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Multi-Criteria Evaluation of Critical Raw Materials in Eco-Design Products within the European Context

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Declaration of Authorship

I hereby confirm that I have written the accompanying thesis by myself, without contributions from any sources other than those cited in the text and acknowledgements.

This applies also to all figures, drawings, maps, and images included in the thesis.

Freiberg, date 11.04.2024

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List of abbreviations

Fe	Iron
Zn	Zinc
Si	Silicon
Cu	Copper
Al	Aluminum
Mg	Magnesium
Mn	Manganese
SP	Supply Risk
PV	Photovoltaics
EU	European Union
UK	United Kingdom
ENV	Environmental
BoM	Bill of materilas
HDD	Hard Disk Drive
PC	Personal Computer
GHG	Greenhouse Gas
LCA	Life Cycle Analysis
LED	Light-emitting Diode
LCD	Liquid-crystal display
CRM	Critical Raw Material
LHV	Lower Heating Value
HHV	Higher Heating Value
EF	Environmental Footprint
PCB	Printed Circuits Board
SRM	Strategic Raw Material
ErP	Energy-related Products
LREE	Light Rare Earth Elements
TSC	Technical Screening Criteria
EIA	Eco design Impact Accounting
HREE	Heavy Rare Earth Elements
LTS	Long-Term Baseline Scenario
CED	Cumulative Energy Demand
EHP	Environmental Hazard Potential
EOL	End-of-Life Recycling Input Rate
DG ENER	Directorate-General for Energy
MDS	Moderate Decarbonization Scenario
WEEE	Waste Electrical and Electronic Equipment

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Abstract

The transition to a sustainable global economy necessitates an immediate re-evaluation of our raw material consumption (Lenzen et al., 2021; Mancini & Nuss, 2020).This endeavors involves finding an equilibrium between economic development, environmental preservation and the efficient use of resources (Basheer et al., 2022).The objective of this thesis is to develop a Multi-criteria classification system for raw materials based on their scarcity, criticality, and environmental relevance, specifically within the European context. In parallel we will conduct a detailed analysis of the raw materials used in various products defined in the product scope (all products which fall under the Ecodesign Directive, excluding "Tyres" and "Lighting." We will also investigate products with the ongoing preparatory study "Tablets and Smartphones" and "Photovoltaic" becouse of high content in critical and strategic raw materilas. Additionally, we will analyzed other products that are still not regulated but relevant in terms of material content and examined in previous Working Plans since the adoption of the first Ecodesign Directive (covering the periods 2009-2011, 2012-2014, 2016-2019 and 2022-2024) e.g."Taps and showers"). We will integrate the findings into a big table, which provides a clear and complete overview of priority ‘couples’ material + product. This system is essential for enabling policymakers to make informed decisions concerning the allocation and responsible utilization of raw materials for all the products regulated by Ecodesign Directive. The reason for focusing on eco-design products is their crucial role in the EU's commitment to a greener economy and existing framework regulation, making it easy to adapt new potential regulatory approaches regarding materials efficiency.:

- *Information requirement (on material weight/weight range).*
- *Requirements on dismantlability (to recover more easily the material).*
- *Requirements setting a minimum share of recycled raw material.*

Traditionally, evaluations of raw materials have emphasized the environmental downsides of their extraction and use. The thesis analyses the positive environmental impacts of certain raw materials, especially those critical for renewable energy and other strategic sectors. This approach challenges conventional methodologies e.g. *“OekoRess,”* which focuses on the potential negative environmental impacts of mining. The thesis introduces a different way to assess raw materials' "environmental relevance" parameters within the "Multi-Criteria Evaluation System of Raw Materials." It suggests that mining operations could increase their value by focusing on materials essential for renewable energy technologies. This perspective not only redefines the environmental criticality of raw materials but also aligns with broader sustainability objectives by underscoring the essential role of certain materials in advancing renewable energy technologies and other sustainable practices.

1 Introduction

1.1 Outline of the thesis

Raw materials play a critical role in driving the green and digital transformations that are essential for maintaining the competitive edge of the European Union (Herrington, 2021). They are instrumental in cultivating strategic autonomy and facilitating the reindustrialization of vital European ecosystems. Critical and strategic raw materials are particularly important for the EU's transition to carbon-neutral production methodologies, which aligns with its ambitious objective to reduce net greenhouse gas emissions by 2030 (European Commission, 2021a). The *“Preparatory study for the Eco design and Energy Labelling Working Plan 2022-2024*”(Directorate-General for Energy, 2022) emphasizes the significance of raw materials, especially those that are scarce, environmentally relevant, and critical.

The *“Taxonomy Regulation of the European Union, 2020/852”* (European Commission, 2021c) is an essential component of the EU's plan to encourage sustainable investment. Its primary objective is to direct investment towards activities that support the EU's environmental goals. The mining sector, which provides essential materials for the circular economy and renewable energy technologies, is not included in the initial scope of the taxonomy's *“Technical Screening Criteria (TSC)”* (European Commission, 2021a). This exclusion can be attributed to the sector's inherent environmental complexities and substantial challenges in quantifying sustainable practices within diverse mining operations. In research papers by (Riva Sanseverino & Luu, 2022; Schlichenmaier & Naegler, 2022), and the *“2023 World Bank Report”* (Hund et al., 2023) the critical role of mining in supporting sustainable energy transitions is highlighted, along with the difficulties in establishing universally applicable sustainability criteria for the sector.

The *Eco design Directive* and the *Energy Labelling Regulation* represent key components within a broader strategy for product policy aimed at enhancing the energy efficiency of products. They are essential components of a broader product policy strategy aimed at improving the energy efficiency of products and reducing their overall environmental impact. These initiatives support the easy movement of energy-related products within the EU and provide consumers with the necessary information to choose from the available energy-efficient products. These regulations play a crucial role in the EU's shift from fossil fuel dependence to cleaner energy, significantly contributing to the EU's commitments under the Paris Agreement to reduce greenhouse gas emissions. The Eco design Directive mandates that companies manufacturing or importing goods into the EU prioritize creating products that consume less energy through the establishment of baseline requirements for energy efficiency. The *Energy Labelling Regulation* enhances consumer awareness by implementing a standardized energy labeling system across Europe. This system ranks products from A (highest efficiency) to G (lowest efficiency), promoting the choice of better products for energy conservation and resource management among EU residents. Additionally, it offers insights into a range of product features, such as their energy use and environmental impact.

Definition of *‘’**Energy-related Products (ErP)** are products that use energy or that do not use energy but have an indirect impact on energy consumption, such as water-using devices, building insulation products, windows, etc. Compared to ErP, energy-using products (EuP) depend on energy input (electricity etc.). All ErP and EuP are subject to energy efficiency requirements.’’ (ErP 2009/125/EC)*

Energy-related products (ErP) refer to a wide range of goods that either consume energy directly or indirectly impact energy consumption. The *“ErP Directive 2009/125/EC of the European Union”* serves as an eco-design regulation that covers a broad range of energy-consuming products throughout their lifecycle, including dishwashers, household electronics, air conditioning units, boilers etc. The primary objective of the *“ErP Directive”* is to encourage manufacturers and importers to introduce products that exhibit better energy and resource efficiency (European Parliament & Council of the European Union, 2009). To achieve ErP certification, a product must be evaluated to verify that it meets predetermined energy and resource consumption thresholds. After a successful evaluation, the product is labelled with the CE mark, enabling it to be distributed throughout the European Union.

1.2 Main Goal and Tasks

The overall research goal of this master's thesis is to conduct a *Multi-Criteria Evaluation of Raw Materials used in Eco-Design Products, specifically focusing on the European Union Context*. This objective is divided into two key goals:

1. The first research aim is to develop the multi-criteria classification system that classify raw materials based on scarcity, environmental relevance, and criticality criteria. This aim is completed in the following stages:
    - Establish definitions and metrics for scarcity, environmental relevance, and criticality criteria.
    - Design and develop a classification model considering the defined criteria.
    - Compile a methodology that categorizes raw materials based on their scarcity, environmental relevance, and criticality.
    - Conduct sensible studies to validate the classification system against known methodology.

2. The second research aim is to conduct an extensive analysis of the raw material content in selected products, identifying material-product combinations that require priority attention. We will undertake the following tasks in support of this goal:
    - Conduct an analysis to identify a list of products that are representative for the research.
    - Examine Bills of Materials for various products to determine their composition and quantify the use of different raw materials.
    - Determine the average content of raw materials in different eco-design product categories and identify priority material-product combinations.
    - Integrate the findings into a “final table”, which provides a clear and complete overview of selected raw materials.

1.3 Structure of the thesis

Chapter 1: Introduction

In the introduction, I established the critical context for the thesis, highlighting the importance of raw materials for Europe's green and digital transformation. I outlined the dual objectives of developing a multi-criteria classification system for raw materials and analyzing the raw material content in selected products. This chapter set the stage for the research by presenting the challenge of sustainable raw material management within the European Union and delineating the scope and structure of the thesis.

Chapter 2: Characteristics of the Material Scope Background and Literature Review of Raw Material Classification: Scarcity, Criticality, and Environmental Relevance

Here, I delved into the complexity of raw material supply, focusing on the concepts of scarcity, criticality, and environmental relevance. By analyzing various factors affecting supply risk, including economic, social, and political dimensions, I presented a comprehensive view of raw material scarcity. I reviewed existing methodologies for assessing raw material criticality, advocating for a detailed approach that incorporates sustainability. Additionally, I critiqued and integrated the "ÖkoRess" methodology into our framework, emphasizing the environmental impacts of raw material extraction and processing.

Chapter 3: Methodology on the analysis of the raw material content

In this chapter, I focused on selecting and categorizing products for analysis under the EU's Eco-design Directive. I described the process of identifying products based on their significance to raw material consumption and outlined the methodological approach for analyzing the raw material content of these products. This included a detailed examination of product categories and the rationale behind their selection, emphasizing their relevance to the study's objectives.I also dedicated to the practical application of our methodologies through the analysis of bills of materials for various products. I provided case studies on specific products such as printed circuit boards and LED/LCD displays, illustrating the methodology in action. Through quantitative assessments, I determined the key raw materials required for the manufacture of these products, offering a deep dive into the raw material composition and its implications for sustainability.

Chapter 4: Methodology of the multi-criteria classification system

I elaborated on the development of a novel classification system for raw materials, which incorporates scarcity, criticality, and environmental relevance. This involved a detailed discussion of the methodology used for assessing each parameter, including the adaptation and critical assessment of the "ÖkoRess" methodology. I also described the model used for final classification, detailing the scoring system, thresholds, and categorization process, which underscored the innovation and comprehensiveness of our approach.

Chapter 5: Initial Results Discussion

I presented the initial findings from the classification of raw materials, highlighting the implications for policy and industry. This included an analysis of how different methodologies affect the classification based on environmental relevance, and a discussion on the outcomes of various scenarios based on different weighting of environmental relevance factors. These results provided valuable insights into potential policy impacts and underscored the flexibility and depth of our classification system.

Chapter 6: Conclusion

In the concluding chapter, I summarized the main findings and contributions of the thesis, emphasizing the development of a robust and innovative classification system for raw materials. I discussed the implications of our research for EU policy, particularly concerning sustainable material management and the Eco-design Directive. I also outlined directions for future research, suggesting areas for refinement and further exploration to continue advancing the field of sustainable raw material management.

Throughout the thesis, my aim was to provide a nuanced understanding of the challenges and opportunities in managing raw materials sustainably within the European Union, contributing valuable methodologies and insights to the field.

2 Background and Literature Review of Raw Material Classification: Scarcity, Criticality, and Environmental Relevance

2.1 Scarcity

Supply risk refers to the vulnerabilities and uncertainties within the supply chain of raw materials. This goes beyond just the possibility of geological scarcity and includes economic, social, and political factors. In other words, the availability of raw materials is not solely dependent on their physical presence in the Earth's crust. It is also linked to human activities, regulatory frameworks, technological advancements, and global market dynamics. The European Commission's report emphasizes that Earth's geology leads to uneven mineral distribution, suggesting that countries' real challenge is not scarcity but rather enhancing exploration and technology for sustainable resource use (European Commission, 2011). (Achzet & Helbig, 2013) highlight the necessity for a more systematic approach in selecting and weighting indicators of supply risk, underscoring the significant variability in existing evaluations. The European Union (EU) has developed and refined methodologies to assess supply risks, the latest version was published in 2023. By considering factors like recycling impacts, supply concentration, geopolitical stability and the economic importance of materials, the EU's model provides a comprehensive framework for evaluating supply chain vulnerabilities (Grohol & Veeh, 2023). This approach helps identify critical raw materials and formulate strategic policies to mitigate supply risks. In the current thesis we will

2.2 Criticality

Understanding the criticality of raw materials is vital for sustainable development, an area extensively reviewed in recent papers. The study of (Schrijvers et al., 2020) thoroughly investigates the methodology used to determine the criticality of raw materials, emphasizing the crucial role of detailed data and strict approaches. The study advocates for developing precise guidelines to ensure the reliability of these assessments. These guidelines should cover all aspects, including setting clear goals, selecting appropriate indicators, and effectively interpreting the results.

The European Union (EU) has developed a methodology to assess critical raw materials (CRMs) that considers two primary factors:

- crucial economic significance of these materials to the EU
- significant risks associated with potential disruptions in their supply chain.

The 2023 assessment (Grohol & Veeh, 2023) is a continuation of the previous methodologies from 2011, 2014, and 2017, (Blengini et al., 2017; European Commission, 2011) which focused on *Economic Importance (EI)* and *Supply Risk (SR)*, with thresholds set at:

- **SR ≥ 1.0**
- **EI ≥ 2.8**

The *"Critical Raw Materials Act"* (CRMA) introduces a new category of materials, Strategic Raw Materials (SRMs), which are integrated into the CRMs list. The CRMA establishes specific standards for the strategic raw materials value chain and for the EU's supply diversification. These standards include:

- Extraction of at least 10% of the EU's annual consumption.
- Processing of at least 40% of the EU's annual consumption.
- Recycling of at least 15% of the EU's annual consumption.
- Limiting the use of a single third country to no more than 65% of the EU's annual consumption. (European Commission, 2023)

2.3 Environmental Relevance

The importance of environmental factors in establishing raw material policies and ethical sourcing methods is increasing. This change is mainly due to the growing awareness among the society about the problems and outcomes that arise from mining and refining ores and minerals (Manhart et al., 2019a).The European Union's industrial sector is predominantly dependent on imported raw materials, rendering it significantly vulnerable to disruptions throughout the supply chain (Nuss et al., 2018).

With the ongoing shift towards renewable energy, there is an anticipated surge in demand for metallic raw materials essential to produce wind turbines, photovoltaic (PV), batteries, electrolyzes, and heat pumps (Carrara et al., 2023). The processes involved in the production of these raw materials, including mining, mineral processing, and smelting, are known for their substantial environmental footprint and generation of waste (Azadi et al., 2020; Haddaway et al., 2019).

The socio-economic and environmental ramifications of raw material extraction and their entire lifecycle have been extensively documented in the literature. Presently, a variety of methodologies are available to evaluate the environmental significance of raw materials. Even though various approaches have been developed to address environmental concerns related to mining activities, most of them focus on specific issues such as toxicological impacts. Additionally, methods like ‘’life cycle assessment’’ (LCA) fail to capture the full scope of environmental consequences associated with mining activities (Manhart et al., 2019a).

A notable *"OekoRess"* (Günter Dehoust et al., 2017) method has been developed to address these limitations, offering a holistic assessment of the environmental implications of raw material extraction and use. This method stands out for its ability to encompass a broad spectrum of issues, from ecological to socio-economic impacts, resulting in a more complete assessment of the environmental relevance of raw materials. The methodology was first introduced in 2017 through the (OekoRess I) (Günter Dehoust et al., 2017) project, which was followed by (OekoRess II) (Günter Dehoust et al., 2020), that applied the same evaluation scheme. Currently, (OekoRess III) (Aissa Rechlin et al., 2022) is in the pilot project phase, analyzing much more mining sites for a more detailed analysis of the environmental hazards of raw materials. The 2017 methodology introduces the term *"Environmental Hazard Potential (EHP)",* which is defined as the aggregate of all probable environmental impacts without suitable mitigation actions. This assessment considers 11 indicators, each paired with its respective EHP value (Günter Dehoust et al., 2017, 2020; Manhart et al., 2019b).

Traditionally, the assessment of raw materials within the material criticality framework has focused solely on the negative impacts and environmental risks associated with the extraction, processing, and utilization of raw materials in various sectors. However, this approach has often overlooked the potential positive environmental contributions that certain raw materials can make, particularly in strategic sectors of the EU.

To address this limitation, a new classification parameter has been developed that represents a significant paradigm shift. This methodology is designed to analyze raw materials that play a critical role in 15 key technologies distributed among five strategic sectors: renewable energy, electromobility, energy-intensive industry, digital, and aerospace/defense (Carrara et al., 2023). A particular emphasis is placed on the renewable energy sector, reflecting its crucial role in sustainable development. The innovative aspect of this methodology lies in its approach to considering the positive environmental relevance of specific raw materials. By assigning higher scores to raw materials that are critical in term of supply chain and have significant environmental benefits for the renewable energy sector. The methodology ensures that materials essential for sustainable technologies are identified as highly relevant. The focus on positive environmental relevance underscores the importance of supporting critical technologies for the EU, thereby facilitating a more informed and sustainable approach to raw material classification and utilization.

2.3.1 Introduction to “ÖkoRess” methodology

The “ÖkoRess” methodology is a pioneering approach to assessing the environmental criticality of raw materials in the face of the escalating environmental impacts of mining activities worldwide. Developed and applied by the *(Öko-Institut)* and other collaborators, this methodology provides an all-inclusive evaluation scheme for mineral raw materials. It focuses on the environmental hazard potentials (EHPs) derived from mining operations and offers associated recommendations for an environmental raw materials policy, thereby addressing the pressing global environmental crisis.

The methodology assumes that the extraction and processing of raw materials are inherently linked to significant environmental impacts, ranging from ecosystem disruption to water and soil contamination. It leverages a wide array of data, including geo-referenced information on mining locations, production volumes, and environmental hazard potentials associated with mining activities and residues.

The ÖkoRess methodology comprises two primary evaluation models: site-related and raw material-related assessments. The site-related evaluation focuses on individual mining projects and considers factors such as geological conditions, mining and processing technologies, and local environmental and social conditions. On the other hand, the raw material-related evaluation aggregates environmental hazard potentials on a global scale, considering the entire production of raw materials. It operates on several key assumptions: that the environmental governance quality within a country (reflected by the Environmental Performance Index, EPI), the size of material and energy flows, and specific mining-related ecologic risks (e.g., potential for Acid Mine Drainage, heavy metal paragenesis, etc.) are crucial determinants of a raw material's environmental criticality. These assumptions guide the systematic use of data from geological characteristics to technological practices and environmental governance quality to derive a raw material's EHP. Such an inclusive approach ensures a nuanced understanding of the complexity of mining impacts.

The ÖkoRess II project, following its precursor ÖkoRess I, undertook the evaluation of a broad selection of 61 raw materials or raw material groups. This evaluation was based on criteria initially established for the criticality assessment by the European Commission. This holistic assessment underscores the importance of identifying the direct environmental impacts and understanding the governance structures that either mitigate or exacerbate these impacts, providing researchers with a deep and thorough understanding of the environmental dimensions of raw material extraction.

2.3.2 Critical Assessment “ÖkoRess” methodology

The “ÖkoRess” methodology advances environmental considerations in raw material criticality assessments but faces several challenges. The methodology focuses primarily on direct environmental impacts associated with mining activities, potentially underestimating the broader ecological footprint of raw materials. This includes the lifecycle impacts of raw materials, from extraction to end-of-life, including transportation, processing, and the production of secondary products. The methodology's effectiveness is partially contingent on the representativeness of its case studies and data sources, which may not adequately capture the full geographical diversity and the array of mining practices globally. This could lead to oversimplified assessments that fail to account for local environmental contexts and variabilities in mining operations.

