	No Target Waste Recycled:- 99% Zero waste to landfill certified: 2 out of 4 sites	Material Consumed EPC: 20,231 MT Materials Consumed:- 21,545 MT In FY22, hazardous waste generated was 406 MT In FY22, the quantum of Non-hazardous waste was 4,997 MT Total Waste Generated:-5,403MT Total Waste Treated:-5,403 MT Waste Recycled:- 5355MT Treated via Landfill:- 48MT	1.No policy 2.The Nirlep and Chakan plants have achieved ZWTL (Zero Waste to Landfill with diversion rate >99%), certified by Intertek, a globally known quality assurance, product testing and certification agency. 3.Other initiatives have been taken towards sustainability in terms of Green Energy through Solar Power generation, Rainwater harvesting, and PNG Gas connection, amongst others. 4.The Chakan plant is equipped with a Solar Grid Power Plant. Another project of solar power plant at Ranjangaon unit is under progress.
Amara Raja Batteries Ltd	No	No	No
Luminous Power Technologies Pvt. Ltd	No	No	No 1.Victory solar light project 2.Pollution Abating Plantation Abhiyan(PAPA)
Exide Industries	No	No	Yes, by 2050

Data was not available for several battery and inverters manufacturers. Finally, we do a similar analysis for manufacturers and brand owners of consumer electronics products (Table 8).

TABLE 8: SUSTAINABILITY STRATEGIES AND TARGETS OF SELECT INDIAN CONSUMER ELECTRONICS PRODUCTS MANUFACTURERS

Producers (Company)	Targets or Practices for Use of Recycled Materials	Existing Data on Material Use	Net-Zero Targets
Samsung	Yes	No	Yes, by 2050
Whirlpool	Yes	No	Yes, by 2030
Philips	Yes	No	Yes
LG	Yes	No	Yes, by 2030
Godrej Appliances	Yes	Yes	Yes
Sony	Yes	Yes	Yes, by 2040
Mitsubishi	Yes	No	Yes, by 2050
Hitachi	No	No	Yes, by 2050

3.4.2 The Informal Sector

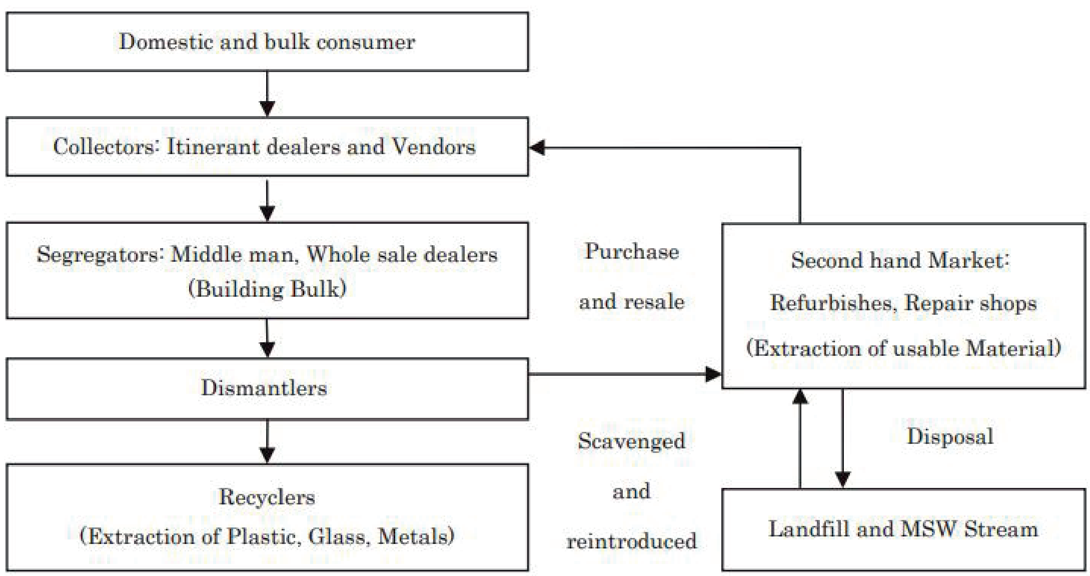
The term 'informal sector' refers to individual entrepreneurs and small to medium sized businesses that provide goods and services that are neither state-registered nor legally constituted through an ad hoc system while typically operating 'off-the-books' and failing to pay all required taxes[57]. The individuals and businesses operating in the informal sector have limited access to legal protections in the absence of official recognition by the government, and they typically avoid paying taxes, licensing fees, and complying with other potentially costly regulations[58]. They are, however, quite rich in resources, especially intangible ones like tacit-knowledge and relational advantages. Many of them function as multi-generational businesses and provide widely available and low-cost services and solutions for sectors and challenges that that others won't or can't, for example 'dirty work' such as handling e-waste[59].

