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Critical Raw Materials for Ireland for a Resource-Efficient Circular Economy (CIRCLE)

Authors: Ahmar Murtaza, Maham Mahnoor, Anum Inam, Ali Akbar Shah, Muhannad Ahmed Obeidi and Inam Ul Ahad

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Rialtas na hÉireann
Government of Ireland

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2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Lead organisation: Dublin City University

Identifying pressures

The Critical Raw Materials for Ireland for a Resource-Efficient Circular Economy (CIRCLE) project addressed the challenge of ensuring the availability and security of critical raw materials (CRMs) in Ireland, which is vital for industrial growth and competitiveness. Global raw material supply is becoming increasingly complex and uncertain, exacerbated by resource scarcity and supply chain vulnerabilities. Ireland lacked a criticality assessment methodology tailored to its unique economic and resource landscape. To address this gap, the CIRCLE project developed a customised methodology for assessing the criticality of raw materials specific to Ireland. This robust framework for evaluating raw materials' criticality supported evidence-based decision-making, crucial for developing strategic policies to ensure resource security and reduce dependency on imports. By identifying CRMs and their supply risks, the project aimed to secure jobs, promote innovation and sustain economic growth. In addition, it emphasised sustainable resource management practices to enhance resource efficiency, reduce waste and drive the circular economy. Thus, the CIRCLE project significantly contributed to Ireland's understanding and management of CRMs, supporting both economic resilience and environmental sustainability.

Informing policy

The CIRCLE project holds significant policy, societal and commercial relevance. The assessment methodology and resulting CRM lists can assist stakeholders in identifying essential materials for various industrial sectors, providing insights into potential supply risks and economic impacts. The CRM lists will support evidence-based decision-making for policymakers by offering a robust framework to evaluate the criticality of raw materials, which is crucial for developing strategic policies that ensure resource security. This is aligned with Ireland's goals for sustainable development and climate change mitigation. By identifying CRMs, the project can help ensure the availability of essential resources for key industries such as the electrical and electronics industry, medical device industry and the manufacturing industry. The focus on sustainable resource management practices can contribute to environmental conservation, benefiting society at large. CIRCLE project outcomes can aid industries in understanding their raw material dependencies and supply risks, which is vital for maintaining competitiveness and fostering resilience against supply chain disruptions.

Developing solutions

The CIRCLE project implemented a CRM methodology tailored to Ireland's economic and resource landscape, characterised by customised CRM assessments and multiple evaluation methods. Three methods were developed for assessing raw material criticality:

- Method I. Identify CRMs when both economic importance (EI) and supply risk (SR) values surpass a threshold.
- Method II. Categorise materials into low, elevated and high criticality based on EI and SR thresholds.
- Method III. Rank materials by the sum of EI and SR values, from most to least critical.

The CIRCLE project recommends the establishment of a national database comprising three vital components:

- CRM data to facilitate strategic decision-making and reduced import reliance;
- circular material use rate data to track progress towards greenhouse gas reduction, waste reduction targets and climate goals;
- material flow analysis to provide insights into material flows and resource consumption in Ireland.

In addition, a knowledge base similar to the EU Raw Materials Knowledge Base is recommended to support data dissemination and partnerships, enhancing resource security and economic resilience.

EPA RESEARCH PROGRAMME 2021–2030

Critical Raw Materials for Ireland for a Resource-Efficient Circular Economy (CIRCLE)

(2021-GCE-1046)

EPA Research Report

Prepared for the Environmental Protection Agency

by

Dublin City University

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This report is based on research carried out/data from January 2022 to July 2023. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

This report provides detailed accounts of research work performed in the Critical Raw Materials for Ireland for a Resource-Efficient Economy (CIRCLE) project, which was funded by the Environmental Protection Agency (Ireland) and co-funded by the Geological Survey Ireland. The project addressed the crucial role of raw material availability for different industries.

The manufacturing industry heavily relies on raw materials, which serve as its fundamental backbone. As manufacturing techniques have evolved, higher-quality products have been introduced, and there is a growing demand for innovative, high-value goods. Consequently, the demand for raw materials has surged due to the digital revolution, which has enabled the production of high-quality, application-specific and customised products. In response to EU policies, the United Nations Sustainable Development Goals and Ireland's ambitious climate targets for 2030, 2040 and 2050, all industrial sectors are now prioritising the adoption of clean and eco-friendly materials and manufacturing processes to attain climate-neutral status. Under these circumstances, several raw materials have attained critical status, driven by various factors affecting their supply and economic significance. The primary objective of the CIRCLE project was to develop the first raw material criticality assessment methodology and provide a list of critical raw materials for Ireland that are essential for maintaining Ireland's status as a resource-efficient economy. Such a list could encourage industries to increase material reuse and look for substitute/alternative materials, in turn fostering economic resilience and addressing environmental challenges through the use of circular and sustainable economic models.

The report begins with a detailed review of the methodologies established by the European Commission, EU Member States and other countries for the assessment of raw materials to determine their criticality status. The assessment methodologies used by the Netherlands, Poland, Portugal and Germany were reviewed. The methodologies developed by several institutions such as the United States National Research Council, Yale University and the British Geological Survey were also reviewed. The raw material criticality analysis conducted by these groups primarily examined the economic importance (EI) and supply risk (SR) associated with the candidate materials. Following the review of criticality methodologies, three different calculation methods were developed and used for the assessment of raw materials for criticality for Ireland. A summary of the results of the raw material criticality assessment is presented, which offers valuable insights into the significance of different raw materials and their implications for Ireland's economy. A total of 42 raw materials were assessed. Twenty materials were identified as critical for the Irish economy as a result of the assessment. Through the second method, 20 materials were identified as having high criticality status, 18 as having elevated criticality status and four as having low criticality status. In the third methodology, raw materials were ranked based on their EI and SR values, with each material's criticality determined by summing these values and arranging them in ascending order from least to most critical. This report also presents recommendations for a national database, emphasising the establishment of a dedicated national-level database comprising three vital components, that is, data pertaining to critical raw materials, circular material use rate and materials flow analysis. In the context of Ireland's transition to a low-carbon and climate-resilient society, this report discusses relevant national and international frameworks, targets and goals. In addition, efforts to align Ireland's transition endeavours with these targets are highlighted, underscoring the country's commitment to sustainable development.

1 Introduction

1.1 Background

Raw materials play a crucial role in the functioning of various industries, providing the necessary inputs for manufacturing processes and supporting economic activities. The availability and accessibility of raw materials are essential for sustaining industrial growth and maintaining competitiveness. However, the global landscape of raw materials has become increasingly complex and uncertain, characterised by resource scarcity, geopolitical tensions and supply chain vulnerabilities.

Recognising the significance of raw materials and their criticality, governments and organisations have developed methodologies to assess and evaluate the importance of and potential risks associated with these materials. The European Commission has been at the forefront of such initiatives and has been developing methodologies to analyse the criticality of raw materials since 2010. These methodologies aim to identify the raw materials that are most essential for European industries and allow evaluation of the potential supply risks (SRs) and impacts on the economy associated with them.

In line with these efforts, the Critical Raw Materials for Ireland for a Resource-Efficient Circular Economy (CIRCLE) project was developed. The CIRCLE project, funded by the EPA (Ireland) and co-funded by the Geological Survey Ireland, aimed to develop the first-ever critical raw materials assessment methodology specifically tailored to Ireland. This groundbreaking project recognised the importance of understanding the criticality of raw materials within the unique context of Ireland's economy and resource needs. The objective of the CIRCLE project was to address the gaps and challenges related to raw material criticality assessment in Ireland. By leveraging the European Commission's methodology as a foundation and customising and refining it, the CIRCLE project sought to accurately reflect the specific requirements and characteristics of the Irish economy. This customised methodology will provide policymakers, industry stakeholders and researchers with valuable insights into the raw materials that are essential if Ireland's economy is to remain resource efficient, and outline the potential risks associated with their availability and supply.

This report presents the outcomes of the CIRCLE project, specifically focusing on the development of the first-ever critical raw materials assessment methodology for Ireland. It highlights the importance of raw material criticality within the context of Ireland's resource-efficient economy and showcases the collaborative efforts of the EPA (Ireland) and the Geological Survey Ireland in funding and supporting this groundbreaking research initiative.

By providing a comprehensive methodology tailored to Ireland, the CIRCLE project aimed to enhance the understanding of raw material criticality and support evidence-based decision-making processes. This report will delve into the details of the developed methodology, its adaptation from the European Commission's approach and its potential applications in informing sustainable resource management strategies in Ireland. Through the CIRCLE project, Ireland is taking a significant step towards understanding and addressing the challenges and opportunities associated with the use of critical raw materials. The outcomes of this project will therefore not only benefit Ireland's economy but also contribute to broader discussions on resource efficiency and sustainable development at the global level.

1.2 Objectives

The primary objectives of the CIRCLE project were as follows:

- Develop a methodology for assessing the criticality of raw materials tailored to Ireland: this report aims to build on the European Commission's methodology for assessing the criticality of raw materials and adapt it to the unique requirements and characteristics of the Irish economy. By customising the methodology, we sought to provide a comprehensive framework that accurately reflects Ireland's resource needs, industry sectors and the specific challenges it faces related to raw materials.