The methodology's complexity and theoretical nature may also make it difficult for policymakers and industry stakeholders to translate findings into actionable insights. It relies heavily on existing datasets, which may not fully reflect the informal mining sectors' complexities and environmental and labor issues. This reliance could limit its effectiveness in capturing the entire ecological footprint of raw materials, including lifecycle impacts and broader socio-economic effects such as community displacement.

Finally, without precise mechanisms to incentivize sustainable practices or to penalize environmentally hazardous ones, the methodology's impact on promoting sustainable mining practices might remain theoretical. Aligning the methodology's outputs with actionable policy levers and industry incentives could significantly enhance its practical implications.

In summary, while the “ÖkoRess” methodology marks a significant stride toward environmentally conscious raw material assessments, its effectiveness is tempered by challenges related to data comprehensiveness, practical applicability, scope of environmental impact assessment, socio-economic consideration, data reliability, complexity, and incentivization of sustainable practices. Addressing these areas could elevate the methodology from a theoretical tool to a practical instrument for driving significant environmental improvements in raw material extraction and usage.

3 Methodology on the analysis of the raw material content

3.1 Select of products that are representative for the research

Regarding our product analysis, we'll focus on energy-related products, emphasizing those already subject to regulation and those under current study for potential regulation. Additionally, we will explore other categories of energy-related products that, while yet to be regulated, are significant due to their material content and were reviewed in previous Working Plans following the implementation of the initial Ecodesign Directive, spanning the periods (2009-2011, 2012-2014, 2016-2019, and 2022-2024). We have classified the products into three main groups, as shown in *(Figure1).*

After conducting a thorough screening process, we arrived at the following classifications:

Category 1 includes all products governed by the Ecodesign Directive, except "Tyres" and "Lighting."

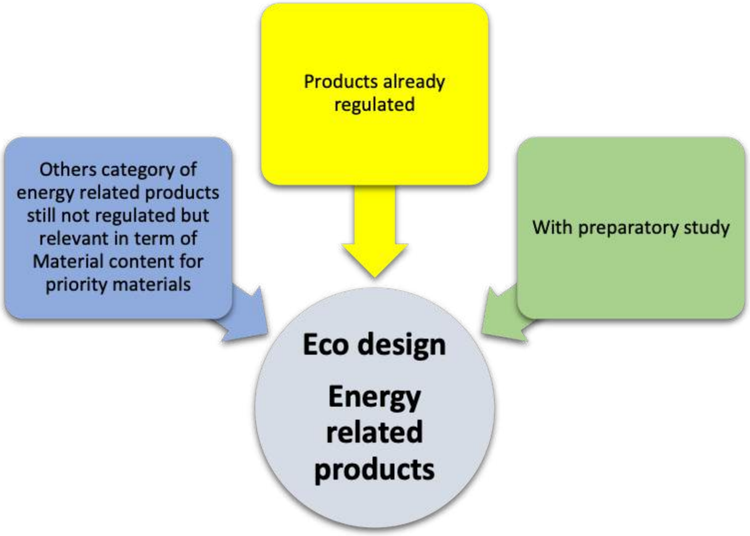
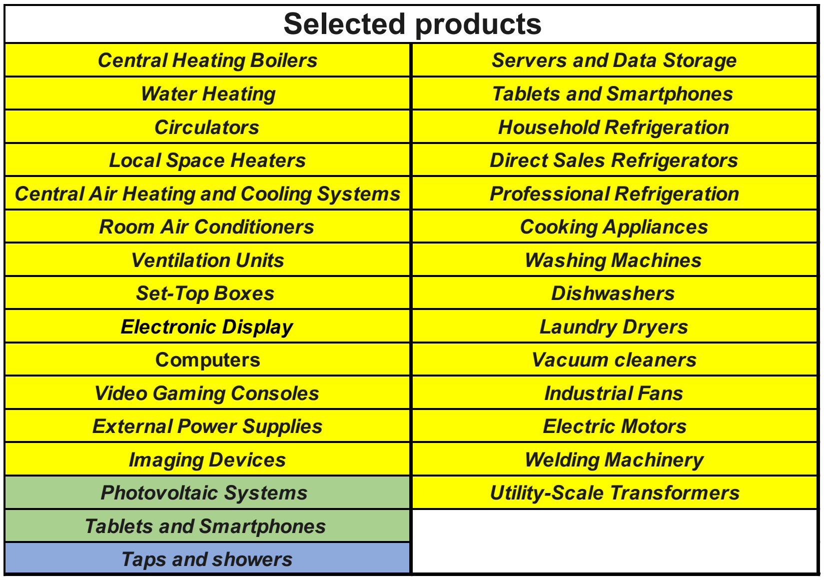


Figure 1 Considered products in the product scope

Category 2 includes "Tablets and Smartphones" and "Photovoltaic Panels" due to their significant content of critical and strategic raw materials.

Category 3 includes only "Taps and Showers."

In *(Figure2).*, we will detail the selected products, utilizing color coding for easy reference.



Selected products	
Central Heating Boilers	*Servers and Data Storage*
Water Heating	*Tablets and Smartphones*
Circulators	*Household Refrigeration*
Local Space Heaters	*Direct Sales Refrigerators*
Central Air Heating and Cooling Systems	*Professional Refrigeration*
Room Air Conditioners	*Cooking Appliances*
Ventilation Units	*Washing Machines*
Set-Top Boxes	*Dishwashers*
Electronic Display	*Laundry Dryers*
Computers	*Vacuum cleaners*
Video Gaming Consoles	*Industrial Fans*
External Power Supplies	*Electric Motors*
Imaging Devices	*Welding Machinery*
Photovoltaic Systems	*Utility-Scale Transformers*
Tablets and Smartphones	
Taps and showers	

Figure 2 Selected products sort by color

Based on the "*2020 Preparatory Study for Solar Photovoltaic Modules, Inverters, and Systems"*, we have chosen photovoltaics as our scope product. We also analyzed the demand for raw materials required by wind and solar PV technologies, (Alves Dias P. et al., 2020) and used a specific database to evaluate material intensities and predict future demands and selected the ''Moderate Decarbonization Scenario'' (MDS) for our analysis, (Carrara et al., 2020). The MDS scenario aligns with the European Union's legally binding targets for 2030 and the ''Long-Term Strategy Baseline Scenario'' (LTS). The goal of this scenario is to achieve a 100% reduction in ''Greenhouse gas emissions'' (GHG) by 2050, (European Commission, 2019b).

The "taps and showers" were considered a potential candidate for the Eco Design Directive based on the *''2013 Preparatory Study on new relevant product groups''*. We selected this group due to the high content of brass, copper, and zinc (alloys) in the Bill of Materials. The sales data from the Preparatory Study was adjusted for EU 27, considering the UK Brexit, using a conversion factor of 0.89, (European Commission - DG Ener, 2022).

Our decision to add tablets and smartphones to our product lineup is assumed on the insights from the *"2021 Preparatory Study on Mobile Devices"*. We primarily rely on data from, (Manhart et al., 2016) for the Bill of Materials (BoM). Our analysis focuses on smartphones and tablets, and we do not consider data on mobile phones and cordless phones. Smartphones and tablets are considered strategic technology based on the “*Foresight Study”*, (Carrara et al., 2023)

3.2 Methodology on Bill of Materials Examination

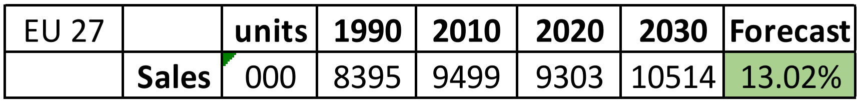
The first step in the process involved a review of the products governed by the *“Eco Design Directive”* and other products that were proposed for inclusion within its framework presented in *Chapter 3.* This task was based on findings from preparatory studies that focused on market figures and the average composition of materials used in the products. The main goal is to identify the amount of priority materials within regulated products, with a focus on both product categories and materials. This process facilitates the recognition of potential product combinations and materials that require regulation. The methodology used two significant phases.

In the first phase, all *“Bills of Materials”* (BoMs) *(Table 3)* were retrieved and analyzed as documented in the preparatory studies. Based on a detailed examination of the materials listed for each product category, which formed the foundation for subsequent analyses.

In the second phase, BoMs were matched with product sales data within the EU 27 based on the current *“Eco Design Impact - Accounting”* (EIA) (European Commission - DG Ener, 2022). This helped to calculate the weight of materials in products sold in 2020 and project these figures based for the year 2030. The analysis was crucial in understanding material trends over time and guiding the prioritization process. To facilitate this investigation, an organized ‘’*Excel’’* document was prepared, containing an info sheet for each product category under review. These categories include building installation products, electronic products, appliances, industrial products, and others. Each info sheet provided detailed information on sales in 2020, projected sales in 2030, forecasts, Bill of Materials, considerations of metal types (especially in steel alloys), and a final table summarizing all materials identified in products from the specific category. This structured approach enabled a systematic and detailed examination of the materials composition of energy-related products, laying the groundwork for targeted regulatory recommendations within the framework of the *“Eco Design Directive”*.

The forecasting model employed in this analysis hinges on projecting the future sales trajectory for various products. Specifically, the forecast is categorized as positive when the sales for a

Table 1 Sales (excel document on water heater) from Impact Assessment 2020



EU 27		**units**	**1990**	**2010**	**2020**	**2030**	**Forecast**
	Sales	000	8395	9499	9303	10514	13.02%

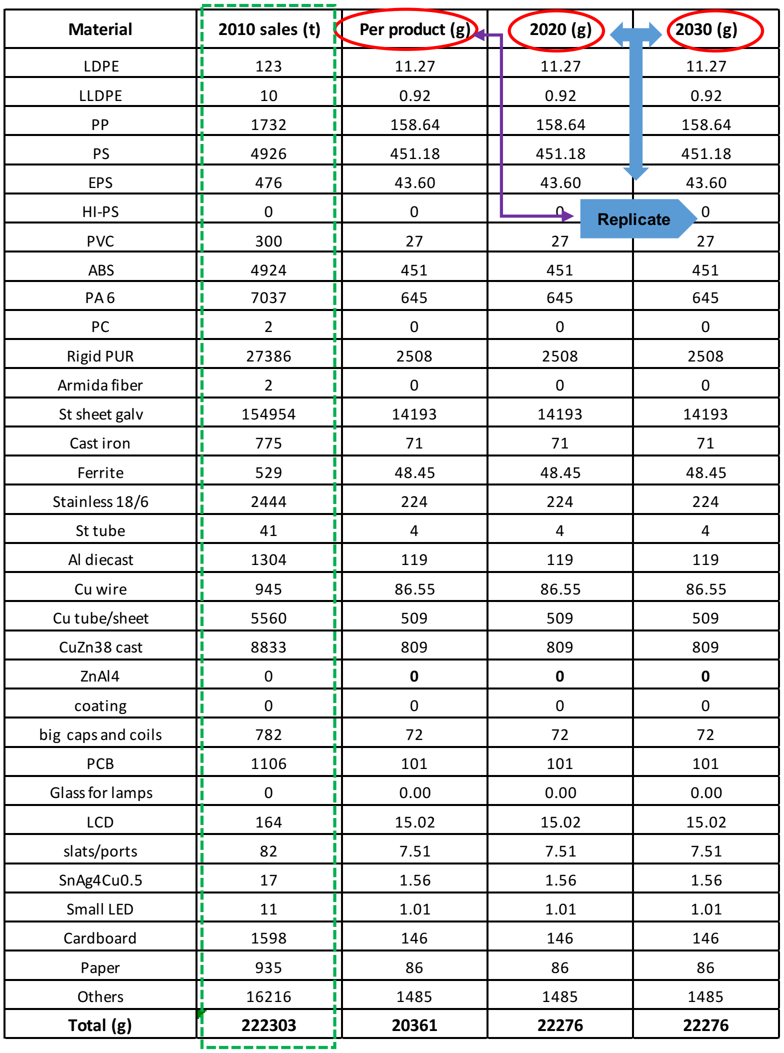
product in 2030 are expected to surpass those in 2020 and, conversely, as negative if a decline in sales is anticipated within the same timeframe, an example is presented in *(Table 2)*. A detailed text can be found in the ***(Appendix III).***

Table 2 Typical Bill of Materials form eco-design preparatory study example of (washing machines)

Material	WM 2007	WM 2015	WD 2015	2020 Ave.	2030 Ave.
Cast iron	6214	1779	1916	1785	1785
Iron	4978				
Stainless Steel	1939	17984	19369	18045	18048
Steel sheet	564	7898	8506	7925	7926
Steel	12521	866	933	869	869
Steel strip	6145			0	0
Sum Ferrous metals	**32361**	**28527**	**30724**	**28624**	**28628**
Al	1503	2347	2527	2355	2355
Aluminum casting (recycle 80%)	729			0	0
Brass	14			0	0
Copper wire	348	379	409	380	380
Cr	1761			0	0
Cu	869	1356	1460	1361	1361
zinc die-casting	85			0	0
Sum Non-ferrous metals	**5311**	**4082**	**4396**	**4096**	**4096**
ABS	1145	1740	1874	1746	1746
LDPE	1675	1613	1727	1618	1618
PA	6	24	26	24	24
PA 66-GF(Glass Fiber Reinforced)	0	6138	6611	6159	6160
PA66	88			0	0
PC	188			0	0
PET	10	22	24	22	22
Plastics, others	1073	632	641	632	632
PMMA	41	172	185	173	173
PP	5402	2000	2155	2007	2007
PP-K40	2533			0	0
PPO (=PPE)	2			0	0
PPS-GF	76			0	0
PVC	221	95	102	95	95
Sum Plastics	**12434**	**12436**	**13345**	**12476**	**12478**
Concrete	18180	20186	20186	20186	20186
Electronic, boards, lamp, etc	**165**	**225**	**225**	**225**	**225**
Glass	1773	1870	1870	1870	1870
Others	500	210	210	210	210
Paper	106	66	66	66	66
Wood	1573	2000	2000	2000	2000
SUM TOTAL (g)	**74225**	**69602**	**73022**	**69752**	**69759**

We have streamlined our methodology to enhance the accuracy of forecasting material usage in product manufacturing. Utilizing *Excel*, this approach dynamically updates in response to data changes, ensuring flexibility in forecasting and analysis. Key steps include designing an efficient data table, extracting, and calculating material weight per product from authoritative reports, expanding the table for future projections, and adjusting for product market share. Visual aids further clarify these processes, making our method accessible and robust for planning purposes. The actionable steps are:

Table 3 BoM (water heaters) adapted from 2016 Material inputs for production



Material	2010 sales (t)	Per product (g)	2020 (g)	2030 (g)
LDPE	123	11.27	11.27	11.27
LLDPE	10	0.92	0.92	0.92
PP	1732	158.64	158.64	158.64
PS	4926	451.18	451.18	451.18
EPS	476	43.60	43.60	43.60
HI-PS	0	0	0	0
PVC	300	27	27	27
ABS	4924	451	451	451
PA 6	7037	645	645	645
PC	2	0	0	0
Rigid PUR	27386	2508	2508	2508
Armida fiber	2	0	0	0
St sheet galv	154954	14193	14193	14193
Cast iron	775	71	71	71
Ferrite	529	48.45	48.45	48.45
Stainless 18/6	2444	224	224	224
St tube	41	4	4	4
Al diecast	1304	119	119	119
Cu wire	945	86.55	86.55	86.55
Cu tube/sheet	5560	509	509	509
CuZn38 cast	8833	809	809	809
ZnAl4	0	**0**	**0**	**0**
coating	0	0	0	0
big caps and coils	782	72	72	72
PCB	1106	101	101	101
Glass for lamps	0	0.00	0.00	0.00
LCD	164	15.02	15.02	15.02
slats/ports	82	7.51	7.51	7.51
SnAg4Cu0.5	17	1.56	1.56	1.56
Small LED	11	1.01	1.01	1.01
Cardboard	1598	146	146	146
Paper	935	86	86	86
Others	16216	1485	1485	1485
Total (g)	**222303**	**20361**	**22276**	**22276**

Step1: Design a Data Table for Efficient Calculations:

- Create a data table in Excel, starting with inputting a formula for the 2020 data.
- Ensure this formula is set to automatically replicate the 2030 data, extending down the entire column *(Table 3).*

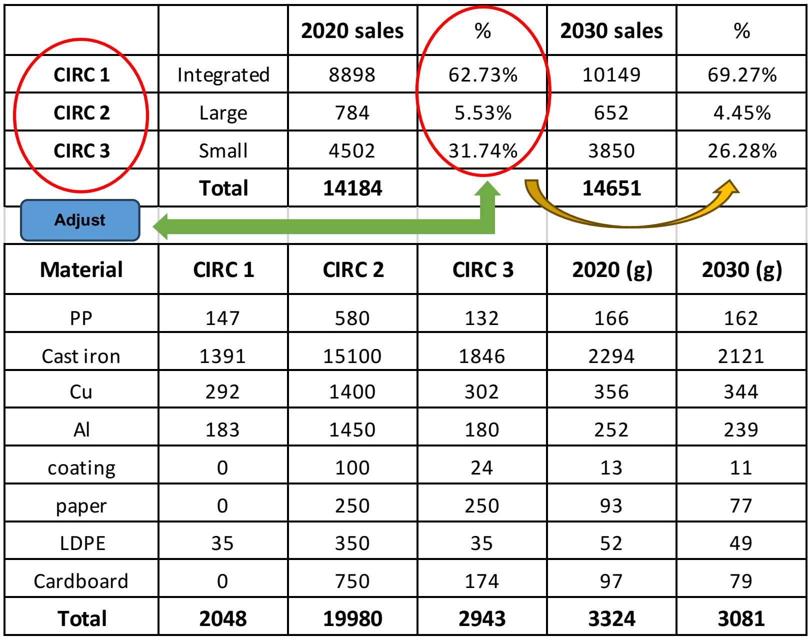
Step 2: Extract Material Weight Data and expand the Table for Future Projections:

- Refer to the "Special Report on Material Inputs for Production" check in *(Table 3).*
- Calculate the material weight per product by multiplying the sales figures (in tons) by 1,000, then dividing by the sales volume from 2010, presenting the result in grams.
- Add two new columns to the table for the years 2020 and 2030.
- Replicate the data from the "Per product (g)" column into these new columns.

Step 3: Analyze Market Share for Product Categories:

- For categories with a range of product types, compile and analyze sales data to calculate each product's market share is explained the *(Table 4).*
- Adjust the material weight for each product according to its market share based on the data for the year 2020.
- Repeat the adjustment for the 2030 data, ensuring all calculations are dynamically linked to the sales data and BoM.

Table 4 Scenario with more than one product in the product category (Example on Circulators)



		2020 sales	%	2030 sales	%
CIRC 1	Integrated	8898	62.73%	10149	69.27%
CIRC 2	Large	784	5.53%	652	4.45%
CIRC 3	Small	4502	31.74%	3850	26.28%
	Total	**14184**		**14651**	

Material	CIRC 1	CIRC 2	CIRC 3	2020 (g)	2030 (g)
PP	147	580	132	166	162
Cast iron	1391	15100	1846	2294	2121
Cu	292	1400	302	356	344
Al	183	1450	180	252	239
coating	0	100	24	13	11
paper	0	250	250	93	77
LDPE	35	350	35	52	49
Cardboard	0	750	174	97	79
Total	**2048**	**19980**	**2943**	**3324**	**3081**

3.3 Printed circuit boards

The composition of Printed Circuit Boards (PCBs) in electronic devices includes a range of Critical Raw Materials (CRMs), which are classified based on the Waste Electrical and Electronic Equipment (WEEE), (Dr Hugh McCoach et al., 2014; Kaya, 2019).