The informal sector in India manages around 90% of e-waste, while only 10% is handled by the formal sector. The formal sector faces challenges such as inadequate collection and disposal mechanisms and a lack of appropriate technologies, particularly when dealing with the vast informal sector. As a result, many households and institutions store obsolete electronic products in their warehouses or storerooms due to the absence of proper collection systems. When these products are eventually sold or exchanged, they are often refurbished and resold, with only a small portion being properly processed as waste. The formal sector also lacks refineries capable of recovering precious metals.

Different opinions exist regarding the issue of granting licences for e-waste imports as a means to sustain formal businesses. One perspective, represented by the toxics link, emphasises the importance of prioritising environmental protection in e-waste management rather than sustaining businesses. Allowing imports would result in the dumping of non-recyclable hazardous materials in landfills, which should be prohibited. Considering the substantial quantity of waste generated within the country, establishing an effective collection mechanism becomes crucial rather than relying on waste imports to maintain plant capacity utilisation.

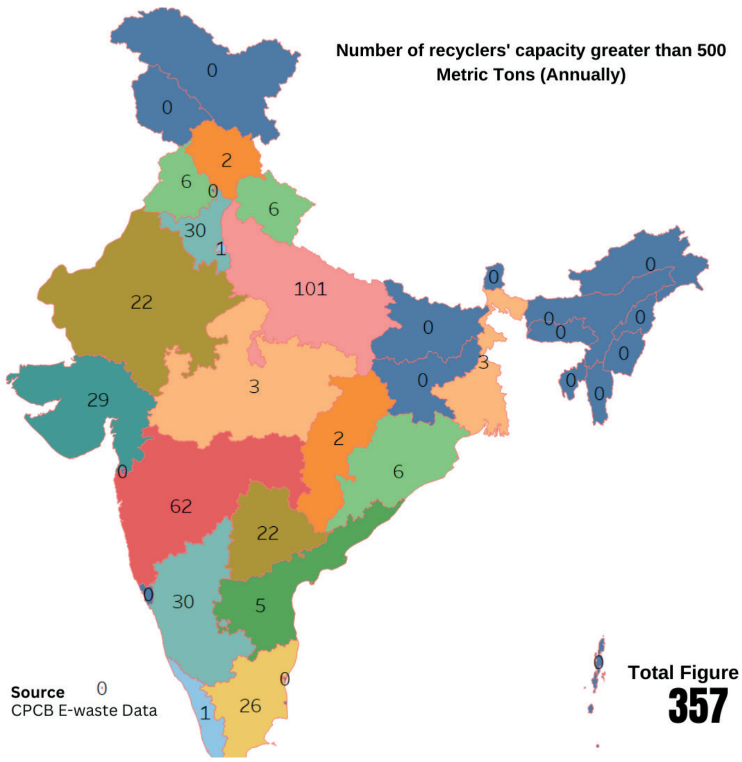
Figure 8 illustrates the flow diagram depicting the process of e-waste management in India. The initial step in the informal sector involves the collection of e-waste by ragpickers, kabadiwalas, or other sources. Once collected, the e-waste is segregated by primary stakeholders, who may include middlemen and wholesalers. Subsequently, dismantlers enter the picture and either send the e-waste to the second-hand market or repair shops for potential reuse through modifications. If the product cannot be reused, it is then sent to recyclers, who extract plastic, glass, and metals from the e-waste. Ultimately, any remaining e-waste is disposed of in landfills or municipal solid waste streams.