- Address the gaps and challenges inherent to raw material criticality assessment in Ireland: this report aims to bridge the existing gaps in understanding the criticality of raw materials in the Irish context. By developing a methodology that considers the economic importance (EI), SR and other relevant factors specific to Ireland, we aimed to provide a robust and reliable framework for assessing the criticality of raw materials within the country.
- Provide policymakers, industry stakeholders and researchers with valuable insights: by developing a comprehensive methodology, this report aims to offer policymakers, industry stakeholders and researchers in Ireland with a practical tool for decision-making and resource management. This methodology will assist in identifying the raw materials that are most critical for Ireland's resource-efficient economy, enabling stakeholders to focus their efforts on ensuring the availability and sustainable use of these materials.
- Compare the results of the developed methodology with the European Commission's methodology, and with the British Geological Survey's (BGS's) and Japan's approach: this report seeks to facilitate a comparative analysis of the outcomes obtained through the developed methodology with those derived from other existing methodologies. By making such comparisons, we can gain a comprehensive understanding of the similarities, differences, strengths and limitations of the various approaches, and thus contribute to the ongoing discussions and knowledge exchange on raw material criticality assessment.

Through these objectives, the CIRCLE project contributed to a broader understanding of raw material criticality within the context of Ireland's resource-efficient economy. By providing a robust methodology tailored to Ireland, we strive to support evidence-based decision-making, promote sustainable resource management practices and foster long-term economic and environmental sustainability in Ireland.

1.3 Methodology Scope and Target Sectors

The scope of the developed methodology for assessing the criticality of raw materials in Ireland was determined by two key factors: the industrial sectors prescribed by the funding agency (EPA) and the availability of data for calculating the EI of these sectors.

The primary target sectors identified by the EPA for this methodology included the following:

Electrical and electronics industry. This sector encompasses the manufacturing of electrical equipment, electronic components and consumer electronics. It plays a vital role in Ireland's economy, contributing to technological advancements and innovation. The availability and accessibility of critical raw materials are crucial for the continued growth and competitiveness of this industry.

Medical device industry. Ireland has established itself as a global hub for the production of medical devices, including equipment, instruments and diagnostic products. This sector is highly reliant on specific raw materials to ensure the quality, safety and efficacy of medical devices. Assessing the criticality of raw materials in this industry is essential for maintaining supply chain resilience and supporting the healthcare sector.

Manufacturing industry. The manufacturing sector encompasses a wide range of subsectors, including machinery, equipment, textiles, and food and beverages. It forms a significant part of Ireland's economy, contributing to employment, exports and overall economic growth. The use of critical raw materials within the manufacturing industry is vital for supporting production processes, maintaining competitiveness and ensuring sustainable development.

Data availability. In addition to these prescribed target sectors, the methodology also considers other manufacturing sectors outlined in the Statistical Classification of Economic Activities in the European Community (NACE) Section C manufacturing classifications. The NACE is a classification system used by the EU, and Eurostat has established user support centres within the "European statistical system" network across most Member States and in some European Free Trade Association countries. Its main purpose is to categorise economic activities uniformly for the collection of precise statistical data across Member States. Table 1.1 lists the industrial sectors with codes according to NACE Revision

Table 1.1. Industrial sectors with codes (NACE Rev. 2, at the two-digit level)

Industrial sector	Code
Mining Support Services	B09
Manufacture of Food Products	C10
Manufacture of Beverages	C11
Manufacture of Paper and Paper Products	C17
Manufacture of Coke and Refined Petroleum Products	C19
Manufacture of Chemical and Chemical Products	C20
Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations	C21
Manufacture of Rubber and Plastic Products	C22
Manufacture of Non-Metallic Mineral Products	C23
Manufacture of Basic Metals	C24
Manufacture of Fabricated Metal Products, except Machinery and Equipment	C25
Manufacture of Computer, Electronics and Optical Products	C26
Manufacture of Electrical Equipment	C27
Manufacture of Machinery and Equipment not elsewhere classified	C28
Manufacture of Motor Vehicles, Trailers and Semi-Trailers	C29
Transport Equipment – Manufacture of Other	C30
Manufacture of Furniture	C31
Other Manufacturing	C32

(Rev.) 2, at the two-digit level. In Ireland, the national statistical agency, the Central Statistics Office (CSO), utilises the NACE for the systematic collection, organisation and standardised presentation of economic information. This broader inclusion allows a more comprehensive assessment of Irish economic dependency and criticality. However, it is important to note that, owing to the unavailability of EI data, two NACE Section C manufacturing sectors, the Manufacture of Coke and Refined Petroleum Products and the Manufacture of Chemicals and Chemical Products, have not been included as target sectors in this methodology. Nevertheless, the methodology can be adapted and expanded in the future to include these sectors as more data becomes available, and the selected target sectors align with Ireland's economic priorities and contribute significantly to its industrial landscape. By assessing the criticality of raw materials in these sectors, the methodology provided valuable insights into the materials essential for the functioning and sustainability of these industries. It also aided in the identification of potential risks associated with, and the development of appropriate strategies to ensure the reliable supply and sustainable use of, critical raw materials. The methodology's scope extends beyond the specific target sectors mentioned above, and it can therefore be applied to other industries in Ireland. Its adaptability allows the inclusion of additional sectors in future assessments, as the availability of data improves and the need arises.

In summary, the developed methodology provided a solid foundation for evaluating the criticality of raw materials in Ireland's key industries. Through its focus on the prescribed target sectors and consideration of the available data, the methodology can support informed decision-making and facilitate the development of resource-efficient strategies.

2 Critical Raw Materials Review

Critical raw materials are natural resources that are essential for the development of various industries and technologies, including renewable energy, electronics, aerospace and defence. These materials have high levels of EI but are characterised by a high SR and limited availability. Therefore, this report focuses on critical raw materials and the SRs associated with them, which can arise because of geopolitical factors, limited production capacities and concentrated sources of these materials in specific countries. The EU recognises the strategic importance of securing a stable supply of critical raw materials to support its industrial competitiveness, innovation and transition to a low-carbon and resource-efficient economy. The EU has identified a list of critical raw materials through the Critical Raw Materials Act. The list is updated regularly to address changes in supply and demand dynamics. Moreover, the EU is currently developing a regulation that will make it less dependent on foreign actors and increase its resilience in the supply of critical raw materials.

2.1 Criticality Analysis of Raw Materials by EU Member States

2.1.1 The Netherlands

For the Dutch critical raw materials assessment, the methodology included the same main parameters as the EU methodology, that is, the EI and SR (Rietveld and Bastein, 2019). In addition, two other parameters were introduced to the methodology: vulnerability and environmental risk. The list of indicators for critical raw materials and their dimensions was used in the Dutch methodology, and the indicators were listed according to their importance in determining criticality. As mentioned above, the two main factors for raw material criticality determination are EI and SR. First, the Dutch methodology included the security of supply perspective factor in its SR calculations, which relates to the uncertainty of supply due to population growth. Second, the price volatility and chains were related to the SR for the critical raw materials. The third factor of "reputation" in SR was also used to calculate the uncertainty in the supply of the material. In the Dutch methodology, the formula for the EI was not used as proposed in the EU methodology. Interestingly, the factor of import reliance (IR) was not used by the Dutch researchers to calculate the SR (which is part of the EU methodology). Using their specialised methodology, the Dutch researchers showed the relationship between the short-term SRs and added value of different materials.

2.1.2 Poland

The researchers from the Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Krakow, proposed an extended version of the EU methodology for the identification of important minerals and their classification into key, strategic and critical mineral categories (Galos *et al*., 2021). A two-stage methodology was used for all mineral groups on the basis of the parameters selected and the threshold applied. For the key mineral category, stage I was used to determine the mean annual value of consumption of the assessed minerals over 10 years (from 2009 to 2018). Using this data, the mineral consumption trends were examined in stage II and the IR of the minerals was calculated. A threshold of 40 million PLN/year was used to categorise the minerals as strongly growing or moderately growing, and with variable consumption or decreasing consumption. In this way, three minerals, (i) gas (natural), (ii) zinc metal and (iii) aluminium (metal, non-alloyed), were identified as key minerals for the Polish economy, as their consumption increased greatly over the examined time period. The EU 2017 criticality methodology should be used only for non-energy raw materials (EC, 2017). This methodology was used by researchers in Poland to assess metallic, non-metallic and energy minerals. The SR was calculated for each material assessed using a two-stage approach, and those materials with an SR value of at least 0.9 were identified. Because of Poland's distinctive mineral sourcing structure, minerals sourced in Poland, rather than in the EU, were used to determine the IR for the minerals consumed in Poland. Once the 0.9 SR threshold was applied in stage II, only those materials that were identified as key or strategic materials were listed as critical raw materials for the Polish economy.

2.1.3 Portugal

Taking the EU methodology as a base, researchers in Portugal assessed the criticality of minerals on the mainland of Portugal (Martins and Castro, 2019). The main factors used, SR and EI, were the same as those proposed in the EU methodology, and a map was designed. The researchers used the Information System of Portuguese Occurrences and Mineral Resources database as a reference to calculate the occurrence of minerals. A geographical map of Portugal was used, in which all the mineral commodities were categorised by the zones of political districts. For each zone, the minerals were categorised by sedimentary, metamorphic and igneous rock types. First, the map categorisation for critical raw materials for Portugal was based on the Australian classification models of mineral deposits. Second, the mineral deposits were categorised by their size, which was associated with their geographical density. Third, mineralisation sources were subdivided as superficial processes, magmatic, magmatic/hydrothermal, metamorphic/hydrothermal and hydrothermal. In the final step of Portugal's methodology for critical raw materials, specifically for minerals, a map based on the different classifications was developed. Before making the classification, the EU methodology was used to identify which of the minerals were critical raw materials. After the critical raw materials had been identified, the map was designed using a methodology developed by Australian researchers.