This thesis investigates the content of CRMs in three different grades of PCBs:

- High-Grade PCBs: These are from advanced electronic devices like computers, laptops, smartphones, and servers.
- Medium-Grade PCBs: These are extracted from electronic display units, imaging equipment, and set-top boxes.
- Low-Grade PCBs: This category includes PCBs in household appliances such as refrigerators, washing machines, and room air conditioners and building installations as room air conditioners, ventilation units, solid fuel boilers and water heaters *(Table 5).*

Table 5 BoM of a low grade PCB example of (Water Heaters)

Material		**2020 (g)**	**2030 (g)**
	[%]	**37.779**	**37.779**
Antimony	0.1%	0.101	0.101
Aluminum	6.0%	6.078	6.078
Barium	0.00700%	0.007	0.007
Beryllium	0.00010%	0.000	0.000
Cadmium	0.00001%	0.000	0.000
Cobalt	0.00200%	0.002	0.002
Copper	20.0%	20.260	20.260
Gold	0.0%	0.002	0.002
Iron	9.5%	9.624	9.624
Tin	0.9%	0.922	0.922
Lead	0.2%	0.223	0.223
Chromium	0.2%	0.203	0.203
Nickel	0.1%	0.101	0.101
Palladium	0.002%	0.002	0.002
Silver	0.005%	0.005	0.005
Zinc	0.2%	0.243	0.243
Strontium	0.0%	0.001	0.001
Bismuth	0.0%	0.005	0.005
Support (glass fibers, epoxy resin, ceramic, flame retardant TBBP-A): remaining percentages		**63.521**	**63.521**

3.4 Material Composition of LED and LCD Displays

The materials used in LED and LCDs are the focus of this investigation, including those found in PC monitors, laptop screens, electronic displays, tablets, and smartphones (Vanegas et al., 2017). The composition of these materials is based on a study analyzing the recycling of critical raw materials from electronic waste, (Babbitt et al., 2020; Peeters et al., 2012; Schleicher et al., 2022). In recent years, there has been a shift from using CCFL (Cold Cathode Fluorescent Lamps) backlighting in LCDs to LED (Light Emitting Diode) backlighting. The calculation examines explicitly scenarios where LED backlighting is used exclusively at a rate of 100%.

3.5 Bill of materials and various metal alloys

Alloys are a combination of different metals that are known to be stronger and more resistant to corrosion compared to pure metals (Paul G. Shewmon, n.d.). The goal of creating alloys is to improve mechanical strength and reduce costs. While some alloys may contain small amounts of additional metals, these amounts become significant on a larger scale in terms of weight (Table 6). Based on scholarly studies, we consider the following metals compose the alloys.

- Electric steel – (Si 3% ; Fe 97%) (Hayakawa, 2021)
- Steel sheet galvanized – (Zn 1.5% ; Fe 98% and Carbon 0.5%) (*Carbon Steel: Properties, Examples and Applications* , n.d.)
- Cast iron – (Carbon 2.5% ; Silicon 1% ; Manganese 0.5% ; Fe 96%) (*Cast Iron: Properties, Processing and Applications*, n.d.)
- Stainless steel 18/6 – (Nickle 6% ; Chromium 18% ; Fe 76%) (*Grades of Stainless Steel* , n.d.)
- Steel tube – (Carbon 1% ; Fe 99%) (*Mechanical Tubing*, n.d.)
- CuZn 38 cast – (Cu 62% ; Zn 38%) (Terence Bell, 2019)
- ZnAl 4 – (Zn 96% ; Al 4%) (Jasionowski et al., 2016)
- SnAgCu 0.5 – (Tin 95.5% ; Ag 4% ; Cu 0.5%) (Seelig & Suraski, 2003)
- Magnesium Alloy – (Mg 90.80% ; Zn 0.63% ; Mn 0.22% ; Al 8.25%)(Liu, 2010; *Magnesium Alloys: Types, Properties and Applications*, n.d.)
- Low alloy steel – (Fe 95% ; Mn 1% ; Carbon 0.5%) (The American Iron and Steel Institute (AISI), 2001)

Table 6 Typical table of Metal alloy (Water Heater)

Consideration	Material	Share	2020 (g)	2030 (g)
Cast iron	Carbon	2.50%	1.8	1.8
	Silicon	1%	1	1
	Manganese	0.50%	0	0
	Fe	96%	68	68
Stainless 18/6	Chromium	18%	40	40
	Nickel	6%	13	13
	Fe	76%	170	170
CuZn38 cast	Cu	62%	502	502
	Zn	38%	307	307
ZnAl4	Al	4%	0	0
	Zn	96%	0	0
St sheet galv	Fe	98%	13909	13909
	Zn	1.50%	213	213
	Carbon	0.50%	71	71
SnAg4Cu0.5	Tin	95.50%	1	1
	Ag	4%	0.062	0.062
	Cu	0.50%	0	0
Steel	Fe	99%	4	4
	Carbon	1%	5.1	5.1

3.6 Quantitative Assessment of key raw materials

Regarding different products' bills of materials, it is essential to precisely know the quantity of raw materials required. We have conducted a thorough analysis to determine the average amount of vital raw materials required to produce Aluminum, Iron, Steel, and Silicon, respectively. These raw materials include Bauxite, Iron Ore, Coking Coal, and Silicon Metal.

3.6.1 Assessment of Bauxite Requirements for Aluminium Manufacture

To derive an estimate, the methodology involved analyzing the global Bauxite production in 2020 and comparing it with the worldwide Aluminum output for the same year. We assumed that approximately 5.8 tons of Bauxite are required to produce one ton of Aluminum, which aligns with figures reported from external sources (Georgitzikis et al., 2021).To determine the amount of Bauxite used in the products distributed in 2020, a multiplication factor of 5.8 was applied to the Aluminum content.

3.6.2 Assessment of Iron Ore Requirements for Iron Manufacture

In this analysis, we have considered the primary extraction of Iron Ore and the adjustment for Iron content post-processing. The conversion factor leads to 94% Iron content in the resultant crude steel (Reichl & Schatz, 2023). To determine the Iron content in Iron Ore, we have used a methodology like the one applied in the Bauxite and Aluminum calculation. Our findings show that the Iron content in Iron Ore is approximately 55%, which is consistent with established literature (Park et al., 2021).

3.6.3 Assessment of Coking Coal Requirements for Steel Production

To produce steel, a significant amount of coking coal is required. We estimated that 770 kilograms of coal are needed to produce one ton of steel. This calculation considers the yield of iron in steel production, assuming a 94% iron content in crude steel. To determine the amount of coking coal required for the products sold in 2020, the iron content of these goods is multiplied by a factor of 0.77 (Paul Baruya, 2020).

3.6.4 Quantitative Assessment of Silicon Metal

According to the analysis, all primary Silicon is obtained from Silicon Metal, which contains 99% Silicon (Burkowicz et al., 2020; *What Is Silica Sand & How Is It Different From Regular Sand?*, n.d.). This assessment provides a foundational understanding of Silicon Metal's contribution to the overall Silicon production.

3.7 Final table

To have a better understanding of the weights of different materials used in our products and to understand the demand for these materials, we created a detailed table. This table lists the names of the raw materials from the bill of materials used in each product, along with additional information necessary to scale the raw material weight in eco designed products and identify the product/material combinations—the completed table is in the **(*Appendix IV*)**. *(Table 7)* outlines the columns that we will be including in the table.

Table 7 Outline of the Final Big table

World production (t)	**EU production (t)**	**2020 total materials (t)**	**2030 total materials (t)**	**Material Share (EU) 2020**	**EOL recycling input rate**	**Energy intensity (MJ) (kg)**		***forecast***	**weight (t)**	
							Materials	***%***	***2020***	***2030***

World Production (t): this column details specific raw materials' primary worldwide extraction volumes (Reichl & Schatz, 2023). It aims to provide a comprehensive overview of the raw material availability and production capacity on a global scale.

EU Production (t): present specifically the production of the same raw materials within the European Union (EU27), including extraction and processing activities. It highlights the EU's contribution to the global supply of these materials, reflecting its role in the raw material market.

2020 Total materials (t): keep records of the amount of each raw material used in the production of all sold products. This provides valuable insight into the demand and utilization of these materials in various products in that specific year.

2030 Total materials (t): parallel 2020, this predicts the expected quantity of each raw material, in tones, that will be used in all products sold during the year 2030. This forecast aims to understand materials' anticipated demand and utilization trends.

Material Share in the EU for 2020: the column presents the ratio, in percentage, of the quantity of each specific raw material used in all products sold in 2020, divided by the total production of this raw material in the EU27. It provides outcomes for understanding the proportion of EU-produced raw materials consumed within the market.

End-of-Life (EOL) Recycling Input Rate: reflects the total volume of material that enters the production system due to recycling post-consumer scrap. It gives an insight into the circular economy practices, highlighting the importance of recycling in reducing the demand for virgin raw materials.

Energy Intensity (MJ/kg): measure the average energy required to produce one kilogram of the listed materials. It indicates the environmental impact and efficiency of the production processes for these materials, facilitating comparisons across different materials.

Forecast Based on 2030 Sales (EIA 2020): this column provides a forecast based on the expected sales of products containing the listed raw materials in 2030, using data and projections from the (EIA) (European Commission - DG Ener, 2022). It aims to predict future trends in material demand, aiding in strategic planning and resource allocation.

4 Methodology of the multi-criteria classification system

The methodology used in this thesis begins by referring to essential documents, such as the *"Raw Materials Foresight Study 2020"* (Bobba et al., 2020) and its updated version, the *"Raw Materials Foresight Study 2023",*(Carrara et al., 2023). These documents provide a more extensive range of analyzed technologies and offer crucial empirical data. The methodology focus on quantifying Supply Risk (SR), which forms the basis for a proposed three-threshold system. The SR used in our methodology is assessed based on the approach from the *“2017 Criticality Assessment”* (Blengini et al., 2017) and updated information from the *“2023 Criticality Assessment”* (Grohol & Veeh, 2023) which is based on the two-threshold system (The thresholds SR ≥ 1.0).

4.1 Overview of Methodology

The methodology begins with a foundation based on up-to-date criticality assessments, which apply thresholds for classifying the *CRMs* as critical (SR ≥ 1.0 and EI ≥ 2.8) and SRMs as *"raw material characterized by its importance for strategic areas such as renewable energy, digital, aerospace, and defense technologies, its projected demand growth and current supply, and the difficulties of scaling up production".* In the proposed methodology from the thesis, we inspired by this approach above and adopt our own system to categorize *SR* into:

- 3 - Very high (supply risk ≥ 2)
- 2 - High (1 ≤ supply risk < 2)
- 1 - Moderate (supply risk < 1)

The proposed three-threshold system is an effective approach to differentiate between levels of supply risk. By categorizing SR as *"Moderate" ,"High"* and *"Very High"* ,stakeholders can better understand the severity of potential supply disruptions. This finer stratification helps to prioritize raw materials for the environmental relevance parameter in the classification methodology.

4.2 Environmental Relevant

The *"Raw Materials Foresight Study 2023"* has identified 15 crucial technologies (Carrara et al., 2023). We represent them as significant methodological aspect of the approach outlined in this thesis involves categorizing these technologies into two distinct groups. The first group is focused solely on the renewable energy sector, comprising five technologies: wind turbines, solar photovoltaic (PV), electrolyzes, heat pumps, and batteries., the information is presented in *(Figure4)* The second group encompasses the remaining technologies across the other sectors. This categorization highlights the importance of renewable energy technologies, giving them a cumulative impact that accounts for 70% of the final analysis outcome. The logical framework for evaluating the Environmental Relevance parameter is presented in *(Figure 3)* and described in the following steps. A detailed text can be found in the ***(Appendix I).*** the medotology is presented in *(Figure 6)*

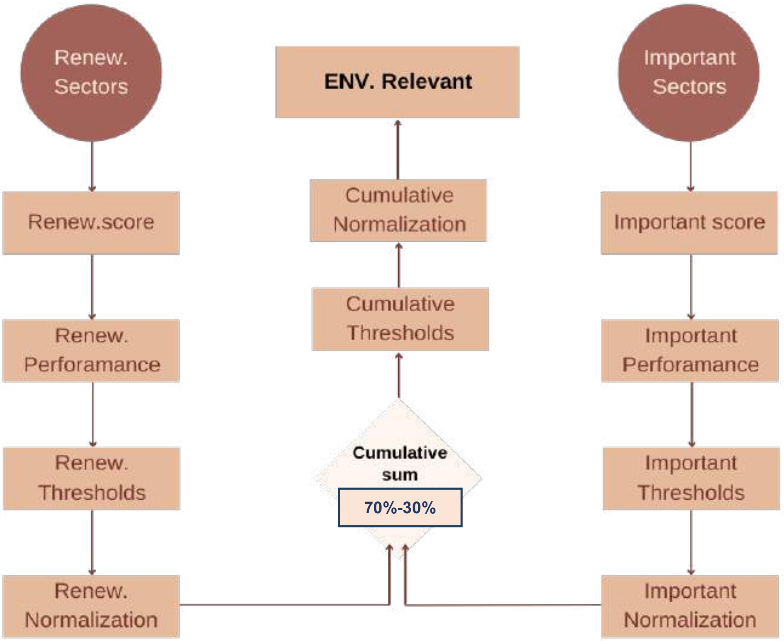


Figure 3 The logical framework for evaluating the Environmental Relevance parameter

Step 1: Categorization of Technologies and Supply Risk

- Classify the 15 crucial technologies into two groups based on the sectors they belong to renewable energy and others.
- Assign supply risk levels (Moderate, High, Very High) based on the threshold system. The results are presented in the *(Figure 5)*

Step 2: Scoring System for Raw Materials

- Allocate points to raw materials based on their importance in each technology within the Renewable Sector (up to 15 points) and Important Sector (up to 30 points).

Step 3: Standardization of Scores

- Normalize scores to a uniform scale (0 to 1) by dividing each raw material's score by the maximum possible in its category (15 for Renewable, 30 for Important).

Step 4: Threshold Levels for Standardized Scores

- Establish a peak performance score as a benchmark (e.g., 0.8).
- Divide this benchmark into ten intervals to categorize raw materials based on their performance.

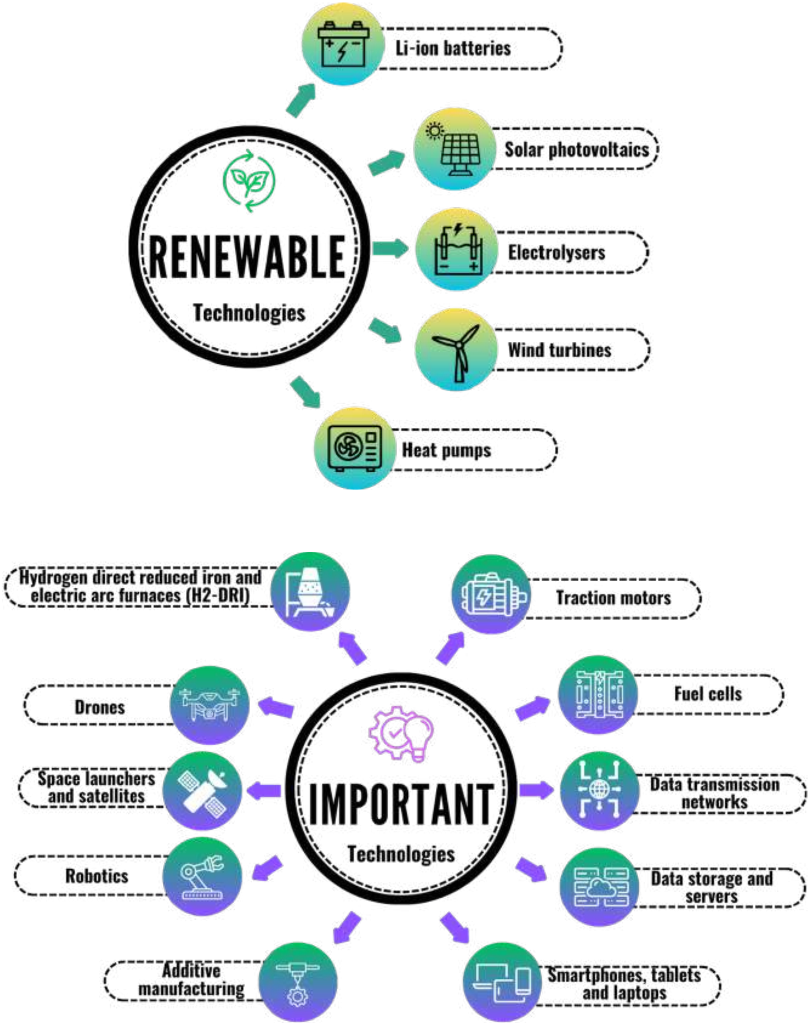


Figure 4 Categorization of 15 crucial techologies

Step 5: Final Categorization and Cumulative Sum *presented in (Figure 7)*

- Place each raw material into a category based on its normalized score.
- Calculate the Cumulative sum by assigning weights to the Renewable (70%) and Important (30%) sector scores and sum them to determine the overall importance.

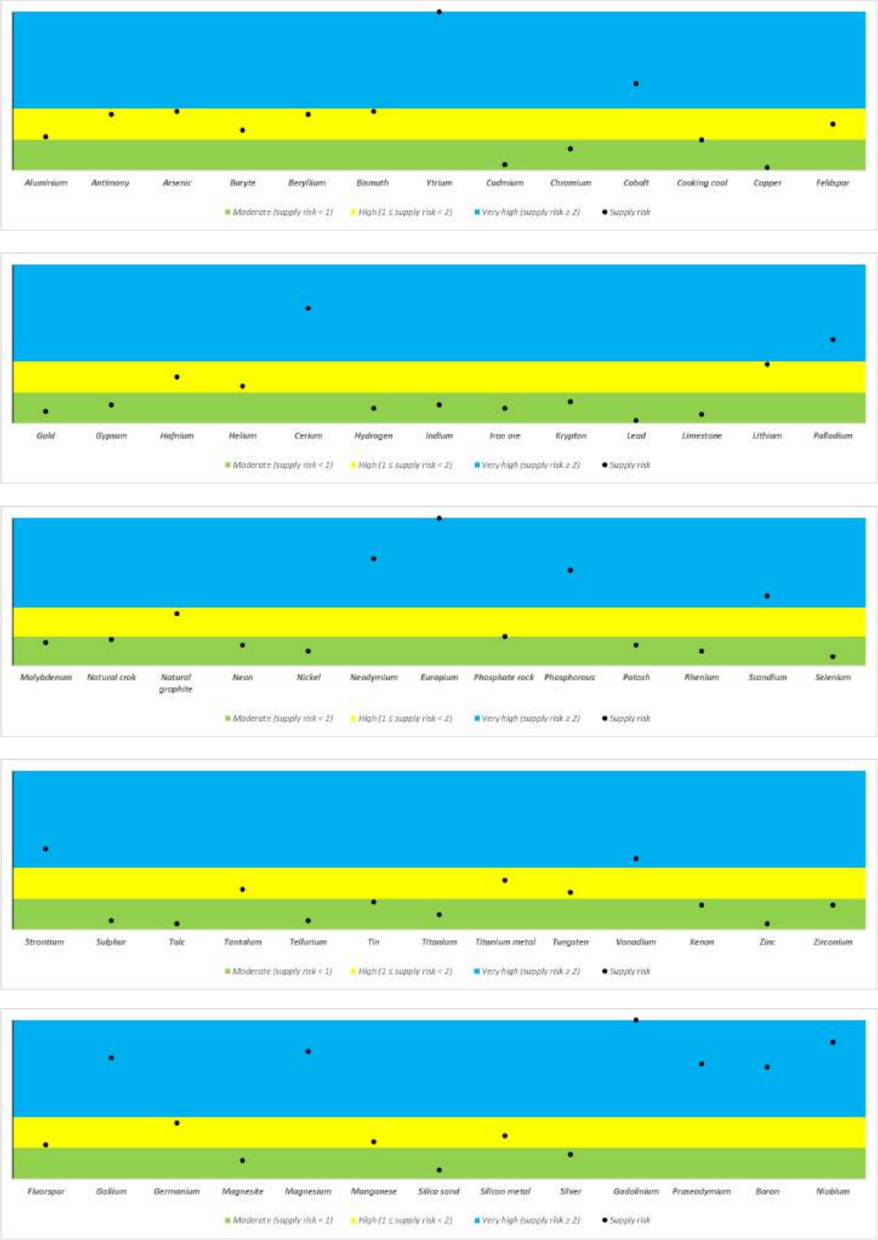
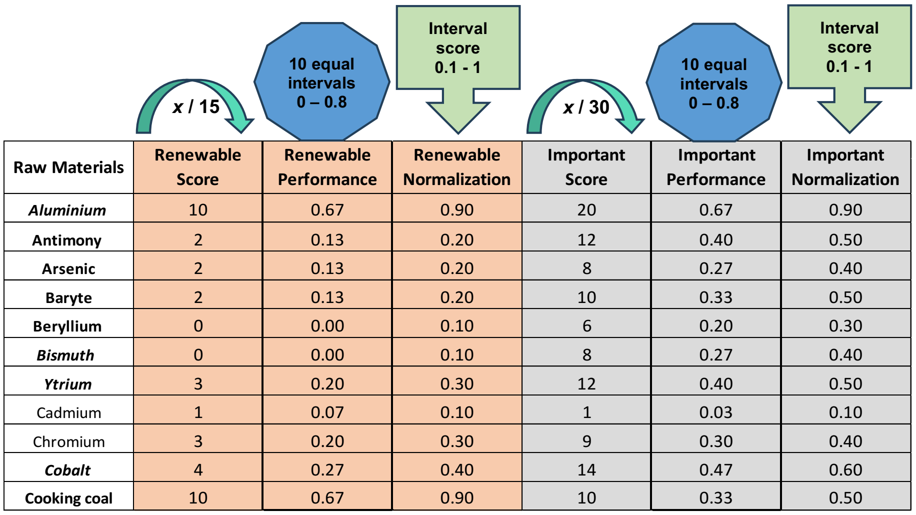