FIGURE 8: FLOW CHART SHOWING PROCESSING OF E-WASTE BY INFORMAL SECTOR IN INDIA



Based on our analysis using the latest e-waste data (updated till June 2023) present on the portal of CPCB[60], our study finds the presence of 370 registered e-waste recyclers across all but sixteen Indian states and Union Territories (UT), as depicted in Figure 9. Notably, Uttar Pradesh has the highest number of recyclers, with 101 establishments, while Maharashtra secures the second position with 62 recyclers, all of whom possess an annual capacity exceeding 500 Mt. However, it is concerning to observe that several states, as indicated by the CPCB e-waste data, do not have a single recycler operating within the formal sector. This raises significant concerns regarding the overall recycling ecosystem within these states.

FIGURE 9: NUMBER OF RECYCLERS CAPACITY GREATER THAN 500 MT



3.5 SRM: Findings & Insights from the Study

The analysis of data presented above reveals several interesting insights for SRM. The first is that there is a direct and strong linkage between CRM and SRM. As governments and businesses develop new policies and strategies for CRM, there is going to be a rub-off effect on SRM. Supply risk is one of the two most common dimensions of criticality and in almost every policy document and research article, recyclability and/or recycling percentage of a material is considered one of the components constituting the supply risk. There is an adverse relationship between the two in the sense that as recyclability of a material goes up or if the recycling percentage of a material goes up, the criticality of a material comes down. This adverse relationship between the two should, and will most likely, attract greater attention from governments, regulators, and businesses alike.

The second, and a related, insight is that recyclability or recycling percentage may not go up immediately in the short term and will generally require a longer timeframe. The experience from the ProSUM project indicates that maintenance of an urban mine platform is a costly affair, both in terms of time and resources. During the webinar, it was revealed by one of the project coordinators that despite more than five years of launch of ProSUM, there are still several challenges in the EU in recycling, including getting reliable and timely data from the producers and recyclers alike. The dominant presence of the informal sector in India isn't likely to make it any easier. Most critical materials require a specialized and costly technique and processes to recover materials from waste streams. Informal sector is less likely to possess the resources and have the motivation to invest in such expensive techniques and processes. In that case, a lot of SRM that could have been potentially recovered and recycled may not be recovered and recycled. The other challenge in this, as pointed out by another expert in the webinar, is that recycling processes often generate their own waste and scrap and this hinders complete circularity.

The third insight that came out during the discussions with producers and subject matter experts was that recycled materials may not have the same utility level as primary materials for many components and applications. This then also puts a question over the likely use of SRM. If secondary materials, after being recovered from e-waste, are unable to completely replace primary materials for some applications, then their alternate use might need to be found out. Those products which are made from such recycled materials might not command the same price and attract the same customers as products made with primary materials. This could then lead to a demand for either supply-side incentive (e.g., for the producers to use recycled materials) or demand-side incentive (e.g., for the consumers to purchase such materials) from the industry.