2.1.4 Germany

A research group from Technische Universität Berlin presented an "integrated method to assess resource efficiency" (Bach *et al*., 2016). This technology was developed in co-operation with five European companies: Daimler, Evonik, Knauer, ThyssenKrupp and Siemens, and the German Copper Institute (Deutsches Kupferinstitut). The German study was performed to identify the restricted availability of resources because of physical and socioeconomic indicators and societal acceptance, a factor that compromises the productivity of companies. The indicators of these categories were used to determine the distance-to-target value based on product design, material selection and supply chain management. To normalise the distance-to-target values for each resource, the global production was scaled to a range between zero and the maximum value observed among the considered materials. This scaling was achieved using the balancing rule of life cycle analysis (LCA) and the characterisation factors (CFs) from life cycle impact assessment (LCIA) results. The objective was to ensure a consistent range of characterisation factors across the SR categories. The results were presented in 19 categories, within which single-point calculation was possible, but not recommended. In these 19 categories, 11 indicators were related to socioeconomic availability and were relevant to criticality, eight indicators were based on life cycle assessments and two were based on social implications. The study, however, stressed that, for each end-of-use sector, additional aspects describing the conditions and needs of the relevant sector should be added where possible. The study comprehensively considered the sustainability aspects of the resources and used them to develop a framework that could advance progress towards achievement of the United Nations Sustainable Development Goals. Hence, the impacts of candidate material use on environmental, economic and societal well-being were taken into account. In the years since this methodology was conceived, it has been enhanced and modified by several research groups (Bach *et al*., 2019; Cimprich *et al*., 2019; Pelzeter *et al*., 2022) and used in case studies for specific materials and industrial sectors (Hackenhaar *et al*., 2022; Lütkehaus *et al*., 2022; Yavor *et al*., 2021).

2.2 Raw Material Criticality Assessment by Non-EU Countries and Regions

The criticality of raw materials has remained an important concern for the development of resource policies in major industrialised countries. Although the CIRCLE project was focused on EU Members States' criticality assessment methods, it is worth providing a summary of the important criticality methodologies developed by non-EU countries. Table 2.1 provides a list of major studies that have been performed on critical raw material assessment by non-EU countries. These methodologies have been developed with a view to assessing the raw materials that are critical to the individual country's

Table 2.1. Major studies performed on critical raw materials assessments (non-EU countries and regions)

Year	Country/level	Remarks	Reference
2008	UK	SRs of materials	Morley and Eatherley, 2008
2008	USA	Economic importance and price volatility associated with the SR	NRC, 2008
2009	Global	Potential SRs and risk from politically unstable countries	Rosenau-Tornow *et al.*, 2009
2009	Japan	SRs associated with price volatility and recycling restrictions	Hatayama and Tahara, 2015a
2012	USA (Yale)	Determination of metal mineral criticality at the corporation and government levels	Graedel *et al.*, 2012
2014	Organisation for Economic Co-operation and Development countries	Risks of disruption in the material supply and impacts on the economies of Organisation for Economic Co-operation and Development countries	Coulomb *et al.*, 2015
2014	South Korea	SRs of the metal and its impacts on the Korean economy	Schrijvers *et al.*, 2020
2016	Global	SRs of metals required for the manufacturing of the wind turbines	Habib and Wenzel, 2016
2016	Global	Supply disruption of photovoltaic materials	Helbig *et al.*, 2018
2018	Global	SRs of materials used to manufacture lithium-ion batteries	Helbig *et al.*, 2016
2020	USA	Dependence on foreign supply and sourcing, and association with the SRs	Nassar *et al.*, 2020
2021	UK	Global SR and its impact on the economy owing to demand growth in the UK	Lusty *et al.*, 2021

mineral policy, resource strategy, economic priorities, consumption of materials for specific industries and supply disruption risk. The criticality assessment is usually based on the classification of raw materials into groups using several indicators. A threshold is usually applied to quantitative values of supply and economic indicators, which are calculated using previous data on the material sourcing and supply chain vulnerability to disruption, consumption and value added to the economy associated with a specific material. The notable critical raw material assessment methodologies developed by non-EU countries are described below.

2.2.1 United States National Research Council

A framework for critical raw materials assessment was developed in 2008 by the National Research Council (NRC) of the United States. This framework is considered a major milestone in critical raw material assessment methodology, as it demonstrates the use of a two-dimensional approach for determining the SR and supply restrictions of the minerals. The minerals were evaluated for SR using five available indices taken from the primary and secondary resources. The assessment of the indicators varied depending on whether they would be used in the short term, medium term or long term. The supply restrictions were calculated using a weighted composite score. The results of the assessment were used to fill a matrix, which enabled the NRC to define the material's degree of criticality. The research and stakeholder groups that participated in the development of the framework identified 30 non-fuel mineral candidates for criticality assessment. As a result, the short- and long-term availability of 11 minerals was determined as critical. The NRC's methodology was developed with consideration given to the SR, material consumption and the type of industrial base in the USA. Nevertheless, many research groups used this framework as their basis when developing a critical raw material assessment methodology for use outside the USA.

In 2018, the US National Science and Technology Council subcommittee for estimating the potential risk of raw materials assessed the criticality of minerals that were both important to the US manufacturing sector and sourced internationally. The assessment was based on the findings of the United States Geological Survey (USGS). A draft report was published, and 35 minerals were identified as critical for the US manufacturing sector (Fortier *et al.*, 2018). This method was revised in 2020 to evaluate the SR of the 52 groups of non-energy materials, and a list of 23 materials that represented the highest SR for the US manufacturing industries was published.

Three broad dimensions were used to measure the risk factor: the distribution potential, which was related to the dependence of the manufacturing sector on global supplies; trade exposure, which covered the net import dependence from foreign sources; and economic vulnerability, which was used to measure the degree to which the pricing and contribution of materials affected the domestic production of products (Nassar *et al*., 2020). In 2022, on the basis of a revised methodology developed in 2020, the USGS released a publication stating that a broad range of minerals (50 in total) are critical to the US economy (USGS, 2022).

2.2.2 *Yale methodology for metal criticality determination*

This assessment policy was developed as an extension of the 2006 US NRC and US economic policies for determining the criticality of metal minerals at the corporation and government levels. This dynamic criticality methodology aims to determine the criticality of (individual) metals of the periodic table (Graedel *et al*., 2012). The approach addresses three levels (company-wide, national and global) based on reserves for the short and medium terms, as well as the reserve base for the long term. It provides detailed scores on an indicator level and utilises indicators across three dimensions. The use indicators corresponded to three dimensions (SR, environmental impact and vulnerability to supply restrictions). The results were then typically displayed in a three-dimensional space to account for the aforementioned three dimensions. The results were to be interpreted as snapshots. The quantitative results of every dimension were then interpreted based on semi-quantitative or qualitative indicators, with scores ranging between 0 and 100 points. In addition, single-score indicator plots were used to define the criticality vector magnitude available after aggregation and normalisation. This methodology was updated so that it could be applied to a wide range of metal and metalloid elements at the national or global level in 2015.

2.2.3 *British Geological Survey*

In 2011, the BGS assessed 52 materials (metallic elements) on the basis of four criteria: scarcity, production concentration, reserve base distribution and governance. From the 52 assessed materials, 25 were found to be at risk of supply disruption and were included in *The British Geological Survey Risk List 2011* (BGS, 2011). In 2012, the material assessment methodology was revised by the BGS and, in addition to the four above-mentioned indicators, recycling rates and substitutability of material criteria were included to determine the SR of the materials (BGS, 2012). However, for some materials, the data for the newly added factors (recycling and substitution) was not available. Hence, only 41 out of the 52 previously assessed materials were selected for assessment. Therefore, *The British Geological Survey Risk List 2012* contained 41 materials for which the relative SR index had been calculated, and which were categorised from low to high SR.

In 2015, the BGS further revised the methodology and removed scarcity as a criterion for the assessment of the SR of materials. Companion metal fraction production was introduced to accurately assess the metals that are produced as by-products during the mining of other metals. Seven criteria were calculated for assessment of the SR of materials, and a SR index for 41 materials was published in *The British Geological Survey Risk List 2015*.

The BGS's material SR assessment methods provided a simple way to calculate the SR index. These indices were easy to use for policymakers and industries that needed to diversify the supply of primary resources, encourage recycling and, ultimately, promote the decreased use of such resources. However, the EI indicators were not used by the BGS, although these were the major contributors to EU critical raw materials assessment methodology (European Commission, 2017). Hence, further specification of the individual circumstances, unique to each metal and technology area, was required to draw an effective conclusion for the UK economy. In 2021, the BGS performed a material criticality assessment that considered two types of risk associated with the raw materials: the global SR ("S") and the risk inherent to the UK's economic vulnerability ("V") (Lusty *et al*., 2021). In relation to the global SR, three broad indicators were used to delineate the complex and dynamic global supply chain from which the UK sources raw materials. For the UK economic vulnerability calculations, six indicators were considered to determine the importance of raw materials to the UK economy. The global production data was aggregated from publicly accessible databases and the scientific literature. Furthermore, to estimate the potential consumption of raw material in domestic production, information from reliable trading partners and a UK-specific dataset were used. A spreadsheet application was developed for the evaluation an aggregated data matrix and when the sum of the weighed value exceeded the proposed threshold, then the material was designated as critical. A total of 26 candidate materials were selected for screening from the identified minerals, published as being “critical” in major criticality studies, and in the BGS study, 18 minerals were labelled “critical”.