Figure 5 Supply risk levels (Moderate, High, Very High) based on the threshold system



Raw Materials	Renewable Score	Renewable Performance	Renewable Normalization	Important Score	Important Performance	Important Normalization
Aluminium	10	0.67	0.90	20	0.67	0.90
Antimony	2	0.13	0.20	12	0.40	0.50
Arsenic	2	0.13	0.20	8	0.27	0.40
Baryte	2	0.13	0.20	10	0.33	0.50
Beryllium	0	0.00	0.10	6	0.20	0.30
Bismuth	0	0.00	0.10	8	0.27	0.40
Ytrium	3	0.20	0.30	12	0.40	0.50
Cadmium	1	0.07	0.10	1	0.03	0.10
Chromium	3	0.20	0.30	9	0.30	0.40
Cobalt	4	0.27	0.40	14	0.47	0.60
Cooking coal	10	0.67	0.90	10	0.33	0.50

Figure 6 Normalization of scores and Intervalls based on the threshold system

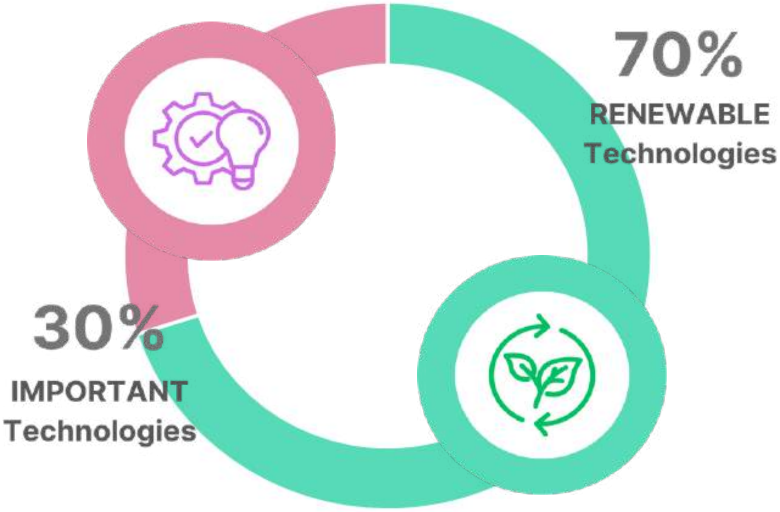


Figure 7 Cumulative sum by assigning weights to the Renewable (70%) and Important sector (30%)

4.3 Environmental Relevant "OekoRess" method

In this thesis, an important aspect is to compare the positive and negative impacts approach for the environmental relevance factor. To achieve this, we integrated the results from the

(Günter Dehoust et al., 2020) project into our framework and thresholds. The *"OekoRess"* method uses the environmental hazard potential (aEHP) to categorize hazards into five intervals: low, low to medium, medium, medium to high, and high. This categorization is based on eight indicators shown in *(Figure 8).*

To integrate data into our system, we assign scores to various intervals: low, low to medium, medium, medium to high, and high. Contrary to what might be expected, materials posing the highest supply risk receive the highest score in our framework. However, we invert this concept to convert external data into our system's metrics. This means that raw materials classified with the highest Environmental Hazard Potential (EHP) are given a score of 0.2, reflecting the highest environmental risk. Following this methodology, the scores are distributed as follows:

- Raw materials with a high EHP are scored at 0.2,
- Those with a medium to high EHP receive a score of 0.4,
- Medium EHP materials are scored at 0.6,
- Low to medium EHP materials receive a score of 0.8,
- Low EHP are assigned a score of 1.

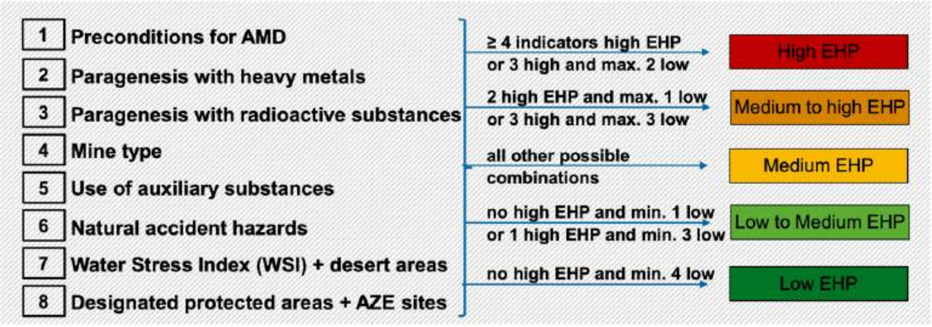


Figure 8 Combination of the eight individual indicators into the aEHP based on ‘‘ÖkoRess‘‘ methodology (Günter Dehoust et al., 2020)

4.4 Scarcity

As previously mentioned, we employ the supply risk score from the most recent report on critical raw materials to determine scarcity (Grohol & Veeh, 2023). The EU Commission supply data in the report slightly varies from the *“Forecasted Study”* (Carrara et al., 2023) primarily concerning *Light Rare Earth Elements* (LREE), *Heavy Rare Earth Elements* (HREE), and the *Platinum group*. The methodology for the parameter *“Scarcity”* is presented in *(Figure 9)*. A detailed text can be found in the ***(Appendix I).*** To illustrate this methodology clearly, it can be broken down into distinct steps: and *presented in (Figure 10)*

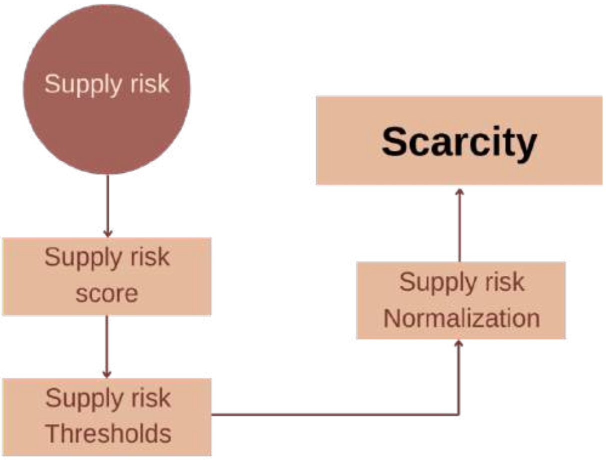


Figure 9 Logical Framework for assessing Scarcity parameter

Step1: Identification of Maximum Benchmark Score

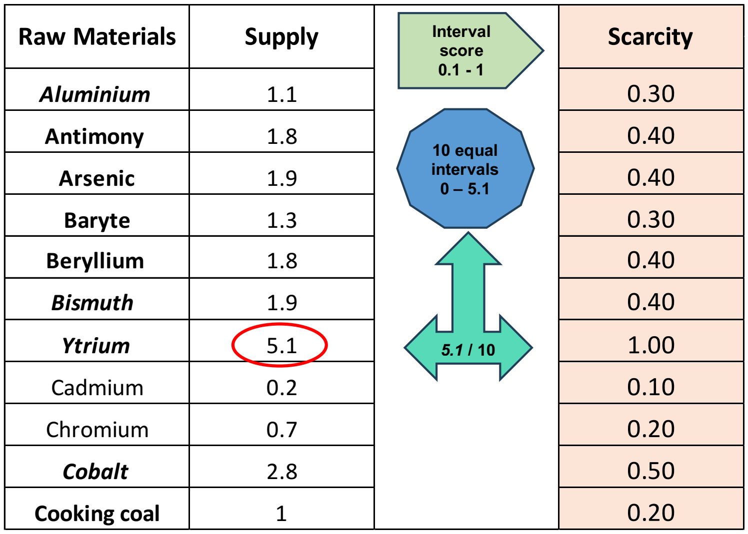
- The highest reported supply risk score is *5.1*

Step2: Establishing a Grading Scale:

- An interval table is created by dividing the maximum score by 10

Step3: Classification of Raw Materials:

- Score from 0.1 to 1 based on the supply risk within grading scale thresholds.



Raw Materials	Supply	Scarcity
Aluminium	1.1	0.30
Antimony	1.8	0.40
Arsenic	1.9	0.40
Baryte	1.3	0.30
Beryllium	1.8	0.40
Bismuth	1.9	0.40
Ytrium	5.1	1.00
Cadmium	0.2	0.10
Chromium	0.7	0.20
Cobalt	2.8	0.50
Cooking coal	1	0.20

Figure 10 Ilustration of steps assesing Scarcity parameter

4.5 Criticality

The method utilized to determine criticality was developed by the European Commission and updated in accordance with the *“Critical Materials Act”*, which identifies Aluminum as a strategic raw material. The workflow is depicted in *(Figure 11).*

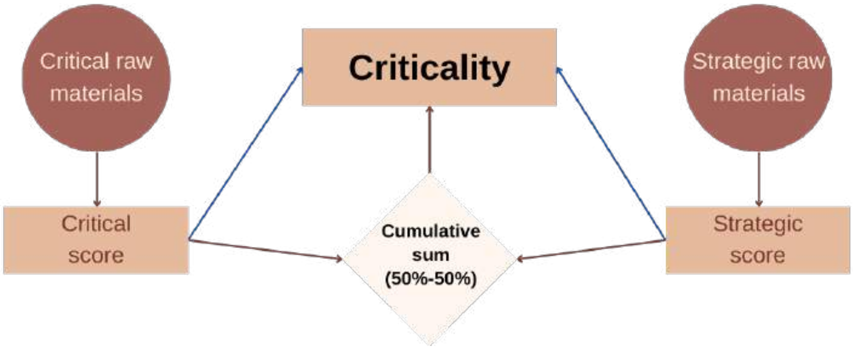


Figure 11 Logical Framework for assessing Criticality parameter

This methodology categorizes raw materials into four types: critical, strategic, both critical and strategic, and neither critical nor strategic. Each category is assigned a distinct score:

- materials that are both *critical* and *strategic* receive a score of 1,
- materials either *critical* or *strategic* receive a score of 0.5,
- materials that are neither *critical* nor *strategic* receive a score of 0.

Consequently, the final criticality score can be 0, 0.5, or 1. A detailed text can be found in the *(Appendix I).*

Raw Materials	CRMs /SRMs	
Aluminium	1.0	Critical and Strategic
Antimony	0.5	Critical or Strategic
Chromium	0.0	neither Critical nor Strategic

Figure 12 Materials classification score based on their criticality

4.6 Final classification

For the final classification, we computed the average score from three key parameters: scarcity, criticality, and environmental relevance, *(Figure 13).*

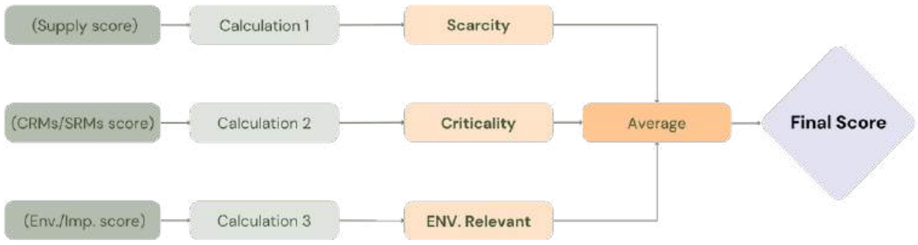


Figure 13 Workflow chart for Final Classification of raw materials

Subsequently, we determined the scoring intervals by examining the range from the highest to the lowest scores and divided this range into five equal parts. The largest score was divided by five to establish the interval magnitude, *(Table 8)* illustrates these intervals alongside their corresponding classifications.

To facilitate easier comparison across different scenarios, we adopted a color-coding scheme for each classification level: *Highest Priority, High Priority, Medium Priority, Low Priority,* and *No Priority*. This color-coded approach significantly simplifies the visualization of comparisons. In subsequent chapters, we will delve into the results, contrasting our findings with those obtained using the *"OekoRess"* method as presented in this thesis. The complete dataset is provided in ***(Appendix IV)***.

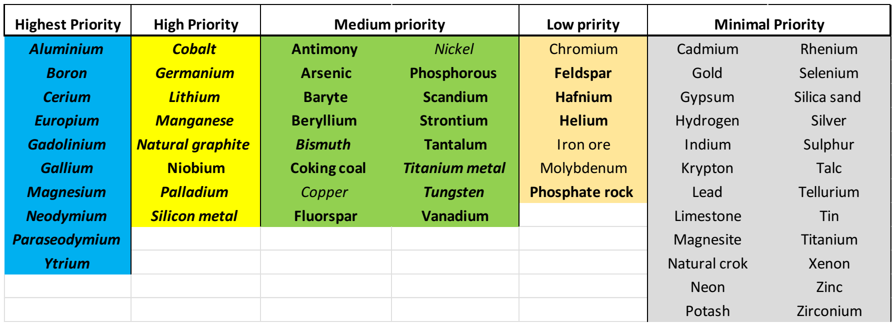
Table 8 The classification of threshold intervals, illustrated through a color-coded scheme

Interval	Clasification
$0.72 < \text{score} \leq 0.9$	Highest priority
$0.54 < \text{score} \leq 0.72$	High priority
$0.36 < \text{score} \leq 0.54$	Medium priority
$0.18 < \text{score} \leq 0.36$	Low priority
$0 < \text{score} \leq 0.18$	Minimal priority

5 Initial results discussion

Using the approach described in *Chapter 4*, we have obtained initial results by assessing 65 different raw materials in terms of their criticality, scarcity, and environmental relevance and then ranking them accordingly. The raw materials have been classified into different groups, as shown in *(Table 9),* while a comprehensive table providing all the scores is available in the **(*Appendix IV)***.

Table 9 The preliminary outcomes for all examined raw materials, where materials marked in bold and italic signify (CRMs) and (SRMs), those in bold alone indicate (CRMs), those in italic indicate (SRMs) and unmarked ones are considered regular raw materials



Highest Priority	High Priority	Medium priority		Low pririty	Minimal Priority	
Aluminium	***Cobalt***	**Antimony**	*Nickel*	Chromium	Cadmium	Rhenium
Boron	***Germanium***	**Arsenic**	**Phosphorous**	**Feldspar**	Gold	Selenium
Cerium	***Lithium***	**Baryte**	**Scandium**	**Hafnium**	Gypsum	Silica sand
Europium	***Manganese***	**Beryllium**	**Strontium**	**Helium**	Hydrogen	Silver
Gadolinium	***Natural graphite***	***Bismuth***	**Tantalum**	Iron ore	Indium	Sulphur
Gallium	**Niobium**	**Coking coal**	***Titanium metal***	Molybdenum	Krypton	Talc
Magnesium	***Palladium***	*Copper*	***Tungsten***	**Phosphate rock**	Lead	Tellurium
Neodymium	***Silicon metal***	**Fluorspar**	**Vanadium**		Limestone	Tin
Paraseodymium					Magnesite	Titanium
Ytrium					Natural crok	Xenon
					Neon	Zinc
					Potash	Zirconium

5.1 Environmental Comparison: Positive vs. Negative

We found that the highest score achieved through our calculations based on data from (OekoRess II) (Günter Dehoust et al., 2020) was 0.8, lower than the initial approach, which scored 0.9. To ensure consistency in classification across the same intervals, we aligned all scores to a uniform system. To do this, we chose to normalize the scores by using a conversion factor. The factor was obtained by dividing 0.9 by 0.8, resulting in a ratio of 1.125. We then multiplied our values by this factor to match the original coordinate system. With this adjustment, we were able to categorize our raw materials into five distinct classes based on their recalibrated scores. This method enabled us to compare the results of our approach with the methodology recommended by the (OekoRess I).

We have refined our selection of raw materials based on the *"OekoRess"* methodology, which incorporates criticality assessments by the European Commission from 2011 to 2017 (Blengini et al., 2017; European Commission, 2011) narrowing down our original options. Our method incorporates the latest version from 2023 (Grohol & Veeh, 2023), resulting in a more detailed list of raw materials.

Table 10 The outcomes of raw materials classification when using Environmental Hazard Potential (EHP) scores as parameters to determine Environmental Relevance scores

Highest Priority	High Priority	Medium priority	Low pririty	Minimal Priority
Ytrium	***Aluminium***	**Antimony**	Chromium	Gold
Boron	***Bismuth***	**Beryllium**	*Copper*	Indium
Cerium	***Cobalt***	Potash	Gypsum	Lead
Europium	**Coking coal**	**Scandium**	Iron ore	Molybdenum
Gadolinium	**Fluorspar**	***Silicon metal***	Magnesite	Rhenium
Gallium	***Germanium***	**Vanadium**	*Nickel*	Selenium
Lithium	***Manganese***		**Phosphate rock**	Silver
Magnesium	**Niobium**		Silica sand	Tellurium
Natural graphite	***Palladium***		Tin	Zinc
Neodymium	**Tantalum**			
Paraseodymium	***Titanium metal***			
Tungsten				

After comparing the two methodologies, we found that around 36% of materials in our list changed their classification. These changes primarily occurred due to adopting two distinct classification approaches regarding environmental relevance. *(Figure 8)* shows a notable quantitative difference in scores and classification intervals between Scenario 1 of the current method and Scenario 2, which incorporates Environmental Hazard Potentials (EHPs).