The fourth insight would be on the role of market-based mechanisms in nudging producers to start using recycled materials and disclose their recycling approaches. As noted in Tables 6 to 8, some, but not all, producers have come out with net-zero targets. Some have also introduced internal targets and policies for using recycled materials. It was also pointed out during one of the workshops by a producer that their electronic products are made of recycled materials and such information is also put on the product brochure and packaging. But the lament from the same producer, and others present in the workshop, was that there is not yet a significant demand from the consumers for such products or a support from the government for such products. In the absence of consumer demand and government support, market-based mechanisms that rely on information disclosures and bring in reputational effects can play some role in nudging companies to introduce recycling targets for some products. Some of the more recent sustainability reporting frameworks that have been introduced recently, e.g., TCFD (Taskforce on Climate Related Financial Disclosure), TNFD (Taskforce on Nature Related Financial Disclosures)and BRSR (Business Responsibility and Sustainability Reporting) in India require companies to explicitly disclose their approach to recycling, material recycled, and recycling targets. Such disclosures norms and frameworks could drive companies to streamline their internal processes and approaches to use more SRM in manufacturing. Gradually as this trend picks up, it could in turn drive initiatives by such companies to source SRM from recyclers.

The fifth and the final insight that came up during discussions with subject matter experts was the importance of the design step in increasing supply of SRM. Most of the focus for SRM is on the post-consumption stage, i.e., e-waste recycling. However, the pre-production and the production phases can have a major influence on whether the products are easier to disassemble and whether the component are easier to recover and recycle. We tried reaching out to one of the leading semiconductor design and manufacturing companies of the world to seek their input but couldn't get a response. However, the published literature backs this claim of the experts that electronic product design, including that of the components and semiconductors can have a significant impact on the quantity and quality of materials recovered. Circular Economy is not just about recycling. The loop cannot be closed by focusing on recycling alone and the ambit of discussions needs to be focus on the design phase as well.

4. POLICY RECOMMENDATIONS

Public policies can influence corporate and business strategies in numerous ways. The absence or the presence of favourable public policies can often lead to the success or failure of business initiatives and societal or environmental objectives. Therefore, designing appropriate public policies for driving sustainability in the EEE sector, especially for CRM and SRM is very important at a juncture when India is attempting to transition to a circular economy. There are several questions and concerns that such public policies would need to address. These questions and concerns could be categorised into system-design-specific, organisation-specific, and societal-specific.

Within the former category, the nature of global production networks (GPN) of the EEE industry needs to be considered. The value chain of the EEE industry is very long, complex, and fragmented, often spreading across multiple geographies and jurisdictions. If the policy environment is those multiple geographies and jurisdictions are not aligned, any domestic policy might not be as effective or efficient in achieving the desired outcome. If there are competing policy environments in those multiple geographies, achieving the desired goals becomes even more difficult.

Closely related to this point is the fact that sustainability in general, and for EEE industry in particular, is not just a problem of one country or firm. No single government, firm, or stakeholder will have the necessary means and desire to address the sustainability issues in the EEE industry. The embedded ideas of responsible consumption and production and circularity are a pressing need for the world today. Taking cues from the manner in which climate change and other environmental concerns, are being managed and addressed, there is a compelling argument in favour of global agreements, frameworks, and solutions for embedding circularity in the EEE industry. Evolving consumption patterns of EEE products and various economic, social, and environmental challenges associated with the rising volumes of e-waste make it imperative for multiple stakeholders to strive for a global multi-pronged approach to solve underlying issues.

Within the set of concerns and questions specific to organisation, the policies need to consider the circularity aspects from the point of view of a firm. The costs of embedded circularity are mostly internalised (within the firm) while the benefits are mostly accrued outside the firm (e.g., to society, to the environment, etc.). In the absence of the right set of balancing of such costs and benefits, the firms would look for the right incentives to align their operations. The incentives could be in the form of government support (e.g., tax, subsidies, public procurement etc.) or market-based mechanisms (e.g., sustainability reporting, reputational gains etc.). Unless the right incentives are visible to the firms, private action is unlikely to match public expectations.

Besides these, lessons drawn from the experiences of firms in the EEE industry that had tried to make supply chain management responsible for conflict minerals (Tin, Tungsten, Tantalum, Gold) need to be considered. After the enactment of Section 1502 of the Dodd-Frank Act 2010 in the United States, many electronic firms had taken various steps, with different levels of success, to make the supply chain of the four conflict minerals responsible. Past research indicates that six organisation-specific factors affected the success of a firm's efforts. These factors include organisational complexity, supply chain complexity, power over suppliers, visibility, reputation, and voluntary CSR participation[lxi]. These lessons become important as India prepares to enact policies for CRM and SRM.