3 Critical Raw Material Methodology

Ultimately, the applicability of the European Commission methodology to Ireland depends on the country's specific circumstances and priorities. It provided a framework for analysis and decision-making, but its implementation and customisation were carried out at the national level, taking into account Ireland's unique raw material resources, industrial sectors, policy objectives and data availability.

3.1 Economic Importance Calculation Method

To calculate the EI of each candidate material, the following steps were taken.

Step 1. The end-use applications for each candidate material were categorised according to the NACE Rev. 2 classification at the two-digit level, specifically in the manufacturing sector of category C (see Table 1.1 for details).

Step 2. The percentage usage of each candidate raw material in its respective end-use applications was extracted from data provided by Solutions for CRitical Raw materials - a European Expert Network and the European Commission.

Step 3. The sectorial gross value-added (GVA) data for the NACE Rev. 2 sectors at the two-digit level was compiled from 2011 to 2021. The average GVA value was calculated for each NACE Section C manufacturing sector and used for EI calculations. However, while compiling the GVA data for Ireland, the following four issues were encountered:

Substep 3.1. The GVA data was available for the following combined groups of sectors: C10–C12, C13–C15, C19–C20 (A38), C29–C30 and C31–32. However, for C29 and C30, individual data was available only for the years 2011 to 2014. For details on NACE Section C coding, see Table 1.1.

Substep 3.2. The GVA data for individual sectors C21, C26, C29 and C30 was confidential for the years 2015 to 2021.

Substep 3.3. The GVA data for individual sectors C19 and C20 in Ireland was confidential for all years.

Substep 3.4. Some candidate raw materials had end-use applications in individual sectors for which GVA data was available only in combination with data for other sectors in which that candidate material had no end-use application (see substep 3.1).

Step 4. To address the issue raised in substep 3.1, the combined GVA data was averaged for the years 2011 to 2021 and then used for further calculations for those candidate materials that had end-use applications in all sectors of each group. However, for the candidate materials with end-use applications in either the C29 sector or the C30 sector, the average GVA data from 2011 to 2014 was used (for example, this was the case for nickel, tantalum and platinum).

To address the issue raised in substep 3.2, the GVA data from 2011 to 2014 was averaged and used.

To address the issues raised in substeps 3.3 and 3.4, that is, when the candidate raw material had end-use application(s) corresponding to sectors for which individual data was not available, the percentage share of end-use applications for which GVA data was available was scaled ($As_{IEadjusted}$) using the method described below.

Substep 4.1. The sum of the end-use sector percentages ($\sum As$) was obtained, where:

$$\sum As = As_1 + As_2 + As_3 + \ldots As_n \tag{3.1}$$

Here, n is the total number of end-use applications for the candidate material.

Substep 4.2. The end-use percentages of individual sectors for which no GVA data was available were subtracted from $\sum As$:

$$As_{adjusted} = \sum As - As_{1*} - As_{2*} - As_{3*} \ldots As_{m*} \tag{3.2}$$

where $m*$ denotes (i) the individual sectors for which no GVA data was available or (ii) individual sectors for which grouped data was available, but the candidate material was not used in all sectors of that group.

Substep 4.3. Each end-use sector for which GVA data was available was divided by the value obtained in substep 4.2 to calculate the adjusted end-use sector percentage for Ireland:

$$As_{IEadjusted} = As_1/As_{adjusted},\ As_2/As_{adjusted},\ As_3/As_{adjusted},\ \ldots\ As_{n-m}/As_{adjusted} \tag{3.3}$$

Step 5. The $As_{IEadjusted}$ value was multiplied by the corresponding GVA (Qs) values for each end-use application sector(s) of the candidate material. For this, the following mathematical expression was used:

$$\sum(As_{IE} \times GVAs_{IE}) \tag{3.4}$$

where As_{IE} and Qs_{IE} were calculated according to the following conditions.

For candidate materials for which GVA data was available for all end-use applications from 2011 to 2021, then:

$$As_{IE} = As \text{ and } GVAs_{IE} = GVAs_{AVG(2011–2021)} \tag{3.5}$$

For candidate materials for which GVA data was available for end-use applications individually or in a group from 2011 to 2021 or from 2011 to 2014, then:

$$As_{IE} = As \text{ and } GVAs_{IE} = GVAs_{AVG(2011–2021)} \text{ or } GVAs_{AVG(2011–2014)} \tag{3.6}$$

If GVA data was confidential or not available for individual end-use applications, then:

$$As_{IE} = As_{IEadjusted} \text{ and } GVAs_{IE} = GVAs_{AVG(2011–2021)} \text{ or } GVAs_{AVG(2011–2014)} \tag{3.7}$$

Step 6. The sum of contributions from end-use applications and GVA data was multiplied by the substitute index for EI (SE_{IE}) to obtain the unscaled EI value. The SE_{IE} values for candidate materials were obtained from the European Commission's *Study on the Critical Raw Materials for the EU 2023* report (EC, 2023):

$$Economic\ Importance_{unscaled} = \sum(As_{IE} \times GVAs_{IE}) \times SI_{EI} \tag{3.8}$$

Step 7. The $EI_{unscaled}$ value was divided by the highest value of the manufacturing sector NACE Rev.2 at the two-digit level. For Ireland, C21 (Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations) had the highest value among the sectors. The resulting value was then multiplied by 10 to obtain the EI value for Ireland:

$$EI_{IE} = \frac{\sum(As_{IE} \times GVAs_{IE}) \times SI_{EI}}{GVA_{C21}} \times 10 \tag{3.9}$$

3.2 Supply Risk Calculation Method

To calculate the SR of raw materials for Ireland, the European Commission's 2017 methodology was adopted, and the calculations were performed using the following steps.

Step 1. The Herfindahl–Hirschman Index (HHI[1]), which is based on the World Governance Index (HHI_{WGI}), was calculated in the first step. For this, each country's share of global material supply was obtained from world mining data and its World Governance Index was obtained from the World Bank's website. By multiplying the share value by the World Governance Index, the HHI was obtained but kept unscaled. The value of trade was obtained from the *Study on the Critical Raw Materials for the EU 2023* report (EC, 2023). The share (expressed as a percentage) of each country was squared and multiplied by the HHI_{WGI} and the trade variable, as expressed by the following equation:

$$HHI_{WGI} = (S_{IRE})^2 \times WGI_{IRE} \times t_{IRE} \tag{3.10}$$

Step 2. The global share at the extraction and processing stages (GS) was calculated in the second step. The $HHI_{WGI,t}$ values were summed to obtain the global share $(HHI_{WGI,t})_{GS}$, as described in the equation below:

$$(HHI_{WGI})GS = \sum_{IRE}(S_{IRE})^2 \times WGI_{IRE} \times t_{IRE} \tag{3.11}$$

Step 3. The IR was calculated. For this, the import and export data was obtained from the CSO trading dataset (2016–2022) at the extraction and processing stages of the candidate raw material. The data on domestic production was obtained from the BGS. Collectively the IR was calculated by dividing the

1 The HHI is a measure of market concentration. A higher HHI may indicate a more concentrated supplier market, posing an increased SR because of potential disruption.

Table 3.1. Material consumption (%) of raw materials in Ireland's industrial sectors

	Target sectors																	
Raw material	**B09**	**C10**	**C11**	**C17**	**C19**	**C20**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**	**C29**	**C30**	**C31**	**C32**
Al									8		41			11	19	19		
Sb						49			5		14		32					
As						7			18	74		1						
Be										1		28		23	17	17		
Bi						84				7								9
Cd										5	3	1	91					
Cu												2	38	25	11	4		21
Pb						4				7	4		85					
Mg										12	36				48	4		
Se						40			30	15		15						
Si						54				38		8						
Sr						45			5	10				40				
Te						10		5			15	70						
Sn						18				6	13	52	6					
Zn						10				32	58							
Zr						14			63	16								
Ben	7		3	3		8			47	32								
B						23			72	4								
Fsp						3			97									
F					4	11			7	58			20					
C						6			26	58			9	2				
Gp									100									
Kn				24	3	5		1	64									
Mgs		7		12		7			17	57								
Per			24						76									
SiO_2 sand								3	84	13								
S				1	24	71				4								
Tlc		8		21		22	2	36	7									
Cr						3			1	3	93							
Co						36					50		10					
Fe										10	52			17	16	2		
Mn										10	53		2	8	14	10		
Mo					23	13					40			24				
Ni										21	10		11	39		19		
Nb										27	45				23	3		
Ta						12					4	60		10		14		
Ti											20			25	10	45		
W						8					6		6	79				
V						5				71	21		3					
Au												13						87
Pd					2	5			1			2	2		67			11
Ag						11	4		6			6	22	13	8			31

B09 – Mining Support Services; C10 – Manufacture of Food Products; C11 – Manufacture of Beverages; C17 – Manufacture of Paper and Paper Products; C19 – Manufacture of Coke and Refined Petroleum Products; C20 – Manufacture of Chemicals and Chemical Products; C21 – Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations; C22 – Manufacture of Rubber and Plastic Products; C23 – Manufacture of Other Non-Metallic Mineral Products; C24 – Manufacture of Basic Metals; C25 – Manufacture of Fabricated Metal Products, except Machinery and Equipment; C26 – Manufacture of Computer, Electronics and Optical Products; C27 – Manufacture of Electrical Equipment; C28 – Manufacture of Machinery and Equipment n.e.c.; C29 – Manufacture of Motor Vehicles, Trailers and Semi-Trailers; C30 – Transport Equipment – Manufacture of Other; C31 – Manufacture of Furniture; C32 – Other Manufacturing; n.e.c. – not elsewhere classified.