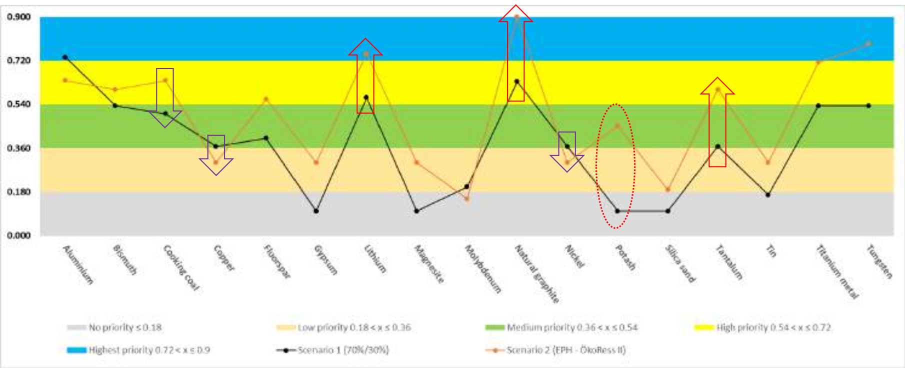
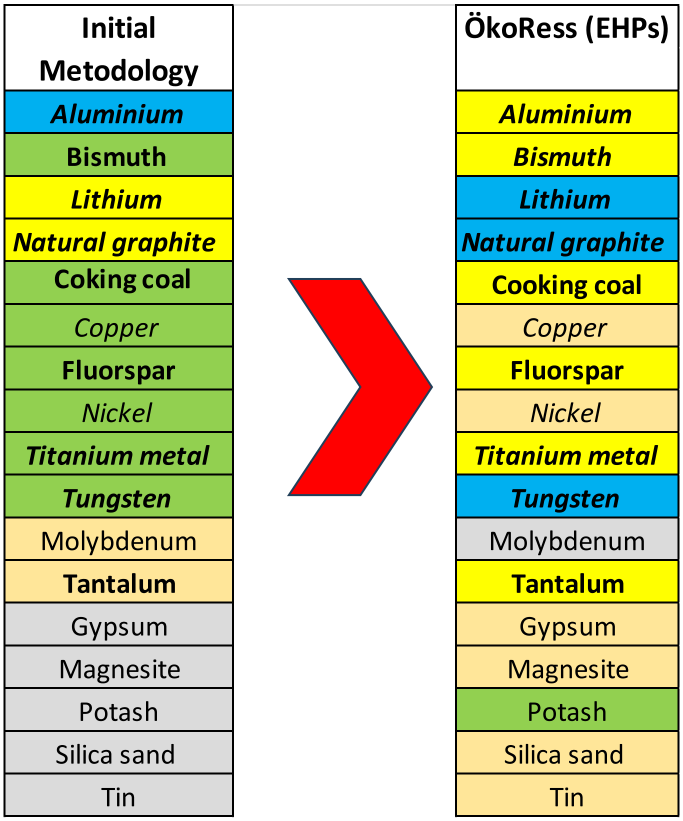


Figure 14 The quantitative disparity in scores and classification ranges when comparing Scenario 1, which utilizes the current method, to Scenario 2 with Environmental Hazard Potentials (EHPs)

(Appendix VII) includes the full data for reference. Among the materials, potash showed the most significant change in classification, moving from a score of 0.1 to 0.45. This shift resulted from the environmental risk assessment process, which reflected a low range of potential hazards, resulting in a higher score in the environmental category. On the other hand, according to (Carrara et al., 2023), potash is not considered to be a high risk for supply in strategic technologies, nor is it deemed critical or strategic according to (Grohol & Veeh, 2023), leading to a lower score in the alternative methodology.

Lithium is a material used primarily in two sectors: lithium-ion batteries, which make up 80% of its global consumption, and ceramics and glass, which comprise 7% of its consumption (Survey, 2023). Due to its significant reliance on battery technology and other strategic technologies, our assessment methodology considers it a high-priority material. Additionally, (OekoRess II) ranks lithium with a medium environmental hazard potential (EHP) score of 0.6, contributing to an overall score of 0.75, which places it within the highest priority category. In comparison, an initial scenario yielded a lower environmental relevance score of 0.3 and a total of 0.57. Adjusting the threshold for determining supply risk might be suggested to address this discrepancy, especially considering the (Carrara et al., 2023; Grohol & Veeh, 2023) where lithium's supply risk is1.9. Considering it close to the next threshold of ≥2 when accounting for



Initial Metodology	**ÖkoRess (EHPs)**
Aluminium	***Aluminium***
Bismuth	***Bismuth***
Lithium	***Lithium***
Natural graphite	***Natural graphite***
Coking coal	**Cooking coal**
Copper	*Copper*
Fluorspar	**Fluorspar**
Nickel	*Nickel*
Titanium metal	***Titanium metal***
Tungsten	***Tungsten***
Molybdenum	Molybdenum
Tantalum	**Tantalum**
Gypsum	Gypsum
Magnesite	Magnesite
Potash	Potash
Silica sand	Silica sand
Tin	Tin

Figure 15 How different methodologies applied to the Environmental Relevance parameter can alter the threshold classification of raw materials

the strategic technologies’ dependent on lithium, an environmental relevance score of 0.5 and a total score of 0.633 are obtained, categorizing it as a high priority rather than the highest.

On the other hand, graphite is primarily used in the steel industry (42%) and batteries (24%), according to (Investing News Network (INN), 2022). (OekoRess II) assessment consider graphite to have a low environmental hazard potential with a score of 1 in the environmental category and a final score of 0.8, compared to our methodology score of 0.63. Despite applying the same evaluative approach as we did in the case of lithium; graphite does not meet the criteria for the highest priority threshold. This comparison underscores the validity of our proposed methodology in distinguishing the priority levels of various raw materials based on their positive environmental in strategic for strategic industries, supply risk, and criticality.

(Carrara et al., 2023) identified aluminum as a key component in all 15 strategic technologies analyzed, alongside copper and nickel, which are present in 14 technologies. (International Energy Agency, 2022) has emphasized the critical role these materials play in developing clean energy technologies, with their demand expected to surge, underlining their pivotal role in sustainable growth. When assessing the environmental impact, copper, nickel, and aluminum showed improved performance in the scenario with positive environmental outcomes compared to those utilizing data from the (EHP) (Günter Dehoust et al., 2020). Copper and nickel are classified with medium priority due to their abundant availability, as indicated by the EU Commission (Grohol & Veeh, 2023) (with supply risks rated at 0.1 for copper and 0.5 for nickel). They each have a moderate environmental relevance score of 0.5. However, from (OekoRess II) methodology resulted in a high environmental hazard potential (EHP) score of 0.2, leading to their classification as low-priority materials.

In contrast, aluminum, facing a higher supply risk, as reported by the EU Commission (Grohol & Veeh, 2023), received a higher score for criticality. The “Critical Raw Material Act of 2023” now considers aluminum strategic and critical (EU Commission, 2024), a shift from its previous classification as only critical in the latest list. Its ubiquitous presence in strategic technologies bolstered its ranking to the highest priority. Nonetheless, aluminum's environmental hazard potential is rated medium to high with a score of 0.4 in the environmental relevance column, a decrease from 0.9 in the main scenario, positioning it as a high-priority material.

5.2 Sensible study

In *Chapter 4*, we outlined our methodology, which prioritizes the renewable sector by attributing 70% importance to its impact, compared to 30% for other significant sectors. Our analysis examines the effect of environmentally relevant parameters across five scenarios. The primary scenario, Scenario 1, allocates a 70%/30% significance ratio between the renewable sector and other key sectors, respectively. Scenario 2 proposes a balanced 50%/50% impact distribution between the renewable and other strategic sectors. Scenarios 3, 4, and 5 progressively emphasize the renewable sector with ratios of 75%/25%, 80%/20%, and 90%/10%, respectively. Through our calculations, we identified two notable discrepancies in the scenario of balanced contribution and significant deviation in Scenarios 4 and 5, where the renewable sector's influence is augmented. Other scenarios revealed minor deviations in the final scores, which did not alter the threshold classifications. In the case of Bismuth and Hafnium, the critical factor for these elements moving beyond their threshold was their zero scores in the renewable sector category, indicating their evaluation was solely based on the Important Sector score. Regarding Gallium, despite its high supply risk and importance in photovoltaic (PV) technologies, its lesser significance in the renewable sector compared to its critical role in six technologies within the important sector led to a decrease in its category ranking in Scenario 4 and 5. However, with a significant score of 0.7, it was near the next threshold. Unlike other cases where deviations were minimal, the variation in the final scores was like in previous instances but with a less pronounced contrast between the renewable sector and important sector scores.

Table 11 The variations across several potential scenarios based on different calculation methods for environmentally relevant parameters

Raw Materials	Scenario 1 (70%/%30)	Scenario 2 (50%/50%)	Scenario 3 (75%/25%)	Scenario 4 (80%/20%)	Scenario 5 (90%/10%)
Aluminium	**0.73**	0.73	0.73	0.73	0.73
Antimony	**0.40**	0.43	0.40	0.40	0.40
Arsenic	**0.40**	0.40	0.40	0.40	0.40
Baryte	**0.37**	0.40	0.37	0.37	0.37
Beryllium	**0.37**	0.37	0.37	0.37	0.37
Bismuth	**0.53**	0.57	0.53	0.53	0.53
Ytrium	**0.80**	0.80	0.80	0.80	0.80
Cadmium	**0.07**	0.07	0.07	0.07	0.07
Chromium	**0.20**	0.20	0.20	0.20	0.20
Cobalt	**0.67**	0.67	0.67	0.67	0.67
Coking coal	**0.50**	0.47	0.50	0.53	0.53
Copper	**0.37**	0.37	0.37	0.37	0.37
Feldspar	**0.33**	0.33	0.33	0.33	0.33
Fluorspar	**0.40**	0.40	0.40	0.40	0.40
Gallium	**0.73**	0.77	0.73	0.70	0.70
Germanium	**0.57**	0.57	0.57	0.57	0.57
Gold	**0.13**	0.13	0.13	0.13	0.13
Gypsum	**0.10**	0.10	0.10	0.10	0.10
Hafnium	**0.33**	0.37	0.33	0.33	0.33
Helium	**0.33**	0.33	0.33	0.33	0.33
Cerium	**0.77**	0.77	0.73	0.73	0.73
Hydrogen	**0.10**	0.10	0.10	0.10	0.10
Indium	**0.13**	0.13	0.13	0.13	0.13
Iron ore	**0.20**	0.20	0.20	0.20	0.20
Krypton	**0.13**	0.13	0.13	0.13	0.13
Lead	**0.13**	0.13	0.13	0.13	0.13
Limestone	**0.10**	0.10	0.10	0.10	0.10
Lithium	**0.57**	0.60	0.57	0.57	0.57
Palladium	**0.667**	0.70	0.67	0.67	0.67
Magnesite	**0.10**	0.10	0.10	0.10	0.10
Magnesium	**0.77**	0.80	0.77	0.73	0.73
Manganese	**0.70**	0.70	0.70	0.70	0.70
Molybdenum	**0.20**	0.20	0.20	0.20	0.20
Natural crok	**0.10**	0.10	0.10	0.10	0.10
Natural graphite	**0.63**	0.63	0.63	0.63	0.63
Neon	**0.10**	0.10	0.10	0.10	0.10
Nickel	**0.37**	0.37	0.37	0.37	0.37
Neodymium	**0.83**	0.83	0.80	0.80	0.80
Europium	**0.73**	0.77	0.73	0.73	0.73
Phosphate rock	**0.27**	0.27	0.27	0.27	0.27
Phosphorous	**0.53**	0.53	0.53	0.53	0.53
Potash	**0.10**	0.10	0.10	0.10	0.10
Rhenium	**0.10**	0.10	0.10	0.10	0.10
Scandium	**0.47**	0.47	0.47	0.47	0.47
Selenium	**0.07**	0.07	0.07	0.07	0.07
Silica sand	**0.10**	0.10	0.10	0.10	0.10
Silicon metal	**0.70**	0.70	0.70	0.70	0.70
Silver	**0.17**	0.17	0.17	0.17	0.17
Strontium	**0.47**	0.47	0.47	0.47	0.47
Sulphur	**0.07**	0.07	0.07	0.07	0.07
Talc	**0.07**	0.07	0.07	0.07	0.07
Tantalum	**0.37**	0.37	0.37	0.37	0.37
Tellurium	**0.10**	0.10	0.10	0.10	0.10
Tin	**0.17**	0.17	0.17	0.17	0.17
Titanium	**0.07**	0.07	0.07	0.07	0.07
Titanium metal	**0.53**	0.53	0.50	0.50	0.50
Tungsten	**0.53**	0.53	0.53	0.53	0.53
Vanadium	**0.50**	0.53	0.50	0.50	0.47
Xenon	**0.13**	0.13	0.13	0.13	0.13
Zinc	**0.17**	0.17	0.17	0.17	0.17
Zirconium	**0.13**	0.13	0.13	0.13	0.13
Gadolinium	**0.83**	0.87	0.83	0.80	0.80
Paraseodymium	**0.80**	0.83	0.80	0.80	0.80
Boron	**0.90**	0.90	0.90	0.90	0.90
Niobium	**0.60**	0.60	0.60	0.60	0.60

5.3 Final Raw Material List

After evaluating 65 raw materials, the selection was narrowed to 36. This reduction was necessary because only a portion of the evaluated materials were included in the bill of materials for the specified products. Additionally, products, especially in the electronics sector, required updated material composition information due to recent technological advances. Despite these adjustments, the analysis provides a reliable basis for estimating the weight of materials used in eco-designed products sold in the EU market in 2020, as well as for projected estimates for 2030.

Table 12 The results of classification according to materials identified in the bill of materials of selected products

Highest Priority	High Priority	Medium priority	Low pririty	Minimal Priority
Aluminium	***Bismuth***	**Antimony**	Chromium	Cadmium
Cerium	**Coking coal**	**Baryte**	Iron ore	Gold
Cobalt	***Germanium***	**Beryllium**	Silver	Indium
Europium	***Tungsten***	*Copper*	Tin	Lead
Gadolinium		*Nickel*	Zinc	Selenium
Gallium		**Strontium**		Silica sand
Magnesium		**Tantalum**		Tellurium
Manganese				
Neodymium				
Palladium				
Praseodymium				
Silicon metal				
Ytrium				

A significant modification from the initial compilation is the adjustment of threshold intervals. This change was made because boron, regardless of having the highest score of 0.9 out of 1 in the preliminary assessment, was not included in the final list of raw materials. As a result, the highest score among the considered materials decreased to 0.83, achieved by Praseodymium and Neodymium. A revised classification of interval thresholds was established by following the methodology outlined in *Chapter 4*. This adjustment led to the reclassification of certain raw materials into different categories. The threshold intervals were reduced by

Table 13 The classification of threshold intervals, illustrated through a color-coded scheme for final list of raw materials

Interval	Clasification
$0.664 < \text{score} \leq 0.83$	Highest priority
$0.498 < \text{score} \leq 0.664$	High priority
$0.332 < \text{score} \leq 0.498$	Medium priority
$0.166 < \text{score} \leq 0.332$	Low priority
$0 < \text{score} \leq 0.166$	Minimal priority

approximately 8%, which resulted in some materials advancing to the next category, previously on the upper limit of their respective intervals. This reclassification affected several materials, including Cobalt, Bismuth, Cooking Coal, Palladium, Manganese, Silicon Metal, Tungsten, Tin, Silver, and Zinc.

5.4 Big Table result

By examining the Bill of Materials (BoMs) for the products highlighted in *Chapter 3*, we have determined the material weight for items sold in 2020 and projected their weight based on expected sales in 2030. A complete table of these findings is included ***(Appendix VII)***.

Table 14 Material weight of products sold in 2020 and forecasts their weight based on anticipated sales in 2030, as per the Impact "Assessment Accountant's" report

Products	2020 (kt)	2030 (kt)	forecast
Central space Heating	335	408	22%
Water Heating	207	234	13%
Circulators	47	45	*-4%*
Solid fuel boilers	212	214	1%
Local Space Heating	507	510	1%
Air Heating and Cooling	532	574	8%
Room air Conditioners	221	297	34%
Ventilation Units	341	422	24%
Electronic Display	587	752	28%
Set Top Boxes	62	62	0%
Computers (PC/Notebook)	231	356	54%
Game consoles	23	23	0%
External Power supplies	60	61	2%
Imaging Equipment	435	388	*-11%*
Servers and Data Storage	225	310	38%
Smartphones and Tablets	25	24	*-6%*
Photovoltaic (PV)	**1572**	**3679**	134%
Household Refrigeration	**1120**	**1154**	3%
Refrigeration with direct sales	382	408	7%
Professional Refrigeration	148	168	14%
Cooking Appliances	**717**	**753**	5%
Washing Machines	**869**	**837**	*-4%*
Dishwashers	377	468	24%
Laundry Dryers	200	213	6%
Vacuum Cleaners	470	502	7%
Taps and showers	319	324	2%
Industrial Fans	**720**	**734**	2%
Electric Motors	**1062**	**1083**	2%
Welding Equipment	68	70	2%
Utility Transformers	577	819	42%
TOTAL (kt)	**12653**	**15891**	26%

The *(Table14)* presents the material composition of the selected products. From all the products, the top six contributing significantly to the overall weight are photovoltaics, household refrigeration, electric motors, washing machines, industrial fans, and cooking appliances. These six products comprise 47% of the total product mass sold in 2020. Their contribution is projected to increase to 51% by 2030, *(Figure 16).* This shift is primarily attributed to Photovoltaics (PV), which is anticipated to have the most significant impact. Given the current trend towards green energy, the demand for PV is expected to rise by more than 135%. This projection for PV's future material demand is based on a medium-demand scenario; (Alves Dias P. et al., 2020; Carrara et al., 2020; Chatzipanagi et al., 2022) in other reports, this figure could range between 200% to 250% in the context of EU (Renewable Energy Agency, 2023).

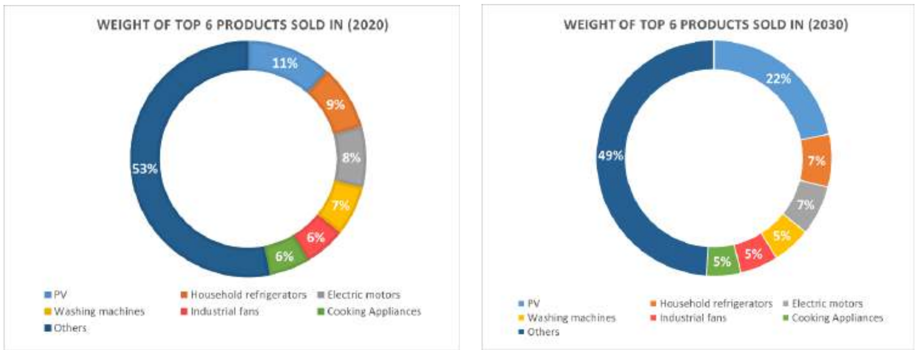


Figure 16 Material mass distribution of the top six products among 30 selected items sold in 2020 (left) and projections for 2030 (right)

As result of our calculation Iron Ore is the most employed material, identified as a Ferrous material in the "EIA Materials Report 2021"(Leo Wierda et al., 2022). To estimate the iron ore content in the surveyed products, we analyzed the alloy composition in different components, including steel tubes, steel sheets, and stainless steel see *Chapter 3*. We calculated the overall iron ore quantity by applying a conversion factor of 1.55, reflective of the mean iron ore grade. Therefore, our analysis includes the primary stages of ore extraction and steel manufacturing, which boasts a 94% Fe content (Dworak et al., 2022; Reichl & Schatz, 2023), providing a nuanced insight into the total iron ore mass.

Our research also shows that coking coal is a crucial raw material for steel production (Paul Baruya, 2020). We found a direct correlation between coking coal usage and crude steel output, indicating that steel demand proportionally increases the need for coking coal. Around 0.77 tons of coking coal are required for every ton of steel produced. While recycling is increasingly important, it cannot be solely depended upon due to the varied lifespans of products. For example, domestic refrigerators, which have an average lifetime of 16 years, become sources of aluminum, copper, and steel at disposal (Leo Wierda et al., 2022; Sanne Aarts et al., 2016).

Conversely, PV panels, lasting an average of 20 years, become sources of materials such as germanium and silicon (Dodd et al., 2018). Electronic devices, notably smartphones with an average lifespan of 2.5 years, have become sources of rare earth elements, including neodymium and yttrium (Cordella et al., 2020; Manhart et al., 2016). Our figures primarily focus on scenarios based on using primary sourced materials.