Finally, the society specific set of concerns and questions need to consider the larger societal costs and benefits from having a circular economy in the EEE sector for CRM and SRM. As documented earlier in this report, CRM and SRM are relevant not just for the EEE sector, but also for the clean tech sector and automobile industry among others. If India has to meet the INDC targets by 2030 and the net zero targets by 2070, a significant transformation of the automotive industry and the energy sector has to happen. CRM and SRM assume even higher significance when one considers their role in the production of solar panels, electric vehicles, batteries, and wind turbines etc. Identification, monitoring and tracking of CRM and SRM will be important in transitioning towards a circular economy framework and will greatly support India's efforts to meet climate targets, enhance domestic manufacturing and economy, and improve energy security.

In the last decade or so, a number of policies and framework documents, with direct and indirect significance to the EEE sector, have been released by various ministries of the Indian government. For example, automobiles, auto components, electronic systems, electrical machinery, information technology, and business process management, and renewable energy are among the 25 focus sectors under the Make in India initiative. Sectoral policies like M-SIPS and SPECS have been released by MeitY to boost electronics manufacturing in India. For transitioning to a circular economy, several frameworks (e.g., National Non-ferrous Metal Scrap Recycling Framework 2019 by the Ministry of Mines, Steel Scrap Recycling Policy 2019 by the Ministry of Steel, and National Resource Efficiency Policy 2019 by MeitY) have been released in the last five years.

Other policies and initiatives that can have an impact on CRM and SRM in the EEE sector include the recent push by the Ministry of Mines to push for the exploration of rare earths and critical minerals by tweaking the Mining Act. Very recently, there has also been a concerted effort by the government to look outward to boost India's positioning in CRM and SRM. Two specific initiatives standout for this. The first one includes the partnerships with the Australian government whereby a consortium of Indian public firms will jointly develop cobalt and lithium mines in Australia. The second one includes the setting up of a multi-country Minerals Security Partnerships (MSP) in 2022 and Indian government's consistent effort to join MSP to develop resources, technologies, and share knowhow related to CRM and SRM.

4.1 CRM and SRM

Based on a review of the existing domestic and global policies, an understanding of the Indian macroeconomic environment, and the domestic policy priorities of the Indian government, following policies are suggested for CRM and SRM:

1). Becoming a part of global alliances for development and sharing of technologies and best practices for CRM and SRM- India should make an attempt to become part of regional and global alliances to share resources, technologies, and best practices for CRM and SRM. India is not a major producer of most of the materials required for manufacturing EEE and also does not possess much known reserves either. The large domestic market and India's manufacturing ambitions in the EEE sector could enhance India's case to be a part of such global and regional alliances.

2). Jointly explore and develop mines outside India, for minerals identified as CRM. The government has taken some steps in this direction in the last one year. The steps taken include setting up of KABIL, for exploration and production of critical minerals outside India, as a joint venture between three government owned public enterprises. Recently there are also reports of Coal India Limited getting into similar space. Such exploration can be carried out by enabling Indian companies to venture out and by also having bilateral agreements with like-minded countries.

3). Work towards a global agreement on setting a minimum universal working definition of CRM. Different countries define criticality differently and this definition can also change with time. These differences can lead to challenges for producers in the EEE sector, especially those with GPN and value chain spread across multiple jurisdictions. A minimum universal working definition that sets out some common dimensions of criticality, but also allow flexibility to domestic governments to add additional dimensions, could help the producers streamline their processes accordingly. This minimum universal working definition may also be required considering increased current and likely bilateral, multilateral and global agreements and partnerships on CRM and SRM.