Source: EC (2023).

net consumption by the apparent consumption, as expressed by the following relationship:

$$IR = \frac{Import - Export}{Domestic\ production + (Import - Export)} = \frac{Net\ consumption}{Apparent\ consumption} \qquad (3.12)$$

Step 4. The end-of-life recycling input rate (EOL_{RIR}) and substitution index related to the SR (SI_{SR}) were obtained from the *Study on the Critical Raw Materials for the EU 2023* report (EC, 2023) for use in the final equation of the SR calculation.

Step 5. Using the values calculated and collected in the previous steps, the SR for candidate raw materials was calculated using the equation below:

$$SR = [\ (HHI_{WGI,t})_{GS} \times {}^{IR}/_{2} + (HHI_{WGI,t})IRLsourcing(1 - {}^{IR}/_{2})\ ] \times (1 - EOL_{RIR}) \times SI_{SR} \qquad (3.13)$$

3.3 Method I – Threshold Values

To assess the criticality of the 42 raw materials for Ireland, calculations were performed according to the steps mentioned in sections 3.1 and 3.2 to obtain values for EI and SR. The results are represented in Figure 3.1. The European Commission set threshold values of 2.8 and 1.0 for the EI and SR, respectively, in 2010 (EC, 2010) and has used the same values in all assessments made since. However, a change in the EI value is warranted for Ireland. Specifically, for Ireland, the adjusted threshold for EI was set at 0.4, and the SR threshold remained unchanged at 1. This adjustment in the EI threshold is justified by Ireland's unique economic landscape, material requirements and supply management considerations. Ireland, as a small country within the EU, possesses distinct characteristics that necessitate a recalibration of the EI threshold. The original threshold value of 2.8, which is applicable to larger economies, is not appropriate for an economy the size of Ireland's. By lowering the EI threshold to 0.4 or below, a more accurate assessment of the EI resulting from raw material supply disruptions in Ireland can be made. The decision to maintain the standardised SR threshold value of 1 for Ireland was based on the understanding that SR is not heavily influenced by the size of the country. Rather, it is primarily determined by factors such as global supply chain stability, geopolitical considerations and natural resource availability. Therefore, maintaining an SR threshold of 1 aligns with this understanding. Implementing these adjusted thresholds offers several advantages. First, it enables a more nuanced evaluation of Ireland's economic vulnerability to supply disruptions. By lowering the EI threshold, even minor disruptions could be captured, which could in turn facilitate the establishment of proactive mitigation measures and enhanced preparedness. Second, it acknowledges Ireland's unique challenges as a smaller economy, enabling a tailored approach to be taken to risk assessment and management.

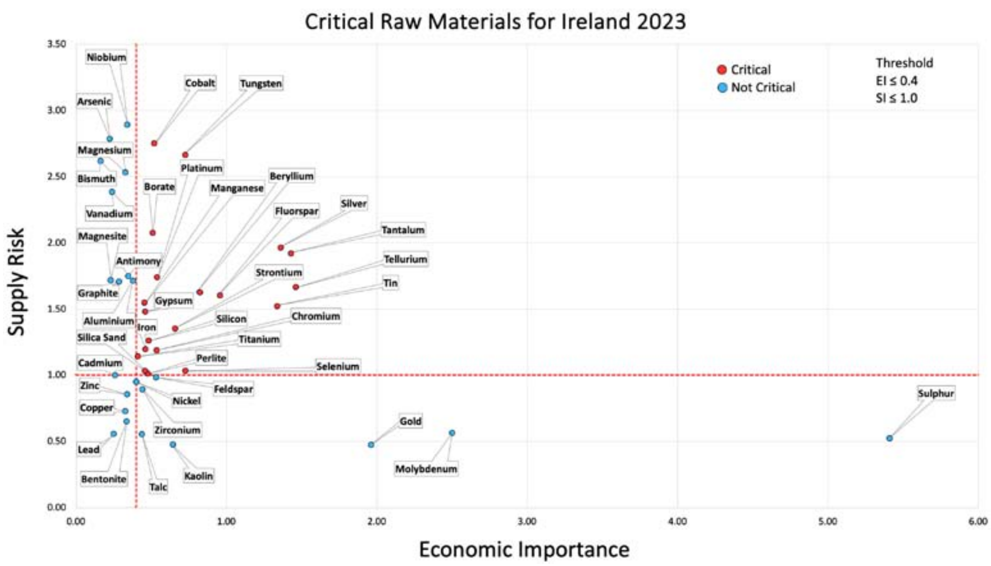

Figure 3.1. Criticality assessment of raw materials using threshold EI values for Ireland.

In terms of visual representation, Figure 3.2 serves as an intuitive tool that depicts the implications of the adjusted thresholds. It effectively showcases the clustering of raw materials based on their EI and associated risks. This graphical representation aids policymakers, supply managers and stakeholders in identifying the critical raw materials that require focused attention and investment, and highlights those with lower EIs or risks. By applying the 1.0 and 0.4 thresholds for SR and EI, 20 out of 42 raw materials have been identified as being critical for the Irish economy.

3.4 Method II – Low, Elevated and High Levels of Criticality

It is well established that all raw materials are important for the economy of any country or region. The BGS (Lusty *et al*., 2021), for example, made the criticality assessment via categorising raw materials according to their criticality severity.

For Ireland, we have proposed a second method for assessing critical raw materials. This assessment considers two key parameters (SR and EI) and the raw materials are classified into three categories (low criticality, elevated criticality and high criticality) based on specific threshold values. For materials to be classified as being of low criticality, they must have SR values below 1 and EI values below 0.4, which indicate that a relatively low risk and EI are associated with their supply. These materials are considered less vulnerable to supply disruptions and have limited economic significance. Materials categorised as having elevated levels of criticality exhibit at least one parameter with a value above the set threshold value. This implies a higher level of risk or EI associated with the supply of these materials. Although they may not be as critical as those in the high-criticality category, careful attention and appropriate management are required to mitigate their potential associated risks. The high-criticality category includes materials situated in the top right quadrant of Figure 3.2, where SR and EI values are equal to or greater than 1 and 0.4, respectively. These materials are associated with a high SR and EI. This indicates that any disruptions or constraints in the supply chain of these materials can have severe consequences for the economy, and that various industries are dependent on their availability. Figure 3.2 serves as a visual representation of this criticality assessment, clearly delineating the different categories based on the SR and EI values. Figure 3.3 enables the rapid identification of materials in the high-criticality category, which require prioritised attention and robust supply chain management strategies. A total of 20 materials have been classed as having high criticality status (including selenium, silicon and strontium); 18 have been classed as having elevated criticality status (including vanadium, gold and feldspar); and four have been classed as having low criticality status (bentonite, zinc, copper and lead) (see Figure 3.1 and Table 3.1).

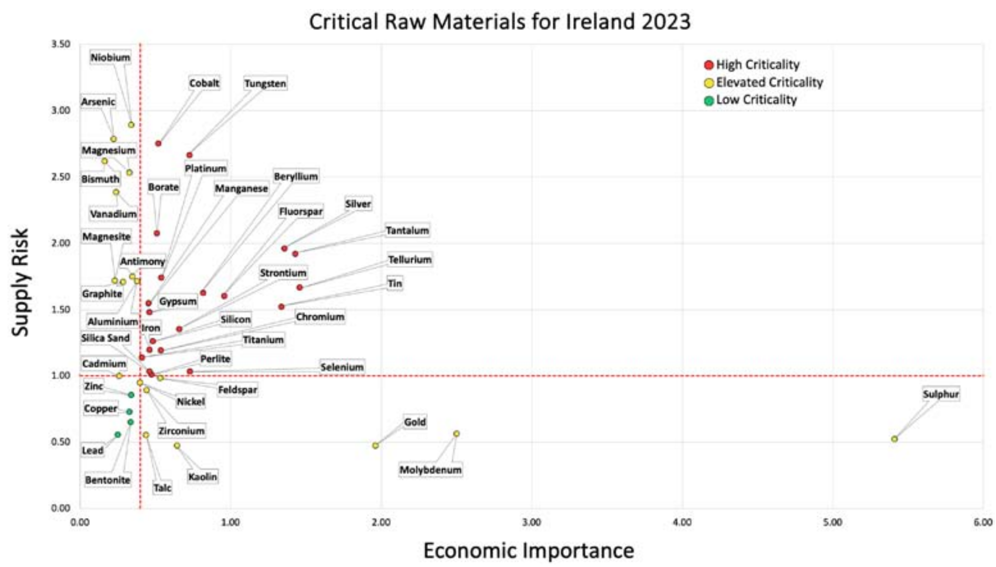

Figure 3.2. Categorical criticality assessment of raw materials for Ireland.