Table 15 Data on the mass of materials, mining production in the EU and globally, and the energy intensity of raw materials

World production (t)	EU production (t)	2020 total materials (t)	2030 total materials (t)	Material Share (EU) 2020	EOL recycling imput rate	Energy intensity (MJ) (kg)	Materials
513,692,499	5,776,108	697,550	891,604	12.08%	12%	163	***Aluminium (Bauxite)***
82,786	0	0.029	0	100.0%	1%	252	***Cerium***
129,110	1,559	1,418	1,533	90.9%	22%	8.7	***Cobalt***
793	0	0.03	0	100.0%	38%	7750	***Europium***
2,790	0	0.40	1	100.0%	1%	914	***Gadolinium***
304	0	1.89	3	100.0%	0%	9.86	***Gallium***
945,795	0	8,293	12,955	100.0%	13.40%	10.1	***Magnesium***
19,276,626	8,450	5,497	5,882	65.1%	9%	14.3	***Manganese***
30,889	0	301	412	100.0%	1%	344	***Neodymium***
199,902	862	15	20	1.7%	10%	211000	***Palladium***
8,934	0	75	103	100.0%	10%	376	***Praseodymium***
3,145,234	122,234	66,883	97,793	54.7%	0%	50.7	***Silicon (Silicon Metal)***
8,492	0	0.47	1	100.0%	31%	295	***Yttrium***
28,408	0	13	17	100.0%	0%	697	***Bismuth***
1,032,028,998	14,076,967	4,891,001	5,954,427	34.7%	0%	-	**Coking coal**
96	0	1.8	4	100.0%	2%	2890	***Germanium***
87,507	1,849	76	78	4.1%	42%	133	***Tungsten***
127,916	0	292	377	100.0%	28%	9.64	**Antimony**
8,085,570	117,656	299	422	0.3%	0%	4	**Baryte**
6,054	0	5.3	7	100.0%	0%	1720	**Beryllium**
20,788,363	868,370	818,910	973,526	94.3%	17%	14	*Copper*
2,491,866	49,959	96,794	161,815	100.0%	16%	11.1	*Nickel*
210,224	121,920	22.034	30.930	0.02%	0%	48.8	**Strontium**
1,682	0	413	612	100.0%	1%	4360	**Tantalum**
18,076,312	690,192	290,135	485,176	42.0%	21%	40.2	Chromium
3,396,849,096	129,997,052	9,845,521	11,986,184	7.6%	0%	0.25	Iron ore
26,248	1,961	409	431	20.9%	4%	4690	Silver
277,291	200	2,987	3,596	100.0%	31%	10.4	Tin
12,608,299	779,087	163,877	174,140	21.0%	34%	14.3	Zinc
24,970	1,771	13	24	0.7%	no info	53	Cadmium
3,213	32	21	27	66.6%	5%	645000	Gold
944	60	11	18	18.64%	1%	10.7	Indium
4,745,983	209,062	715	978	0.3%	83%	12.2	Lead
3,334	708	8	16	1.1%	1%	65.5	Selenium
8,639,643	3,376,372	670,322	1,214,374	19.9%	1%	-	Silica sand
444	164	14	24	8.3%	1%	435	Tellurium
379,021,701	1,566,715	1,133	1,885	100.0%	0%	-	*Bauxite ore*
1,874,290,239	108,815,512	6,351,949	7,733,022	5.8%	31%	10	Crude steel (94% content -processing)

The 2020 data on aluminum and copper usage in the EU stood at 9,119 kilotons and 4,667 kilotons, respectively (Leo Wierda et al., 2022). We have examined 30 products that were marketed within the same year. Our findings indicate that these products accounted for 7.5% of the total aluminum consumption and 17.5% of the overall copper consumption in the European Union.

Mining typically involves extracting and processing ore, including steps like smelting and refinement. The key method employed in assessing the environmental impact of producing 1 kg of virgin material is the Life Cycle Assessment (LCA). This method evaluates the energy requirements at different stages of production (Nuss & Eckelman, 2014) utilized LCA to calculate aluminum's Cumulative Energy Demand (CED), examining bauxite, primary, and secondary aluminum scrap. This calculation incorporates a weighted average based on the material's supply percentage, as detailed in (Nuss & Eckelman, 2014) supplementary Table S38.

Two approaches to calculating CED include the higher heating value (HHV) or the lower heating value (LHV), which affect the impact measurement per kg of material due to their differing characterization factors. For instance, the energy content per kg of natural gas can be measured as 33.64 MJ for HHV or 30.3 MJ for LHV, leading to variances in calculated impacts per kg. (Nuss & Eckelman, 2014) study does not clarify which of the two values, HHV or LHV, was used in their analysis.

Regarding CED and the resource usage of fossil fuels, both the HHV and LHV CED calculations consider six impact categories:

- Non-renewable, fossil
- Non-renewable, nuclear
- Non-renewable, biomass
- Renewable, biomass
- Renewable, wind, solar, geothermal
- Renewable, water

The *Environmental Footprint* (EF) category for *"Resource use of fossil fuels"* shares the same characterization factors as the *"Non-renewable, fossil"* category from the LHV CED. However, (EF) does not account for primary energy sourced from renewables.

Given the discrepancies highlighted by (Nuss & Eckelman, 2014), comparing impacts directly is not straightforward. It's essential to review their assumptions for each material and replicate the process for all (EF) datasets for the materials in question, including evaluating bauxite and both primary and secondary aluminum scrap, to arrive at a comprehensive and accurate impact assessment.

In addition to the methodology described earlier, the European Commission has developed its own tool (Mancini & Nuss, 2020) , which mirrors the Life Cycle Assessment (LCA) approach in evaluating the environmental impact of producing materials. This instrument also comprehensively analyzes the energy consumption and environmental impacts associated with producing primary raw materials, employing similar datasets to assess cumulative energy demand (CED) and other impact categories. The data we mainly include in our table is the one consider by EU Commission. Analyzing all the raw materials we could conclude that materials which are more energy-intensive to produce are gold and palladium. Gold production is energy-intensive, primarily due to the extraction of low-grade ores and refining processes (Farjana et al., 2019). The energy demand is further increased by decreasing ore grades. Adopting sustainable practices and innovations that promote efficiency, such as using renewable energy and advanced technologies, is essential to reduce this demand. For more information on the energy and environmental impacts of gold production, key references include "*Global Trends in Gold Mining"* by Mudd (Mudd, 2007) and *"Assessing the environmental impact of Gold Production"* (Kadivar et al., 2023).

5.5 Priority material - product (component)

Based on our analysis of the content weight in products, we have found that raw materials such as Aluminum, Cooking coal, Copper, Nickel, Chromium, and Zinc contributed the most to the product mass sold in 2020 *(Table 15)*. These materials are essential for ensuring the products are durable, efficient, and high performing. They provide conductivity, strength, and corrosion resistance. In the electronics industry, where the material content per product is lower, lightweight materials such as Magnesium are used to create durable casings for mobile phones, laptops, and other portable electronics. Due to its low melting point, Tin plays a crucial role in the assembly of circuit boards and the connection of various electronic parts. Additionally, rare earth materials such as Neodymium are essential for their powerful magnetic properties.

From the *final table*, we can identify ‘couples’ of materials + products. Products featuring the maximum concentration of materials within the highest priority group: check the *(Table 16)*

- PV
- Industrial Fans
- Electric Motors
- Electronic Display
- Computers

Products featuring the maximum concentration of materials within the high priority group:

- PV
- Electric Motors
- Industrial Fans
- Household Refrigeration
- Cooking Appliances

Table 16 The raw materials that have the highest contribution to various products, highlighting specific material-product combination

Material	Forecast (2030)	Quantity (t) 2020	Quantity (t) 2030	Products
Al	2%	141914	144143	Industrial fans
	3%	96551	99002	Electric Motors
	136%	85021	200431	PV
Mg	66%	6871	11435	Computers
	7%	1356	1454	Tablets and Smartphones
	0%	65.8	65.8	Game consoles
Nd	38%	187	258	Servers and Data storage
	47%	76	112	Computers
	14%	31.0	35.3	Tablets and Smartphones
C coal	136%	450157	1061218	PV
	28%	382	490	Electric Motors
	2%	392019	398153	Industrial Fans
Bi	37%	2.95	4.04	Servers and Data storage
	28%	2.73	3.49	Electronic Display
	58%	2.6	4.1	Computers
Cu	2%	113873	115887	Taps and showers
	136%	52637	124089	PV
	2%	107367	109367	Electric Motors
Ni	136%	46154	108806	PV
	5%	23823	25028	Cooking Appliances
	-4%	13498	12989	Washing Machines
Ta	62%	236	382	Computers
	37%	143	195	Servers and Data storage
	0%	30	30	Game consoles
Cr	136%	138462	326417	PV
	5%	71462	75075	Cooking Appliances
	-4%	40490	38966	Washing Machines
Zn	2%	94337	96015	Taps and showers
	8%	24698	26647	Air Heating and Cooling
	5%	5813	6096	Central space Heating
Sn	28%	496	636	Electronic Display
	59%	422	673	Computers
	37%	395	541	Servers and Data storage
Pb	37%	241	330	Servers and Data storage
	58%	214	338	Computers
	28%	120	154	Electronic Display
Au	4%	5.6	5.9	Smartphones and Tablets
	37%	4.9	6.7	Servers and Data storage
	58%	4.4	6.9	Computers
Cd	81%	13.1	23.7	PV
	37%	0.025	0.034	Servers and Data storage
	58%	0.0219	0.0345	Computers

Products featuring the maximum concentration of materials within the medium priority group:

- Taps and showers
- Electric Motors
- PV
- Utility Transformers
- Air Heating and Cooling

Products featuring the maximum concentration of materials within the low priority group:

- Electric Motors
- PV
- Industrial Fans
- Household Refrigeration
- Local Space Heating

Products featuring the maximum concentration of materials within the minimal priority group:

- Computers
- Servers and Data Storage
- Electronic Display
- Vacuum Cleaners
- PV

5.6 Limitations and critics

There are several accuracy concerns with the data, including:

- The possibility of double counting of electric motors.
- Use outdated data from 2007 to 2020 in the Bill of Materials.
- Variability introduced by different authors in the preparatory studies.
- Flawed assumption regarding the material content of PCBs, which led to the categorization of PCBs into three types based on their concentration of critical raw materials (CRMs) high, medium, and low grade.
- Incorrect estimations of the permanent magnet content in hard disk drives (HDDs).
- Miscalculations of CRM content in liquid crystal displays (LCDs).
- Inaccurate assumptions about the content of metals like nickel, zinc, chromium, silicon, and manganese in metallic alloys.
- Certain electronic materials, including integrated circuits, LEDs, large capacitors, and coils, are excluded from the calculations.
- Minimal material contents, such as cadmium and lead, are omitted, contrary to the restrictions outlined in Directive 2011/65/EU on hazardous substances in electronic and electrical equipment.
- Calculation errors due to human oversight.

6 Conclusion

This thesis presents a multi-criteria classification system for evaluating raw materials within the European eco-design framework. It significantly enhances our understanding of raw materials' criticality, scarcity, and environmental relevance. This work prioritizes raw materials essential for the EU's sustainability and economic resilience goals through meticulous development and validation of mathematical models. The models integrate various data sources, presenting a robust methodology for accurate classification, as highlighted in the details in *Chapters*, *3*, and *4*.

This thesis presents a multi-criteria classification system for evaluating raw materials within the European eco-design framework. It significantly enhances our understanding of raw materials' criticality, scarcity, and environmental relevance.

Through the establishment of clear definitions, metrics, and a robust classification model, the research has meticulously addressed the first objective by laying down a framework that segregates raw materials based on their scarcity, environmental relevance, and criticality.

Further, in pursuit of the second research goal, an extensive analysis of raw material content in selected products identifies priority material-product combinations, emphasizing Aluminum, Cerium, Cobalt, Silicon, and Neodymium due to their scarcity and environmental significance. This analysis, grounded in an exhaustive examination of industry reports, academic research, and government publications, aligns with the EU's eco-design directives and sustainability ambitions, contrasting existing methodologies like "OekoRess" by focusing on the positive contributions of specific raw materials towards sustainability and carbon neutrality.

The thesis successfully compiles a comprehensive methodology for categorizing raw materials and integrating findings into a "final table" reference table. Thus, it is complemented by determining the average content of raw materials across different eco-design product categories and identifying those requiring priority attention.

This significant accomplishment enables a deeper understanding and facilitates informed decision-making .Moreover, this work brings to the fore the importance of amulti-criteria classification system for evaluating raw materials it, suggesting paths for future research and policy development to include and refine criteria for sustainable mining within the EU Taxonomy.

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List of Appendixes

Appendix I

Methodology (Environmental Relevant)

A raw material can score up to 15 points in the ***Renewable Sector*** column. This is achieved when the raw material is considered highly important regarding supply risk across all five renewable technologies. The supply risk must a score of two or higher based on (Carrara et al., 2023), allowing for a maximum of three points per technology. The lowest score is zero, which can occur when there is insufficient information. On the other hand, in the ***Important Sector*** column, raw materials can score up to 30 points based on the evaluation of ten technologies. Supply risk is graded on a scale of 1-3, with a score of 2 or higher, the raw material earns three points, a score between 1 and less than 2, earns two points, and a score below 1 earning one point. The lowest possible score is zero. Upon completing the assessments for these two columns, two additional columns are generated: ***Renewable Score*** and ***Important Score***, using the logic illustrated in *(Figure 3)*.

In the next step, we standardize the scores of each raw material by calculating the proportion of its actual score to the highest possible score it can achieve. This is done by dividing the score of each material by its respective maximum score, which is 15 for the ***Renewable sector*** and 30 for the ***Important sector***. This normalization process adjusts the scores to a uniform scale ranging from 0 to 1. This adjustment makes it easier to compare the performance or quality of each product directly, regardless of the differences in their original scoring metrics.

The next step is to divide our score into specific threshold levels. This process involves two main actions: Firstly, determine the highest performance score as a benchmark (e.g., 0.8). Secondly, divide this peak score by 10 to establish a scale for classification, which assigns each raw material to a respective category or *"threshold"*. By dividing the top score into tenths, we set the range of each threshold interval. Comparing each product's adjusted score with these intervals allows us to place them in the appropriate category. This approach enables a relative evaluation of raw materials, grouping them into a fixed number of categories, based on their performance. The entire figure can be found in the **(*Appendix I)***.

Using the specified categorization logic, a score falls within an interval if it meets or exceeds the lower bound and does not surpass the upper bound. In this case, a score of 0.8 aligns precisely with Interval 10, defined by the range of 0.72 and, simultaneously, less than or equal to 0.8. Thus, 0.8, matching the interval's upper limit, belongs to Interval 10. Following this rationale, a score of 0.067 is lower than the upper limit of 0.08 and falls within Interval 1. This method ensures inclusive coverage of all scores from 0.0 to 0.8 across the ten intervals, eliminating potential gaps or overlaps.

The final column shows the ***Renewable Normalization*** and the corresponding ***Importance Normalization***. Each raw material is assigned a score, ranging from 0.1 to 1, based on its threshold interval.

To calculate the ***Cumulative sum***, we need to find the mathematical values for two categories: ***Renewable*** and ***Important sectors***. We multiply each number in these categories by weight and then sum the results. Our approach considers the materials essential for sustainable technologies in the renewable energy sector by assigning higher scores to them to highlight their importance. We allocate 70% significance to the impact of the ***Renewable sector*** and 30% to the ***Important sector***. In the next chapters, we will examine different scenarios and their effects on the overall score.

Next, we proceed with the final two steps, ***Cumulative Threshold***, and ***Cumulative Normalization***, employing the earlier method. Ultimately, we list the final score for each raw material in the last column labelled *"ENV. Relevance".* This score will be associated with parameters of scarcity and criticality to determine the raw material final classification.

Methodology (Scarcity)

As previously mentioned, we employ the supply risk score from the most recent report on critical raw materials to determine scarcity (Grohol & Veeh, 2023). The EU Commission supply data in the report slightly varies from the *"Forecasted Study"* (Carrara et al., 2023) primarily concerning *Light Rare Earth Elements* (LREE), *Heavy Rare Earth Elements* (HREE), and the *Platinum group*. These are assessed for supply risk on a group basis rather than individually. The methodology for the parameter *"Scarcity"* is presented in *(Figure 5)*. It begins with identifying the highest benchmark score (5.1). This maximum score is divided by 10 to establish a grading scale, delineating distinct "thresholds" for classification. Following this, scores ranging from 0.1 to 1 are assigned to each raw material, depending on their classification within the established threshold intervals. This scoring mechanism constitutes one of the three key factors in computing the final assessment.

Appendix II

Scarcity

Interval	Score
4.59 < result ≤ 5.1	1
4.08 < result ≤ 4.59	0.9
3.57 < result ≤ 4.08	0.8
3.06 < result ≤ 3.57	0.7
2.55 < result ≤ 3.06	0.6
2.04 < result ≤ 2.55	0.5
1.53 < result ≤ 2.04	0.4
1.02 < result ≤ 1.53	0.3
0.52 < result ≤ 1.02	0.2
0 < result ≤ 0.51	0.1

Important Normalization

Interval	Score
0.72 < result ≤ 0.8	1
0.64 < result ≤ 0.72	0.9
0.56 < result ≤ 0.64	0.8
0.48 < result ≤ 0.56	0.7
0.4 < result ≤ 0.48	0.6
0.32 < result ≤ 0.4	0.5
0.24 < result ≤ 0.32	0.4
0.16 < result ≤ 0.24	0.3
0.08 < result ≤ 0.16	0.2
0 < result ≤ 0.08	0.1

Renewable Normalization

Interval	Score
0.72 < result ≤ 0.8	1
0.64 < result ≤ 0.72	0.9
0.56 < result ≤ 0.64	0.8
0.48 < result ≤ 0.56	0.7
0.4 < result ≤ 0.48	0.6
0.32 < result ≤ 0.4	0.5
0.24 < result ≤ 0.32	0.4
0.16 < result ≤ 0.24	0.3
0.08 < result ≤ 0.16	0.2
0 < result ≤ 0.08	0.1

Cumulative Normalization

Interval	Score
0.9 < result ≤ 1	1
0.8 < result ≤ 0.9	0.9
0.7 < result ≤ 0.8	0.8
0.6 < result ≤ 0.7	0.7
0.5 < result ≤ 0.6	0.6
0.4 < result ≤ 0.5	0.5
0.3 < result ≤ 0.4	0.4
0.2 < result ≤ 0.3	0.3
0.1 < result ≤ 0.2	0.2
0 < result ≤ 0.1	0.1

Appendix III

Methodology (Material Imput)

The methodology utilized in this study involves the strategic design of the data table, which aims to enhance the efficiency of calculations using *Excel* formulas. Therefore, by creating a formula in the cell for the 2020 data, which is automatically replicated in the corresponding cell for the year 2030. This formula extends throughout the entire column. The design feature significantly streamlines the calculation process. It ensures that the final table values (as shown in *Table 2*) are dynamically updated in response to any changes made to preceding figures. The systematic approach optimizes the computational process and provides flexibility and accuracy in the forecasting and analysis of the results.

In some cases, we extract the BoM from the *"Special Report on Material Inputs for Production"* (Sanne Aarts et al., 2016). Specifically, the BoM is derived from Annex C, titled *"Materials Input Sales and Stocks"*. ''Annex C - provides information on the total weight of materials (in tons) used in products sold in 2010, along with data on the total sales of products in units (10^6) and the product weight in kilotons''. To calculate the material weight per product, we first multiply the sales figures from 2010 (in tons) by 1,000 and then divide this product by the sales volume of products from 2010, as reported in Annex C (Sanne Aarts et al., 2016). This process generates the material weight per single product, shown in the column ***"Per product (g)"***.

The subsequent step involves adding two columns for 2020 and 2030 to the table, into which we replicate the data from the ***"Per product (g)"*** column. This action enables the creation of an automated tool for future calculations, as depicted in *(Table 3).*

A product category may include various types of products. To analyze this, we create a table that records sales data for each product and evaluates its market share. Then, we look at the Bill of Materials (BoM) table to determine the average material weight per product. By using the data for the year 2020 (measured in grams) present in *(Table 4),* we adjust each product's material weight based on its market share. We repeat this process for the data for 2030. The sales data is taken from the 2021 (EIA) report (European Commission - DG Ener, 2022), while the BoM information comes from the latest preparatory study available.