4). Considering the dynamic nature of criticality, the domestic list of critical minerals should be periodically updated. The process of periodic updating the list should be clearly spelt out and involve multiple stakeholders to increase transparency, trust in the process, and reduce information asymmetry. Among others, the stakeholders should include representatives from producers, recyclers, component manufacturers, policy thinktanks, and research institutions. The updated list should reflect changes in dimensions of criticality, such as those in economic importance, supply risks, or environmental parameters.

5). Simultaneously, efforts should be directed towards setting up a minimum domestic and global standard for recycling, use of recycled content in products and components used in the EEE sector. These minimum standards, once established, could promote judicious use of CRM and increased use of SRM in EEE sector, both essential for embedding circularity. Harmonization between global and domestic standards would ensure that goods designed for world can be sold in India and vice versa. It could also promote producers to produce goods in India and sell in both domestic and global markets.

6). As a demand side incentive, gradually shift public procurement towards components and products with recycled content above a certain threshold. Governments in India have been introducing mandates and norms for nudge business consumers to move towards more 'greener' options in recent years. These include mandate for renewable energy, electric vehicles, and energy efficiency. On the similar lines, governments could consider nudging or mandating bulk consumers of EEE products towards products made using recycled content.

7). Past research on conflict minerals indicate that organisation's responses are influenced by six factors: organisational complexity, supply chain complexity, power over suppliers, visibility, reputation, and voluntary CSR participation. For the latter three, government policies promoting information disclosures can play a role. It can be achieved by promoting voluntary and mandatory disclosures of key sustainability indicators and performance by companies in their annual reports- The new sustainability reporting framework, BRSR, came into force for the top 1000 listed companies (by market capitalization) in India from the current financial year. BRSR specifically requires companies to disclose category of waste generated and total waste recovered through recycling, re-using or other recovery options. Such disclosure norms, with time, could bring a change in the way companies approach the topics of waste management and recycling. However, most of the large electronics companies with leading market share in India are not listed on Indian exchanges. For such firms, other voluntary global disclosure frameworks, that also include disclosures on recycling, could be an option. The government should work with multiple stakeholders including GRI and IFRS to incorporate circular economy indicators and targets into their existing global sustainability reporting frameworks and bring a convergence on these subjects with the Indian reporting frameworks.

8). Connected to the above point is the role of CSR in driving responsible business practices. India is perhaps the only country in the world with mandates on both EPR and CSR. For producers in the EEE sector, this then provides unique opportunity to streamline their responsible business practices and bring a convergence in their strategies for managing e-waste, judicious use of CRM and improved usage of SRM. If certain activities related to boosting the recycling ecosystem in India, upskilling the informal sector, and improving the livelihoods of the informal sector are brough under the ambit of eligible CSR activities, firms in the EEE sector can potentially be more inclined to invest in such responsible business practices.

9). Incentivize firms for their actions on the circular economy front by reducing GST on input components (required for manufacturing) and on final products and components containing recycled content (above a certain threshold). The former would act as a supply side incentive for the producers while the latter will act as a demand side incentive for the consumers. Another measure that could complement these steps could be the introduction of a government backed eco-label to denote the environment (sustainability) attributes of a product. The criteria should be developed using a multi-stakeholder platform and be objective, verifiable, measurable, and reliable. Among other things, it should promote judicious use of CRM, increased usage of SRM, and better recycling practices. Such ecolabels could reduce the information asymmetry between the producers and consumers of such 'greener' products and boost domestic recycling ecosystem. The ecolabels could be developed for products and components made with recycled content (above a certain threshold). Finally, upfront subsidy for retail consumers and minimum mandate for bulk procurement could also be considered as demand-side measures to help drive the demand for such products.

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European Resource Efficiency Initiative
B5/2, Safdarjung Enclave
New Delhi – 110029
T: 011 49495353
E: rachna.arora@giz.de
E: reva.prakash@giz.de
I: www. eu-rei.com