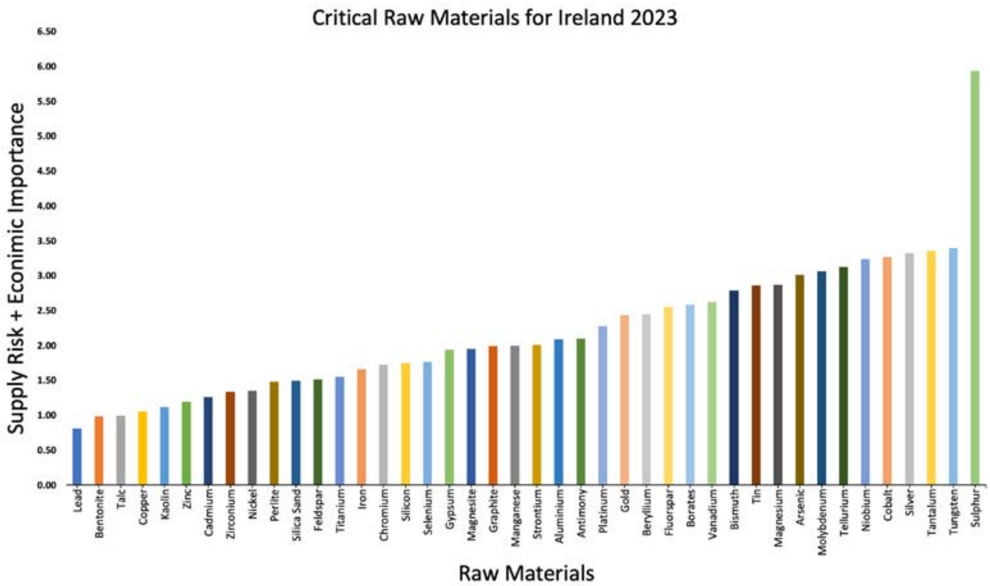

Figure 3.3. Materials ranked by summed EI and SR values.

By adapting the BGS method and utilising this criticality assessment framework, decision-makers, supply managers and stakeholders can effectively identify materials that demand heightened scrutiny and make targeted risk mitigation efforts. This approach assists in prioritising resource allocation, fostering resilience in supply chains and ensuring the uninterrupted availability of the critical materials that are essential for various sectors of the economy.

3.5 Method III – Ranking Method

We used another method based on the ranking of raw materials to present the list of critical raw materials for Ireland. This ranking method draws inspiration from the approach to representing critical raw materials set out in a study carried out in Japan (Hatayama and Tahara, 2015b). In this study, materials were ranked based on their importance across both the EI and SR categories. We have employed a similar ranking approach by summing the SR and EI values for each material. The materials are then arranged in ascending order based on the calculated sum, reflecting their criticality from least to most significant.

For Ireland, the material ranking obtained using this method indicates that lead is the least critical material, and that sulphur is the most critical material. The use of sulphur in chemical applications and refining petroleum products makes it an essential element and economically important in many industries. Figure 3.3 visually presents this ranking, offering a clear representation of the materials' relative criticality. By adopting this ranking method, we can effectively prioritise materials based on their combined SR and EI values. The summing process allows a comprehensive assessment, which takes into account both the potential disruptions in supply and the economic implications associated with each material, to be made. The ranking method provides a simplified yet informative approach to identifying critical materials in Ireland. It enables decision-makers, supply managers and stakeholders to allocate resources and devise appropriate strategies to manage and safeguard the supply chains of these critical materials. By focusing on the materials associated with high EI and SR risks, such as sulphur, proactive measures can be implemented to mitigate risks and ensure the continued availability of these materials for industries and the sectors dependent on them.

4 Summary of Raw Material Criticality Assessment Results for Ireland

The summary of 42 raw materials assessed for their criticality status in Ireland using the three developed methods is provided in Table 4.1.

Comparison of the three methods. Method I utilises adjusted thresholds for the EI of assessed materials in Ireland and the European Commission's threshold SR value, thus providing a nuanced evaluation tailored to Ireland's economic landscape while also considering similar SRs associated with these materials in the international market. Method II, which entails materials being categorised as having low, elevated or high criticality status based on specific SR and EI thresholds, offers a detailed classification. In method III, a ranking system based on combined EI and SR values is introduced, providing a simplified yet comprehensive assessment. Each method contributes unique insights while collectively enriching the understanding of raw material criticality in Ireland. The variations in approach and criteria highlight the multifaceted nature of the assessment, offering decision-makers a comprehensive toolkit for managing and safeguarding critical material supply chains in the Irish context.

Reasons for different rankings. It is noteworthy that method I's adjustments consider Ireland's size, economic nuances and supply management, leading to the establishment of a distinct ranking. In method II's categorisation, the impact of SR or EI values crossing the threshold prompts materials to shift from non-critical status to elevated criticality status and low criticality status. This highlights the importance of each raw material, emphasising a spectrum of criticality that is essential for enhancing a country's resilience. Method III's ranking, derived from combined EI and SR values, highlights specific materials such as sulphur. The differing criteria and methodologies in each method contribute to variations in rankings, showcasing the multifaceted nature of raw material criticality.

Suitability for the Irish context. Method I's adjustment for Ireland's unique characteristics enhances its suitability and provides tailored insights into raw material criticality. Method II's categorisation aligns with the need for nuanced risk assessment, offering a fine-grained understanding of raw material criticality. Method III's ranking method simplifies assessment while prioritising materials efficiently. Together, these methods cater to Ireland's context by addressing its economic challenges, allowing detailed risk management to be carried out and providing decision-makers with a range of tools to safeguard critical material supply chains.

4.1 Method III: Rank = EI + SR

Table 4.1 provides significant insights into the materials identified as being critical in method I but which obtained a lower criticality ranking when subjected to the method III criticality assessment. Notably, some materials such as iron, chromium and silica sand, deemed critical with the use of method I, exhibited lower criticality rankings with the use of method III. This highlights a crucial nuance: a material's EI may lead to it being classed as critical, but the same material having a lower overall criticality ranking with the use of method III underscores the influence of minimal-associated SRs, even if surpassing the threshold. This nuanced perspective underscores the importance of considering both the EI and SR in the comprehensive evaluation of raw material criticality.

Some raw materials were assigned non-critical status with the use of method I, but were assigned elevated criticality status with the use of method II. Notably, materials such as aluminium, antimony, arsenic, bismuth, cadmium and magnesium, initially deemed non-critical with the use of method I, were classified as having elevated criticality with the use of method II. This shift underscores the significance of method II's dual-parameter categorisation, which takes into account the fact that either the SR or EI value can influence the criticality status of a raw material.

The contingencies involved while assessing these materials are outlined in Table 4.2, along with the limitations we encountered in their analysis because of the confidentiality of the data.

Table 4.1. List of assessed materials

Material	Method I	Method II	Method III
Lead	Non-critical	Low criticality	1
Bentonite	Non-critical	Low criticality	2
Talc	Non-critical	Elevated criticality	3
Tantalum	Critical	High criticality	4
Copper	Non-critical	Low criticality	4
Kaolin	Non-critical	Elevated criticality	5
Zinc	Non-critical	Low criticality	6
Cadmium	Non-critical	Elevated criticality	7
Zirconium	Non-critical	Elevated criticality	8
Nickel	Non-critical	Elevated criticality	9
Perlite	Critical	High criticality	10
Silica sand	Critical	High criticality	11
Feldspar	Non-critical	Elevated criticality	12
Titanium	Critical	High criticality	13
Iron	Critical	High criticality	14
Chromium	Critical	High criticality	15
Silicon	Critical	High criticality	16
Selenium	Critical	High criticality	17
Gypsum	Critical	High criticality	18
Magnesite	Non-critical	Elevated criticality	19
Graphite	Non-critical	Elevated criticality	20
Manganese	Critical	High criticality	21
Strontium	Critical	High criticality	22
Aluminium	Non-critical	Elevated criticality	23
Antimony	Non-critical	Elevated criticality	24
Platinum	Critical	High criticality	25
Gold	Non-critical	Elevated criticality	26
Beryllium	Critical	High criticality	27
Fluorspar	Critical	High criticality	28
Borates	Critical	High criticality	29
Vanadium	Non-critical	Elevated criticality	30
Bismuth	Non-critical	Elevated criticality	31
Tin	Critical	High criticality	32
Magnesium	Non-critical	Elevated criticality	33
Arsenic	Non-critical	Elevated criticality	34
Molybdenum	Non-critical	Elevated criticality	35
Tellurium	Critical	High criticality	36
Niobium	Non-critical	Elevated criticality	37
Cobalt	Critical	High criticality	38
Silver	Critical	High criticality	39
Tungsten	Critical	High criticality	41
Sulphur	Non-critical	Elevated criticality	42

Method I: if the EI is ≥0.4 and the SR≥1, then the material is classed as critical.

Method II: if the EI is ≥0.4 and the SR≥1, then the material is classed as critical; if the EI is ≥0.4 or the SR≥1, then the material is classed as having elevated criticality; and if the EI is <0.4 and the SR<1, then the material is classed as having low criticality.