Appendix IV

Supply	Raw Materials	CRMs /SRMs	Scarcity	Renewable Sector	Important Sectors	Renewable Score	Renewable Perforamance	Renewable Normalization
1.1	***Aluminium***	1.0	0.30	5	10	10	0.67	0.90
1.8	**Antimony**	0.5	0.40	1	6	2	0.13	0.20
1.9	**Arsenic**	0.5	0.40	1	4	2	0.13	0.20
1.3	**Baryte**	0.5	0.30	1	5	2	0.13	0.20
1.8	**Beryllium**	0.5	0.40	0	3	0	0.00	0.10
1.9	***Bismuth***	1.0	0.40	0	4	0	0.00	0.10
5.1	***Ytrium***	1.0	1.00	1	4	3	0.20	0.30
0.2	Cadmium	0.0	0.10	1	1	1	0.07	0.10
0.7	Chromium	0.0	0.20	3	9	3	0.20	0.30
2.8	***Cobalt***	1.0	0.50	2	7	4	0.27	0.40
1	**Coking coal**	0.5	0.20	10	10	10	0.67	0.90
0.1	*Copper*	0.5	0.10	5	9	5	0.33	0.50
1.5	**Feldspar**	0.5	0.30	0	2	0	0.00	0.10
1.1	**Fluorspar**	0.5	0.20	3	5	6	0.40	0.50
3.9	***Gallium***	1.0	0.70	1	6	3	0.20	0.30
1.8	***Germanium***	1.0	0.40	1	4	2	0.13	0.20
0.4	Gold	0.0	0.10	2	6	2	0.13	0.20
0.6	Gypsum	0.0	0.20	0	1	0	0.00	0.10
1.5	**Hafnium**	0.5	0.30	0	4	0	0.00	0.10
1.2	**Helium**	0.5	0.30	0	2	0	0.00	0.10
3.7	***Cerium***	1.0	0.80	1	5	3	0.20	0.30
0.5	Hydrogen	0.0	0.10	0	3	0	0.00	0.10
0.6	Indium	0.0	0.20	1	6	1	0.07	0.10
0.5	Iron ore	0.0	0.10	5	10	5	0.33	0.50
0.7	Krypton	0.0	0.20	0	3	0	0.00	0.10
0.1	Lead	0.0	0.10	2	5	2	0.13	0.20
0.3	Limestone	0.0	0.10	1	3	1	0.07	0.10
1.9	***Lithium***	1.0	0.40	1	5	2	0.13	0.20
2.7	***Palladium***	1.0	0.60	1	7	3	0.20	0.30
0.6	Magnesite	0.0	0.20	0	1	0	0.00	0.10
4.1	***Magnesium***	1.0	0.80	1	6	3	0.20	0.30
1.2	***Manganese***	1.0	0.30	4	9	8	0.53	0.70
0.8	Molybdenum	0.0	0.20	4	7	4	0.27	0.40
0.9	Natural crok	0.0	0.20	0	1	0	0.00	0.10
1.8	***Natural graphite***	1.0	0.40	2	6	4	0.27	0.40
0.7	Neon	0.0	0.20	0	2	0	0.00	0.10
0.5	*Nickel*	0.5	0.10	5	9	5	0.33	0.50
3.7	***Neodymium***	1.0	0.80	2	7	6	0.40	0.50
5.1	***Europium***	1.0	1.00	0	3	0	0.00	0.10
1	**Phosphate rock**	0.5	0.20	0	1	0	0.00	0.10
3.3	**Phosphorous**	0.5	0.60	2	4	6	0.40	0.50
0.7	Potash	0.0	0.20	1	2	1	0.07	0.10
0.5	Rhenium	0.0	0.10	0	3	0	0.00	0.10
2.4	**Scandium**	0.5	0.50	1	3	3	0.20	0.30
0.3	Selenium	0.0	0.10	1	2	1	0.07	0.10
0.3	Silica sand	0.0	0.10	2	3	2	0.13	0.20
1.4	***Silicon metal***	1.0	0.30	4	10	8	0.53	0.70
0.8	Silver	0.0	0.20	3	6	3	0.20	0.30
2.6	**Strontium**	0.5	0.50	1	3	3	0.20	0.30
0.3	Sulphur	0.0	0.10	0	1	0	0.00	0.10
0.2	Talc	0.0	0.10	0	1	0	0.00	0.10
1.3	**Tantalum**	0.5	0.30	1	4	2	0.13	0.20
0.3	Tellurium	0.0	0.10	1	3	1	0.07	0.10
0.9	Tin	0.0	0.20	2	5	2	0.13	0.20
0.5	Titanium	0.0	0.10	1	2	1	0.07	0.10
1.6	***Titanium metal***	1.0	0.30	0	5	0	0.00	0.10
1.2	***Tungsten***	1.0	0.30	1	4	2	0.13	0.20
2.3	**Vanadium**	0.5	0.50	1	7	3	0.20	0.30
0.8	Xenon	0.0	0.20	0	3	0	0.00	0.10
0.2	Zinc	0.0	0.10	4	6	4	0.27	0.40
0.8	Zirconium	0.0	0.20	1	5	1	0.07	0.10
5.1	***Gadolinium***	1.0	1.00	1	6	3	0.20	0.30
3.7	***Praseodymium***	1.0	0.80	2	6	6	0.40	0.50
3.6	***Boron***	1.0	0.70	4	8	12	0.80	1.00
4.4	**Niobium**	0.5	0.80	2	4	6	0.40	0.50

Important Score	Important Perforamance	Important Normalization	Cumulative sum (70%-30%)	Cumulative Normalization	Final Score
20	0.67	0.90	0.90	0.90	**0.73**
12	0.40	0.50	0.29	0.30	**0.40**
8	0.27	0.40	0.26	0.30	**0.40**
10	0.33	0.50	0.29	0.30	**0.37**
6	0.20	0.30	0.16	0.20	**0.37**
8	0.27	0.40	0.19	0.20	**0.53**
12	0.40	0.50	0.36	0.40	**0.80**
1	0.03	0.10	0.10	0.10	**0.07**
9	0.30	0.40	0.33	0.40	**0.20**
14	0.47	0.60	0.46	0.50	**0.67**
10	0.33	0.50	0.78	0.80	**0.50**
9	0.30	0.40	0.47	0.50	**0.37**
4	0.13	0.20	0.13	0.20	**0.33**
10	0.33	0.50	0.50	0.50	**0.40**
18	0.60	0.80	0.45	0.50	**0.73**
8	0.27	0.40	0.26	0.30	**0.57**
6	0.20	0.30	0.23	0.30	**0.13**
1	0.03	0.10	0.10	0.10	**0.10**
8	0.27	0.40	0.19	0.20	**0.33**
4	0.13	0.20	0.13	0.20	**0.33**
15	0.50	0.70	0.42	0.50	**0.77**
3	0.10	0.20	0.13	0.20	**0.10**
6	0.20	0.30	0.16	0.20	**0.13**
10	0.33	0.50	0.50	0.50	**0.20**
3	0.10	0.20	0.13	0.20	**0.13**
5	0.17	0.30	0.23	0.30	**0.13**
3	0.10	0.20	0.13	0.20	**0.10**
10	0.33	0.50	0.29	0.30	**0.57**
14	0.47	0.60	0.39	0.40	**0.67**
1	0.03	0.10	0.10	0.10	**0.10**
18	0.60	0.80	0.45	0.50	**0.77**
18	0.60	0.80	0.73	0.80	**0.70**
7	0.23	0.30	0.37	0.40	**0.20**
1	0.03	0.10	0.10	0.10	**0.10**
12	0.40	0.50	0.43	0.50	**0.63**
2	0.07	0.10	0.10	0.10	**0.10**
9	0.30	0.40	0.47	0.50	**0.37**
21	0.70	0.90	0.62	0.70	**0.83**
9	0.30	0.40	0.19	0.20	**0.73**
2	0.07	0.10	0.10	0.10	**0.27**
12	0.40	0.50	0.50	0.50	**0.53**
2	0.07	0.10	0.10	0.10	**0.10**
3	0.10	0.20	0.13	0.20	**0.10**
9	0.30	0.40	0.33	0.40	**0.47**
2	0.07	0.10	0.10	0.10	**0.07**
3	0.10	0.20	0.20	0.20	**0.10**
20	0.67	0.90	0.76	0.80	**0.70**
6	0.20	0.30	0.30	0.30	**0.17**
9	0.30	0.40	0.33	0.40	**0.47**
1	0.03	0.10	0.10	0.10	**0.07**
1	0.03	0.10	0.10	0.10	**0.07**
8	0.27	0.40	0.26	0.30	**0.37**
3	0.10	0.20	0.13	0.20	**0.10**
5	0.17	0.30	0.23	0.30	**0.17**
2	0.07	0.10	0.10	0.10	**0.07**
10	0.33	0.50	0.22	0.30	**0.53**
8	0.27	0.40	0.26	0.30	**0.53**
21	0.70	0.90	0.48	0.50	**0.50**
3	0.10	0.20	0.13	0.20	**0.13**
6	0.20	0.30	0.37	0.40	**0.17**
5	0.17	0.30	0.16	0.20	**0.13**
18	0.60	0.80	0.45	0.50	**0.83**
18	0.60	0.80	0.59	0.60	**0.80**
24	0.80	1.00	1.00	1.00	**0.90**
12	0.40	0.50	0.50	0.50	**0.60**

Appendix V

EPH/25/25 with factor	Only EPH with factor	GSMEF	eGOV	EPH ind	Only EPH	EPH/25/25	Supply	Raw Materials
0.64	0.64	0.20	0.60	0.40	0.57	0.57	1.1	***Aluminium***
0.45	0.41	0.60	0.20	0.20	0.37	0.40	1.8	**Antimony**
							1.9	**Arsenic**
							1.3	**Baryte**
0.60	0.49	1.00	1.00	0.40	0.43	0.53	1.8	**Beryllium**
0.71	0.60	1.00	0.60	0.20	0.53	0.63	1.9	***Bismuth***
0.90	0.90	0.60	0.20	0.40	0.80	0.80	5.1	***Ytrium***
							0.2	Cadmium
0.23	0.30	0.20	0.20	0.60	0.27	0.20	0.7	Chromium
0.68	0.64	0.60	0.20	0.20	0.57	0.60	2.8	***Cobalt***
0.53	0.64	0.20	0.60	1.00	0.57	0.47	1	**Coking coal**
0.34	0.30	0.20	0.60	0.20	0.27	0.30	0.1	*Copper*
							1.5	**Feldspar**
0.53	0.56	0.60	0.60	0.80	0.50	0.47	1.1	**Fluorspar**
0.86	0.79	1.00	0.60	0.40	0.70	0.77	3.9	***Gallium***
0.75	0.60	1.00	1.00	0.20	0.53	0.67	1.8	***Germanium***
0.15	0.11	0.20	0.60	0.20	0.10	0.13	0.4	Gold
0.30	0.30	0.60	0.60	0.60	0.27	0.27	0.6	Gypsum
							1.5	**Hafnium**
							1.2	**Helium**
0.83	0.75	0.60	0.60	0.20	0.67	0.73	3.7	***Cerium***
							0.5	Hydrogen
0.23	0.15	0.60	0.60	0.20	0.13	0.20	0.6	Indium
0.26	0.26	0.20	1.00	0.60	0.23	0.23	0.5	Iron ore
							0.7	Krypton
0.19	0.11	0.60	0.60	0.20	0.10	0.17	0.1	Lead
							0.3	Limestone
0.83	0.75	1.00	1.00	0.60	0.67	0.73	1.9	***Lithium***
0.75	0.68	0.60	0.60	0.20	0.60	0.67	2.7	***Palladium***
0.30	0.30	0.60	0.60	0.60	0.27	0.27	0.6	Magnesite
0.86	0.90	0.60	0.20	0.60	0.80	0.77	4.1	***Magnesium***
0.68	0.71	0.60	0.20	0.60	0.63	0.60	1.2	***Manganese***
0.23	0.15	0.60	0.60	0.20	0.13	0.20	0.8	Molybdenum
							0.9	Natural crok
0.83	0.90	1.00	0.20	1.00	0.80	0.73	1.8	***Natural graphite***
							0.7	Neon
0.41	0.30	0.60	1.00	0.20	0.27	0.37	0.5	*Nickel*
0.83	0.75	0.60	0.60	0.20	0.67	0.73	3.7	***Neodymium***
0.90	0.90	0.60	0.20	0.40	0.80	0.80	5.1	***Europium***
0.38	0.34	0.20	0.60	0.20	0.30	0.33	1	**Phosphate rock**
							3.3	**Phosphorous**
0.38	0.45	0.20	1.00	1.00	0.40	0.33	0.7	Potash
0.26	0.11	1.00	1.00	0.20	0.10	0.23	0.5	Rhenium
0.60	0.53	1.00	0.60	0.40	0.47	0.53	2.4	**Scandium**
0.23	0.11	1.00	0.60	0.20	0.10	0.20	0.3	Selenium
0.26	0.19	0.60	1.00	0.40	0.17	0.23	0.3	Silica sand
							1.4	***Silicon metal***
0.23	0.15	0.60	0.60	0.20	0.13	0.20	0.8	Silver
							2.6	**Strontium**
							0.3	Sulphur
							0.2	Talc
0.53	0.60	0.60	0.20	0.80	0.53	0.47	1.3	**Tantalum**
0.23	0.11	1.00	0.60	0.20	0.10	0.20	0.3	Tellurium
0.23	0.30	0.20	0.20	0.60	0.27	0.20	0.9	Tin
0.26	0.26	0.20	1.00	0.60	0.23	0.23	0.5	Titanium
0.71	0.71	0.20	1.00	0.60	0.63	0.63	1.6	***Titanium metal***
0.75	0.79	0.60	0.60	0.80	0.70	0.67	1.2	***Tungsten***
0.49	0.45	0.60	0.20	0.20	0.40	0.43	2.3	**Vanadium**
							0.8	Xenon
0.15	0.11	0.20	0.60	0.20	0.10	0.13	0.2	Zinc
							0.8	Zirconium
0.90	0.90	0.60	0.20	0.40	0.80	0.80	5.1	***Gadolinium***
0.83	0.75	0.60	0.60	0.20	0.67	0.73	3.7	***Praseodymium***
0.83	0.79	0.60	0.60	0.40	0.70	0.73	3.6	***Boron***
0.71	0.64	0.60	1.00	0.40	0.57	0.63	4.4	**Niobium**

Appendix VI

Materials	Central space Heating			Water Heating			Circulators			Solid fuel boilers			Local Space Heating		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***
Aluminium (Bauxite)	31%	20699	27190	13%	1168	1320	-2%	3576	3496	1%	66	67	1%	8258	8316
Cerium	8%	1.95105E-06	2.1156E-06	13%	1.6E-06	1.8E-06		0	0		0	0		0	0
Cobalt	9%	0.028	0.031	13%	0.019	0.021		0	0	1%	0.022	0.022	1%	0.061	0.062
Europium	8%	5.85314E-07	6.3468E-07	13%	5E-07	5E-07		0	0		0	0		0	0
Gadolinium	8%	3.17045E-05	3.43785E-05	13%	2.5E-05	2.9E-05		0	0		0	0		0	0
Gallium	8%	0.00003	0.00003	13%	2.5E-05	2.9E-05		0	0		0	0		0	0
Magnesium		0.00	0.00		0	0		0	0		0	0		0	0
Manganese	27%	86	109	13%	3	4	-4%	163	155	1%	682	688	1%	1155	1164
Neodymium		0	0		0	0		0	0		0	0		0	0
Palladium	9%	0.03	0.03	13%	0.02	0.02		0	0	1%	0.02	0.02	1%	0.06	0.06
Praseodymium		0	0		0	0		0	0		0	0		0	0
Silicon (Silicon Metal)	27%	171	218	13%	6.6	7.5	-4%	325	311	1%	1364.8	1375.1	1%	2310.7	2327.1
Yttrium	8%	3.12167E-05	3.38496E-05	13%	2.5E-05	2.8E-05		0	0		0	0		0	0
Bismuth	9%	0.070	0.077	13%	0.047	0.053		0	0	1%	0.055	0.055	1%	0.153	0.154
Coking coal	18%	162206	191651		101782	115031		24047	22966		126716	127666		309552	311748
Germanium		0	0		0	0		0	0		0	0		0	0
Tungsten		0.00	0.00		0	0		0	0		0	0		0	0
Antimony	9%	1.409	1.541	13%	0.942	1.065		0	0	1%	1.101	1.110	1%	3.066	3.088
Baryte	9%	0.10	0.11	13%	0.07	0.07		0	0	1%	0.08	0.08	1%	0.21	0.22
Beryllium	9%	0.001	0.002	13%	0.0009	0.0011		0	0	1%	0.0011	0.0011	1%	0.0031	0.0031
Copper	15%	39883	45827	13%	10398	11751	0%	5056	5039	1%	25643	25835	1%	8924	8987
Nickel	13%	1407	1589	13%	126	142		0	0	1%	1	1	1%	3	3
Strontium	9%	0.014	0.015		0.009	0.011		0	0		0.011	0.011		0.031	0.031
Tantalum		0.00	0.00		0	0		0	0		0	0		0	0
Chromium	13%	4220	4765	13%	377	426		0	0	1%	2	2	1%	6	6
Iron ore		326518	385791		204885	231556		48407	46231		255077	256990		623124	627546
Silver	9%	0.07	0.08	13%	0.6	0.7		0	0	1%	0.1	0.1	1%	0.2	0.2
Tin	9%	13	14	13%	22	25		0	0	1%	10	10	1%	28	28
Zinc	5%	5813	6096	13%	4843	5473		0	0	1%	514	518	1%	2004	2018
Cadmium	9%	0.00014	0.00015	13%	0.00009	0.00011		0	0	1%	0.00011	0.00011	1%	0.00031	0.00031
Gold	9%	0.028	0.031	13%	0.0	0.0		0	0	1%	0.0	0.0	1%	0.1	0.1
Indium	8%	0.00026	0.00029	13%	0.00021	0.00024		0	0		0	0		0	0
Lead	9%	3.10	3.39	13%	2.1	2.3		0	0	1%	2.4	2.4	1%	6.7	6.8
Selenium		0	0		0	0		0	0		0	0		0	0
Silica sand		0	0		0	0		0	0		0	0		0	0
Tellurium		0	0		0	0		0	0		0	0		0	0
Bauxite ore		0.00	0.00		0	0		0	0		0	0		0	0
Crude steel (94% content -processing)	18%	210657	248897	13%	132184	149391	-4%	31230	29826	1%	164566	165800	1%	402015	404868