Table 4.2. Contingencies associated with the critical raw material assessment performed on raw materials for which full data was not available

Material	NACE Rev. two-digit	PRODCOM/CN eight-digit and six-digit and CPA five-digit and six-digit (applications)	Share (%)	Current criticality status	Comments
Antimony	C20	Flame retardants	43	Elevated	EI has a value of 0.34. Currently, 49% of the data is confidential. There is a high chance that this material will be classed as highly critical if all data is used
		Plastics	6		
Arsenic	C20	Chemicals	7	Elevated	EI has a value of 0.22. Currently, 7% of the data is confidential, and 1% has not been available since 2015. There is a low chance that this material will be classed as highly critical if all data is used
	C26	Electronics	1*		
Bismuth	C20	Chemicals	84	Elevated	EI has a value of 0.16. Currently, 93% of the data is confidential. There is a high chance that this material will be classed as highly critical if all data is used
	C32	Low-melting alloys	9		
Copper	C26	Electronics	2*	Low	EI has a value of 0.32. Currently, 21% of the data is confidential and 2% has not been available since 2015. There is a low chance that this material will be classed as elevated critical if all data is used
	C32	Manufacture, other, diverse	13		
	C32	Manufacture, other,	8		
		Consumer and general products			
Lead	C20	Lead compounds	4	Low	EI has a value of 0.25. Currently, 4% of the data is confidential. There is no chance of this material being classed as elevated critical if all data is used
Selenium	C20	Pigments	15	High	EI has a value of 0.73. Currently, 45% of the data is confidential and 10% has not been available since 2015. Using all data will not impact criticality
		Agricultural biological products	15		
		Other applications	10		
	C26	Electronics	15*		
Tellurium	C20	Chemical manufacture	10	High	EI has a value of 1.46. Currently, 10% of the data is confidential and 70% has not been available since 2015. Using all data will not impact criticality
	C26	Solar power	40*		
		Thermoelectric devices	30*		
Tin	C20	Chemicals	18	High	EI has a value of 1.33. Currently, 18% of the data is confidential and 52% has not been available since 2015. Using all data will not impact criticality
	C26	Solders	52*		
Zinc	C20	Zinc compounds (including dust and powder)	10	Low	EI has a value of 0.33. Currently, 10% of the data is confidential, and there is no chance of this material being classed as elevated critical if all data is used
Zirconium	C20	Chemicals	11	Elevated	EI has a value of 0.44. Currently, 14% of the data is confidential. Using all data will not impact criticality, as the SR threshold is low
		Pigments	3		
Bentonite	B09	Drilling specialties and drilling fluids	7	Low	EI has a value of 0.33. Currently, 20% of the data is confidential. There is a low chance of this material being classed as elevated critical if all data is used
	C11	Food and wine production	3		
	C20	Oil absorbents and others	10		

Table 4.2. Continued

Material	NACE Rev. two-digit	PRODCOM/CN eight-digit and six-digit and CPA five-digit and six-digit (applications)	Share (%)	Current criticality status	Comments
Borate	C20	Fertilisers	15	High	EI has a value of 0.51. Currently, 23% of the data is confidential. Using all data will not impact criticality
		Chemicals manufacture	4		
		Construction materials (flame retardants, plasters, wood preservatives)	4		
Feldspar	C20	Others (filler, extender, adhesive, etc.)	3	Elevated	EI has a value of 0.52. Currently, 3% of the data is confidential. Using all data will not impact criticality, as the SR threshold is low
Graphite	C20	Lubricants	6	Elevated	EI has a value of 0.28. Currently, 6% of the data is confidential. There is no chance of this material being classed as high critical if all data is used
Magnesite	C10	Agriculture (2 of 2)	7	Elevated	EI has a value of 0.23. Currently, 14% of the data is confidential. There is no chance of this material being classed as high critical if all data is used
	C20	Agriculture (1 of 2)	7		
Perlite	C11	Filter aid	24	High	EI has a value of 0.47. Currently, 24% of the data is confidential. Using all data will not impact criticality
Talc	C10	Feed	8	Elevated	EI has a value of 0.44. Currently, 32% of the data is confidential and 2% has not been available since 2015. Using all data will not impact criticality, as the SR threshold is low
	C20	Paint and coatings	20		
	C20	Fertilisers	4		
	C21	Cosmetics and pharmaceuticals	2*		
Chromium	C20	Products made of chromium chemicals	3	High	EI has a value of 0.53. Currently, 3% of the data is confidential. Using all data will not impact criticality
Cobalt	C20	Pigments and inks	13	High	EI has a value of 0.52. Currently, 42% of the data is confidential. Using all data will not impact criticality
	C20	Catalysts	12		
	C20	Tyre adhesives and paint dryers	11		
	C20	Other – biotech, surface treatment, etc.	6		
Nickel	C30	Transport (steel)	19*	Low	EI has a value of 0.39. A total of 19% of the data has not been available since 2015. There is a high chance that this material will be classed as elevated critical if all data is used
Tantalum	C20	Chemicals	12	High	EI has a value of 1.43. Currently, 12% of the data is confidential and 74% has not been available since 2015. Using all data will not impact criticality
	C26	Capacitors	40*		
	C26	Sputtering targets	20*		
	C30	Superalloys	14*		
Tungsten	C20	Catalysts and pigments	8	High	EI has a value of 0.72. Currently, 8% of the data is confidential. Using all data will not impact criticality
Vanadium	C20	Chemicals	5	Elevated	EI has a value of 0.23. Currently, 5% of the data is confidential. Using all data will not impact criticality

Table 4.2. Continued

Material	NACE Rev. two-digit	PRODCOM/CN eight-digit and six-digit and CPA five-digit and six-digit (applications)	Share (%)	Current criticality status	Comments
Gold	C26	Electronics	13*	Elevated	EI has a value of 1.96. Currently, 87% of the data is confidential and 13% has not been available since 2015. Using all data will not impact criticality, as the SR threshold is low
	C32	Jewellery	85		
	C32	Decorative and dental	2		
Platinum	C26	Electronics	2*	High	EI has a value of 0.53. Currently, 11% of the data is confidential and 69% has not been available since 2015. Using all data will not impact criticality
	C29	Autocatalyst	67*		
	C32	Jewellery, medical and biomedical	11		
Silver	C20	Catalysts	7	High	EI has a value of 1.36. Currently, 11% of the data is confidential and 42% has not been available since 2015. Using all data will not impact criticality
	C20	Photography	4		
	C21	Medicine	4*		
	C26	Electronic parts	6*		
	C32	Jewellery, silverware, recreative products	24		
	C32	Silverware	7		

***The data for these sectors is confidential and has not been available since 2015.**

5 Recommendations for National Database

To achieve a circular economy and compete with the technological advancements made by other high-income nations, Ireland must ensure sustainable access to raw materials in its manufacturing sectors. Meeting the challenges associated with resources requires a thorough understanding of raw material reserves, resource stocks, imports, exports and resource flow throughout the entire production cycle, including the waste management and recycling stages. Unfortunately, Ireland currently lacks a publicly accessible national database on reserves, resource stocks, product streams and materials. The existing national statistical information is reported using different systems, standards or codes that are not directly convertible or understandable, making it difficult to obtain specific figures on Irish resources for any given commodity. Therefore, it is crucial to improve accessibility to comprehensive and reliable data on raw materials in Ireland through online platforms.

After conducting a critical analysis and successfully developing a methodology for assessing the criticality of raw materials in Ireland, we encountered several obstacles during the research process, such as those related to the confidentiality and availability of the data. In the light of these challenges, we propose several recommendations that could be instrumental in providing valuable resources for various stakeholders, including policymakers, researchers, industries and the general public. These recommendations aim to enhance the understanding and management of critical raw materials within Ireland.

5.1 Establishment of a National Database on Critical Raw Materials

To address the need for comprehensive information on critical raw materials in Ireland, the creation of a centralised and dedicated online database is recommended. This platform would serve as a hub for gathering, organising and disseminating data on critical raw materials. This database would provide policymakers, industry stakeholders, researchers and the general public with easy access to relevant and up-to-date information and research studies. It would also would play a crucial role in raising awareness among relevant groups regarding the criticality of materials and provide insights into the global and Irish supply sourcing at stages I and II, shedding light on the importance of, and risks associated with, each material. The two key parameters for assessing the criticality of a raw material are its EI and SR. These parameters are determined based on factors such as the share of end-use, the value added to the sector, the substitution index, the EI and SR based on the World Governance Index, the HHI, the trade parameter, IR and the end-of-life recycling input rate, as illustrated in Figures 5.1 and 5.2. Unhindered access to the data on all the parameters for SR and EI will help in the establishment of a well-structured database for critical raw materials in Ireland.

Having access to these crucial parameters is essential for accurately assessing the criticality of each raw

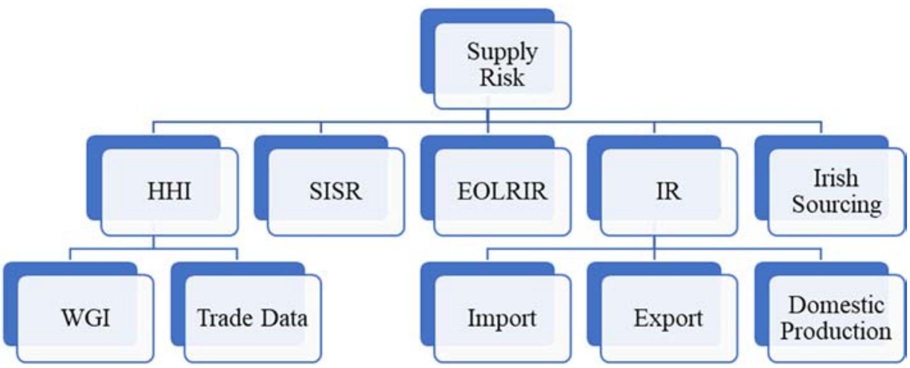

Figure 5.1. Indicators required to calculate the SR of raw materials. EOLRIR, end-of-life recycling input rate; SISR, substitution index related to SR; WGI, World Governance Index.

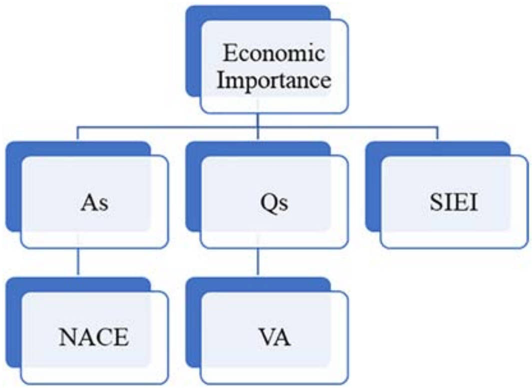

Figure 5.2. Indicators required to calculate the EI of raw materials. As, the share of end-use of a raw material in a NACE Rev. 2 (two-digit level) sector; Qs, the sector's VA at the NACE Rev. 2 (two-digit level); SIEI, economic importance-specific substitution index; VA, value added.

material in Ireland. Therefore, the establishment of a national database will provide a valuable resource for conducting comprehensive assessments and facilitating informed decision-making related to critical raw materials.