Materials	**Air Heating and Cooling**			**Room air Conditioners**			**Ventilation Units**			**Electronic Display**			**Set Top Boxes**		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***
Aluminium (Bauxite)	8%	42282	45618	34%	15886	21352	18%	25792	30469	28%	51664	66211	0%	2566	2566
Cerium		0	0		0	0		0	0		0.016	0.020		0	0
Cobalt	8%	0.132	0.142	34%	0.133	0.178	81%	0.026	0.047		1.09	1.40	0%	0.14	0.14
Europium		0	0		0	0		0	0		0.005	0.006		0	0
Gadolinium		0	0		0	0		0	0		0.25	0.32		0	0
Gallium		0	0		0	0		0	0		0.25	0.32		0	0
Magnesium		0	0		0	0		0	0		0	0		0	0
Manganese	8%	56	60	34%	50	67	63%	16	26		0	0		0	0
Neodymium		0	0		0	0		0	0		0	0		0	0
Palladium	8%	0.132	0.142	34%	0.133	0.178	81%	0.03	0.05	28%	1.09	1.40	0%	0.14	0.14
Praseodymium		0	0		0	0		0	0		0	0		0	0
Silicon (Silicon Metal)	8%	112.0	120.8	34%	996	1338	63%	32	52		0	0		0	0
Yttrium		0	0		0	0		0	0		0.25	0.31		0	0
Bismuth	8%	0.330	0.356	34%	0.332	0.446	81%	0.065	0.118	28%	2.73	3.49	0%	0.34	0.34
Coking coal		251389	271223		74085	99573		190568	226665		167623	214821		15414	15414
Germanium		0	0		0	0		0	0		0	0		0	0
Tungsten		0	0		0	0		0	0		0	0		0	0
Antimony	8%	6.595	7.115	34%	6.640	8.923	81%	1.310	2.368	28%	54.52	69.87	0%	6.81	6.81
Baryte	8%	0.46	0.50	34%	0.46	0.62	81%	0.1	0.2		3.82	4.89	0%	0.477	0.477
Beryllium	8%	0.0066	0.0071	34%	0.007	0.009	81%	0.001	0.002		0.05	0.07	0%	0.00681	0.00681
Copper	8%	43242	46654	34%	38942	52339	27%	23623	29894	28%	18867	24180	0%	2917	2917
Nickel	8%	564	608	34%	6.6	8.9	81%	1	2		55	70	0%	1022	1022
Strontium		0.066	0.071		0.066	0.089		0.013	0.024		0.545	0.699		0.06808	0.06808
Tantalum		0	0		0	0		0	0		0	0		0	0
Chromium	8%	1685	1818	34%	13	18	81%	2.6	4.7	28%	109	140	0%	3058	3058
Iron ore		506044	545969		149132	200439		383611	456273		337424	432433		31028	31028
Silver	8%	0.3	0.4	34%	0.3	0.4	81%	0	0		25	32	0%	9	9
Tin	8%	60	65	34%	60	81	81%	11.9	21.5	28%	496	636	0%	204	204
Zinc	8%	24698	26647	34%	16	21	18%	4025	4752		3525	4518	0%	215	215
Cadmium	8%	0.00066	0.00071	34%	0.001	0.001	81%	0.00	0.00	28%	0.005	0.007	0%	0.00068	0.00068
Gold	8%	0.1	0.1	34%	0.13	0.18	81%	0.03	0.05	28%	3.52	4.51	0%	0.44	0.44
Indium		0	0		0	0		0	0	13%	3.53	3.98		0	0
Lead	8%	14.5	15.7	34%	15	20	81%	2.9	5.2	28%	120	154	0%	14.98	14.98
Selenium		0	0		0	0		0	0		0	0		0	0
Silica sand		0	0		0	0		0	0		0	0		0	0
Tellurium		0	0		0	0		0	0		0	0		0	0
Bauxite ore		0	0		0	0		0	0		0	0		0	0
Crude steel (94% content-processing)	8%	326480	352238	34%	96214	129316	19%	247491	294370	28%	217693	278989	0%	20018	20018

Materials	Computers (PC/Notebook)			Game consoles			External Power supplies			Imaging Equipment			Servers and Data Storage		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*
Aluminium (Bauxite)	56%	21674	33917	0%	2054	2054	2%	1026	1042	-11%	5237	4660	36%	11556	15681
Cerium		0.004	0.007	0%	0.00004	0.00004		0	0	-13%	0.0007	0.0006		0	0
Cobalt		2.2	3.5	0%	0.5	0.5	2%	0.08	0.08	-12%	0.39	0.34	37%	2.5	3.4
Europium		0.001	0.002	0%	0.00001	0.00001		0	0	-13%	0.00020	0.00018		0	0
Gadolinium	66%	0.07	0.11	0%	0.00069	0.00069		0	0	-13%	0.0109	0.0096		0	0
Gallium		0.29	0.5	0%	0.053	0.053		0	0	-13%	0.011	0.010	37%	0.25	0.34
Magnesium	66%	6871	11435	0%	65.8	65.8		0	0		0	0		0	0
Manganese	60%	235	378	0%	39	39		0	0	-11%	1.2	1.1	39%	186	259
Neodymium	47%	76	112	0%	7.7	7.7		0	0		0	0	38%	187	258
Palladium	58%	4.4	6.9	0%	1.0	1.0	2%	0.0797	0.0809	-12%	0.39	0.34	37%	4.9	6.7
Praseodymium	47%	19	28	0%	1.9	1.9		0	0		0	0	38%	47	64
Silicon (Silicon Metal)		197	328		0	0		0	0	-11%	2.5	2.2		0	0
Yttrium		0.068	0.113	0%	0.0007	0.0007		0	0	-13%	0.0108	0.0094		0	0
Bismuth	58%	2.6	4.1	0%	0.5	0.5	2%	0.20	0.20	-12%	0.97	0.85	37%	2.95	4.04
Coking coal		62623	93463		4284	4284		572	581		116980	104336		113413	156512
Germanium		0	0		0	0		0	0		0	0		0	0
Tungsten		0	0		0	0		0	0		0	0		0	0
Antimony	58%	66	104	0%	16	16	2%	3.98	4.05	-12%	19.47	17.04	37%	74	101
Baryte		123	193	0%	29	29	2%	0.279	0.283	-12%	1.4	1.2	37%	138	189
Beryllium		2.2	3.5	0%	0.5	0.5	2%	0.00398	0.00405	-12%	0.019	0.017	37%	2.5	3.4
Copper	53%	11139	17073	0%	4125	4125	2%	7066	7176	-11%	13855	12314	37%	8810	12102
Nickel	60%	235	378	0%	31	31	2%	17	17	-11%	314	280	35%	278	376
Strontium		8.7503	13.81		2.069	2.069		0.03984	0.04046		0.19471	0.17039		9.845	13.481
Tantalum		236	382	0%	30	30		0	0		0	0	37%	143	195
Chromium	65%	677	1120	0%	18	18	2%	46	47	-11%	923	823	34%	474	637
Iron ore		126060	188139		8623	8623		1151	1169		235478	210026		228298	315057
Silver	63%	61	100	0%	6	6	2%	18	18	-12%	9	8	36%	28	38
Tin	59%	422	673	0%	83	83	2%	416	422	-12%	177	155	37%	395	541
Zinc	50%	1469	2211	0%	86	86	2%	428	435	-11%	2279	2032	38%	2853	3934
Cadmium	58%	0.0219	0.0345	99%	0.005	0.010	2%	0.00040	0.00040	-12%	0.00195	0.00170	37%	0.025	0.034
Gold	58%	4.4	6.9	0%	1	1	2%	0.3	0.3		0	0	37%	4.9	6.7
Indium	66%	1.9	3.1	0%	0.0057	0.0057		0	0	-13%	0.091	0.080		0	0
Lead	58%	214	338	0%	1.0	1.0	2%	8.8	8.9		0	0	37%	241	330
Selenium		0	0		0	0		0	0		0	0		0	0
Silica sand	66%	367	611		0	0		0	0		0	0		0	0
Tellurium		0	0		0	0		0	0		0	0		0	0
Bauxite ore	66%	195	325		0	0		0	0		0	0		0	0
Crude steel (94% content -processing)	49%	81329	121380	0%	5563	5563	2%	743	754	-11%	151921	135501	38%	147289	203263

Materials	Smartphones and Tablets			PV			Household Refrigeration			Refrigeration direct sales			Professional Refrigeration		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*
Aluminium (Bauxite)	7%	5516	5928	136%	85021	200431	3%	27179	28007	7%	14971	15999	14%	5035	5722
Cerium	9%	0.008	0.009		0	0		0	0	7%	0.000001587	0.000001696	14%	1.95292E-06	2.21949E-06
Cobalt	8%	1410	1522		0	0	3%	0.05	0.06	7%	0.00555	0.01	10%	0.001	0.001
Europium	8%	0.03	0.03		0	0		0	0	7%	4.761E-07	5.088E-07	14%	5.85875E-07	6.65846E-07
Gadolinium	10%	0.07	0.08		0	0		0	0	7%	2.57888E-05	0.00002756	14%	3.17349E-05	3.60666E-05
Gallium	10%	0.1	0.2	122%	0.9	2.0		0.00	0.00	7%	0.00003	0.00003	14%	0.00003	0.00004
Magnesium	7%	1356	1454		0	0		0.00	0.00		0	0		0.00	0.00
Manganese		0	0		0	0	3%	1294	1334	7%	26	28	14%	102	116
Neodymium	14%	31.0	35.3		0	0		0	0		0	0		0	0
Palladium	4%	1.9	2.0		0	0	3%	0.05	0.06	7%	0.01	0.01	10%	0.001	0.001
Praseodymium	14%	7.4	8.4		0	0		0	0		0	0		0	0
Silicon (Silicon Metal)	0%	69	69	73%	41117	71305	3%	2588	2667	7%	52	55	14%	204	232
Yttrium	10%	0.1	0.2		0	0		0	0	7%	0.000025392	0.000027136	14%	3.12466E-05	3.55118E-05
Bismuth		0	0		0	0	3%	0.14	0.14	7%	0.01	0.01	10%	0.003	0.004
Coking coal		1139	1146		450157	1061218		382852	394522		159018	169940		84312	95820
Germanium		0	0	139%	1.8	4.3		0	0		0	0		0	0
Tungsten	3%	76	78		0	0		0.00	0.00		0	0		0.00	0.00
Antimony		0	0		0	0	3%	2.71	2.79	7%	0.28	0.30	10%	0.06	0.07
Baryte		0	0		0	0	3%	0.19	0.20	7%	0.02	0.02	10%	0.0045	0.0050
Beryllium		0	0		0	0	3%	0.003	0.003	7%	0.000	0.000	10%	0.00006	0.00007
Copper	8%	3847	4144	136%	52637	124089	3%	37901	39056	7%	14468	15462	14%	9492	10787
Nickel	0%	168	169	136%	46154	108806	3%	606	625	7%	180	192	14%	6	6
Strontium	0%	0	0	0%	0	0	3%	0.027	0.028		0.003	0.003		0.001	0.001
Tantalum	6%	4.5	4.8		0	0		0.00	0.00		0	0		0.00	0.00
Chromium	0%	297	299	136%	138462	326417	3%	1817	1872	7%	539	575	-99%	17	0
Iron ore		2292	2308		906160	2136218		770677	794168		320101	342086		169719	192885
Silver	4%	58	61	-19%	192	156	3%	0.14	0.14	7%	0.01	0.01	10%	0.003	0.004
Tin	8%	305	328		0	0	3%	25	25	7%	3	3	10%	1	1
Zinc	0%	206	207		0	0	3%	3229	3328	7%	3065	3275	14%	718	816
Cadmium		0	0	81%	13.1	23.7	3%	0.00027	0.00028	7%	0.00003	0.00003	10%	0.00001	0.00001
Gold	4%	5.6	5.9		0	0	3%	0.054	0.056	7%	0.006	0.006	10%	0.001	0.001
Indium	6%	2.3	2.4	138%	3.4	8.1		0.00	0.00	7%	0.0002	0.0002	14%	0.0003	0.0003
Lead		0	0		0	0	3%	5.96	6.15	7%	0.61	0.65	10%	0.14	0.16
Selenium		0	0	106%	7.8	16.1		0	0		0	0		0	0
Silica sand		0	0		0	0		0	0		0	0		0	0
Tellurium		0	0	74%	13.6	23.7		0	0		0	0		0	0
Bauxite ore		0	0		0	0		0.00	0.00		0	0		0.00	0.00
Crude steel (94% content -processing)	1%	1479	1489	136%	584619	1378205	3%	497211	512366	7%	206517	220701	14%	109496	124442

Materials	Cooking Appliances			Washing Machines			Dishwashers			Laundry Dryers			Vacuum Cleaners		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*	*%*	*2020*	*2030*
Aluminium (Bauxite)	5%	9135	9597	-4%	29520	28409	24%	2314	2874	15%	7951	9113	7%	42100	44944
Cerium		0	0		0	0		0	0		0	0		0	0
Cobalt	5%	0.16	0.16	-4%	0.06	0.05	24%	0.07	0.09	7%	0.04	0.04	12%	0.19	0.21
Europium		0	0		0	0		0	0		0	0		0	0
Gadolinium		0	0		0	0		0	0		0	0		0	0
Gallium		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Magnesium		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Manganese		0	0	-4%	111	107		0	0	4%	44	46	7%	303	326
Neodymium		0	0		0	0		0	0		0	0		0	0
Palladium	5%	0.16	0.16	-4%	0.06	0.05	24%	0.07	0.09	7%	0.04	0.04	12%	0.19	0.21
Praseodymium		0	0		0	0		0	0		0	0		0	0
Silicon (Silicon Metal)		0	0	-4%	222	214		0	0	4%	89	93	7%	606	651
Yttrium		0	0		0	0		0	0		0	0		0	0
Bismuth	5%	0.39	0.41	-4%	0.14	0.13	24%	0.18	0.22	7%	0.09	0.10	12%	0.48	0.54
Coking coal		330252	346949		231061	222364		152221	189028		71968	75099		45527	48916
Germanium		0	0		0	0		0	0		0	0		0	0
Tungsten		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Antimony	5%	7.78	8.17	-4%	2.80	2.70	24%	3.51	4.36	7%	1.84	1.96	12%	9.61	10.73
Baryte	5%	0.54	0.57	-4%	0.20	0.19	24%	0.25	0.30	7%	0.13	0.14	12%	0.67	0.75
Beryllium	5%	0.008	0.008	-4%	0.003	0.003	24%	0.004	0.004	7%	0.002	0.002	12%	0.010	0.011
Copper	0%	22494	22494	-4%	22259	21421	24%	6737	8366	13%	10406	11728	7%	26916	28873
Nickel	5%	23823	25028	-4%	13498	12989	24%	4088	5077	4%	4199	4382	12%	10	11
Strontium		0.078	0.082		0.028	0.027		0.035	0.044		0.018	0.020		0.096	0.107
Tantalum		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Chromium	5%	71462	75075	-4%	40490	38966	24%	12819	15919	4%	12596	13144	12%	19	21
Iron ore		664793	698405		465123	447615		306420	380511		144870	151174		91645	98468
Silver	5%	0.39	0.41	-4%	0.14	0.13	24%	0.18	0.22	7%	0.09	0.10	12%	0.48	0.54
Tin	5%	71	74	-4%	26	25	24%	32	40	7%	17	18	12%	87	98
Zinc	5%	2854	2998	-4%	1488	1432	24%	229	285	4%	437	457	12%	23	26
Cadmium	5%	0.00078	0.00082	-4%	0.00028	0.00027	24%	0.00035	0.00044	7%	0.00018	0.00020	12%	0.00096	0.00107
Gold	5%	0.156	0.163	-4%	0.056	0.054	24%	0.070	0.087	7%	0.037	0.039	12%	0.192	0.215
Indium		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Lead	5%	17.11	17.97	-4%	6.17	5.94	24%	7.72	9.58	7%	4.05	4.31	12%	21.15	23.61
Selenium		0	0		0	0		0	0		0	0		0	0
Silica sand		0	0		0	0		0	0		0	0		0	0
Tellurium		0	0		0	0		0	0		0	0		0	0
Bauxite ore		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00		0.00	0.00
Crude steel (94% content -processing)	5%	428899	450584	-4%	300079	288784	24%	197690	245491	4%	93465	97532	7%	59126	63528

Materials	Taps and showers			Industrial Fans			Electric Motors			Welding Equipment			Utility Transformers		
	forecast	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)		*forecast*	weight (t)	
	%	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***	*%*	***2020***	***2030***
Aluminium (Bauxite)	2%	1023	1041	2%	141914	144143	3%	96551	99002	2%	468	479	112%	14215	30072
Cerium		0	0		0	0		0	0		0	0		0	0
Cobalt		0	0		0	0	17%	0.04	0.05	2%	0.01	0.01		0	0
Europium		0	0		0	0		0	0		0	0		0	0
Gadolinium		0	0		0	0		0	0		0	0		0	0
Gallium		0	0		0	0		0	0		0	0		0	0
Magnesium		0	0		0	0		0	0		0	0		0	0
Manganese		0	0	14%	53	61	3%	887	912	2%	3.63	3.71		0	0
Neodymium		0	0		0	0		0	0		0	0		0	0
Palladium		0	0		0	0	17%	0.04	0.05	2%	0.01	0.01		0	0
Praseodymium		0	0		0	0		0	0		0	0		0	0
Silicon (Silicon Metal)		0	0	14%	107	122	2%	16979	17284	2%	7.3	7.4		0	0
Yttrium		0	0		0	0		0	0		0	0		0	0
Bismuth		0	0		0	0	17%	0.10	0.12	2%	0.02	0.02		0	0
Coking coal		0	0		392019	398153		584775	596614		37258	38101		247189	360621
Germanium		0	0		0	0		0	0		0	0		0	0
Tungsten		0	0		0	0		0	0		0	0		0	0
Antimony		0	0		0	0	17%	2.08	2.43	2%	0.48	0.49		0	0
Baryte		0	0		0	0	17%	0.15	0.17	2%	0.034	0.034		0	0
Beryllium		0	0		0	0	17%	0.0021	0.0024	2%	0.0005	0.0005		0	0
Copper	2%	113873	115887	2%	35005	35679	2%	107367	109367	2%	3053	3122	30%	89964	116838
Nickel		0	0		0	0	17%	2.08	2.43	2%	0.57	0.58		0	0
Strontium		0	0		0	0	17%	0.021	0.024	2%	0.005	0.005		0	0
Tantalum		0	0		0	0		0	0		0	0		0	0
Chromium		0	0		0	0	17%	4.2	4.9	2%	1.2	1.2		0	0
Iron ore		0	0		789129	801477		1177145	1200976		75000	76697		497588	725926
Silver		0	0		0	0	17%	0.10	0.12	2%	0.02	0.02		0	0
Tin		0	0		0	0	17%	18.9	22.1	2%	4.4	4.5		0	0
Zinc	2%	94337	96015	2%	161	164	17%	4.99	5.83	2%	737	754	50%	3618	5420
Cadmium		0	0		0	0	17%	0.00	0.00	2%	0.0000	0.0000		0	0
Gold		0	0		0	0	17%	0.04	0.05	2%	0.010	0.010		0	0
Indium		0	0		0	0		0	0		0	0		0	0
Lead		0	0		0	0	17%	4.58	5.35	2%	1.055	1.079		0	0
Selenium		0	0		0	0		0	0		0	0		0	0
Silica sand		0	0		0	0		0	0		0	0		0	0
Tellurium		0	0		0	0		0	0		0	0		0	0
Bauxite ore		0	0		0	0		0	0		0	0		0	0
Crude steel (94% content -processing)		0	0	2%	509115	517082	2%	759449	774823	2%	48387	49482	46%	321024	468339

Appendix VII

Materials	Scenario 1 (70%/30%)	Scenario 2 (EPH - ÖkoRess II)	Minimal priority ≤ 0.18	Low priority 0.18 < x ≤ 0.36	Medium priority 0.36 < x ≤ 0.54	High priority 0.54 < x ≤ 0.72	Highest priority 0.72 < x ≤ 0.9
Aluminium	0.73	0.64	0.18	0.18	0.18	0.18	0.18
Bismuth	0.53	0.60	0.18	0.18	0.18	0.18	0.18
Cooking coal	0.50	0.64	0.18	0.18	0.18	0.18	0.18
Copper	0.37	0.30	0.18	0.18	0.18	0.18	0.18
Fluorspar	0.40	0.56	0.18	0.18	0.18	0.18	0.18
Gypsum	0.10	0.30	0.18	0.18	0.18	0.18	0.18
Lithium	0.57	0.75	0.18	0.18	0.18	0.18	0.18
Magnesite	0.10	0.30	0.18	0.18	0.18	0.18	0.18
Molybdenum	0.20	0.15	0.18	0.18	0.18	0.18	0.18
Natural graphite	0.63	0.90	0.18	0.18	0.18	0.18	0.18
Nickel	0.37	0.30	0.18	0.18	0.18	0.18	0.18
Potash	0.10	0.45	0.18	0.18	0.18	0.18	0.18
Silica sand	0.10	0.19	0.18	0.18	0.18	0.18	0.18
Tantalum	0.37	0.60	0.18	0.18	0.18	0.18	0.18
Tin	0.17	0.30	0.18	0.18	0.18	0.18	0.18
Titanium metal	0.53	0.71	0.18	0.18	0.18	0.18	0.18
Tungsten	0.53	0.79	0.18	0.18	0.18	0.18	0.18