The key components of a national database of Ireland may include the following.

5.1.1 Raw material inventory

Raw material deposits. The inclusion of comprehensive information about known and potential raw material deposits in Ireland, such as their location, type, quantity, quality and accessibility.

Geological data. The incorporation of geological surveys, maps and reports that provide insights into the geology and mineralogy of raw material resources.

Exploration data. The capturing of data on ongoing exploration activities, including exploration permits, drilling results and resource estimation.

5.1.2 Production data

Mining operations. The gathering of data on active and historic mining operations in Ireland, including that related to production volumes, extraction methods and mine-specific characteristics.

Processing facilities. The inclusion of information about processing facilities and their capacities, the technologies employed and the output of processed raw materials.

5.1.3 Consumption data

Industrial sectors. The collection of data on raw material consumption by different industrial sectors in Ireland, such as construction, manufacturing, energy and electronics.

Sector-specific analysis. The conducting of a sector-specific analysis to identify the trends, patterns and drivers of raw material consumption in each sector.

5.1.4 Trade statistics

Import and export data. The capturing of information on the import and export of raw materials, including quantities, values, origins and destinations. This provides insights into Ireland's raw material trade balance and market dynamics.

Trade partners. The identification of key trading partners for raw materials and track changes in trade patterns over time.

5.1.5 Waste management information

Recycling and recovery. The European Commission's Eurostat aggregates the data from EU Member States related to the consumption of critical raw materials with respect to various waste streams, so that the recovery measures concerning critical raw material flow can be promoted by Member States.

Waste generation. This category focuses on tracking waste materials generated from the extraction, processing and consumption of raw materials. While it is important to monitor all waste materials, prioritising those enriched with critical raw materials is crucial. The criticality status, as presented in Table 3.1, aids in identifying which raw materials require more stringent monitoring.

These key components of the national database will provide a comprehensive overview of Ireland's raw materials landscape, covering the entire value chain from inventory to consumption and waste management. By incorporating such data, the database will facilitate evidence-based decision-making, resource planning and policy development in the field of raw material management.

5.2 Circular Material Use Rate

The Government of Ireland has set ambitious targets for greenhouse emission reduction, namely that it reaches 51% by 2030 and that net-zero emissions is achieved by 2050. It has been found that 45% of the greenhouse emission footprint comes from the manufacturing sector. A successful transition to a circular economy will require not only changes to systems, but also increased understanding of a circular economy's relationship to climate change among relevant stakeholders. The 12th United Nations Sustainable Development Goal is focused on "Responsible Consumption and Production". In assessing the progress towards achieving this Sustainable Development Goal, the circular material use rate (CMUR) is the most significant indicator to evaluate. It is also the most important factor in assessing the "circularity gap", which is a measure of the difference between the actual and target CMUR of a country. The CMUR measures the share of material recovered and fed back into the economy in overall material use, and is expressed as the ratio of the circular use of materials to the overall material use. Globally, the long-term target for the CMUR is 19%; however, the EU average for 2020 was 12.8%. Ireland is facing major challenges in bridging the circularity gap, as it had a CMUR of 1.8% in 2020, which was nevertheless a slight improvement from the 2019 figure of 1.6%. Ireland has set an ambitious target of having a CMUR above the EU average by 2030.

To conduct a comprehensive analysis and address Ireland's low CMUR, it is crucial to use data on material flow. The CMUR plays a critical role in assessing the criticality of raw materials and provides insights into the sustainability and resilience of resource utilisation within the circular economy framework (Circular Economy Monitor Flanders, undated). It measures the extent to which raw materials are recycled, reused or remanufactured instead of being discarded as waste. A high CMUR indicates efficient resource utilisation, reducing the need for new extractions and minimising the strain on scarce resources. This, in turn, reduces the vulnerability associated with resource depletion and enhances the sustainability of material supply chains. By promoting circularity, therefore, it is possible to mitigate the criticality of raw materials. With this in mind, it is essential that the CMUR of every raw material used in Ireland is made available online. This would enable the identification of opportunities for resource efficiency, waste reduction and the development of efficient circular economy practices.

The CMUR is expressed as the ratio of the circular use of materials (U) to the overall material use (M). The factors required to calculate these values are presented in Figures 5.3 and 5.4.

Material inputs. This refers to the total quantity of raw materials or inputs used in a given period, including both primary and secondary materials.

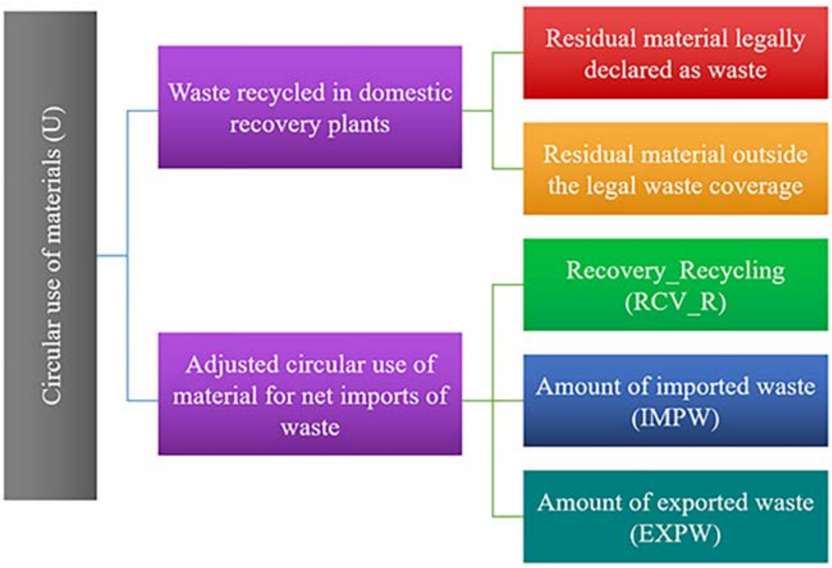

Figure 5.3. Data fields required to calculate the circular use of materials (U).

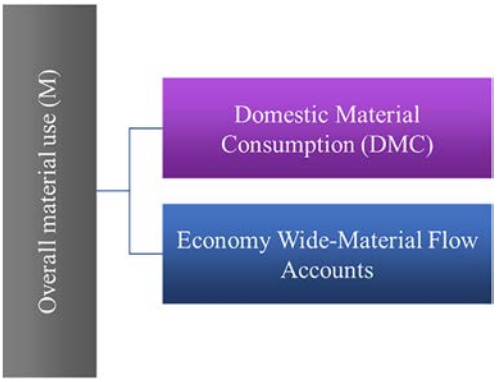

Figure 5.4. Data fields required to calculate the overall material use (M).

Recycled material. The quantity of materials that are recycled or recovered from waste streams and reintroduced into the economy.

Reused material. The quantity of materials that are reused or repurposed without undergoing significant processing.

Remanufactured material. The quantity of materials that are remanufactured or refurbished to extend their useful life.

Material outputs. This includes the quantity of materials that become waste, such as materials that are discarded or disposed of.

5.3 Material Flow Analysis

Material flow analysis (MFA) is an evaluation method that leverages data from material flow accounts to measure the efficiency of material utilisation (Guyonnet *et al.*, 2015). This analysis helps in the identification of the inefficient use and wastage of natural resources and other raw materials in an economy, which may not be easily identifiable through conventional economic monitoring systems. For a more comprehensive understanding of each material's journey, complete analyses spanning from production to utilisation should be readily accessible online, empowering relevant stakeholders and individuals to make informed decisions.

MFA serves as a tool for assessing and quantifying the flow of materials within the functional systems, whether at the country, regional or manufacturing sector level. It enables a comprehensive understanding of how resources are consumed, how waste is generated and what impacts these processes have on the environment. This is made possible by a detailed picture of how elements enter, move through and leave the system. MFA involves tracing the physical flows of raw materials from mining or production through various stages of end-use and actual consumption, to their final disposal and recycling by considering both direct and indirect processes. In addition, MFA can be deployed at different scales, from small operations or for small institutions to large operations on a national or international scale (OECD, 2008).

The MFA tool has a variety of significant capabilities, as outlined in Figure 5.5, that are particularly important for the understanding of material flow and its implications for sustainable resource management, some of which are described below.

Quantifying material flows. MFA calculates the amounts of different materials flowing through a defined system, which may encompass the entire economy of a country or a specific sector, such as the manufacturing industry. It measures material flows in physical units (e.g. kilograms, tonnes) and is able to represent them in flow charts to visualise material movements. MFA can locate key material sources, conversions, losses and destinations, and provide information on resource efficiency and waste generation.

Resource efficiency. The MFA system provides a broader monitoring scope for the identification of material-related inefficiencies and losses to highlight opportunities for resource conservation and waste reduction. This broader scope can help in identifying the resource consumption hotspots for policymakers and industries, which could in turn be used to develop targeted strategies to maximise material use and minimise waste generation.

Circular economy. MFA makes it possible to understand and promote the concept of the circular economy. It provides a complete picture of how materials are flowing and defines the possible prospects for recycling or recovery, which can lead to the identification of ways to reduce dependencies on the primary resources and contribute to the design of an efficient recycling system.

Environmental implications. MFA helps in the assessment of the environmental impact of material extraction, production and disposal. MFA also helps in the identification of environmentally significant

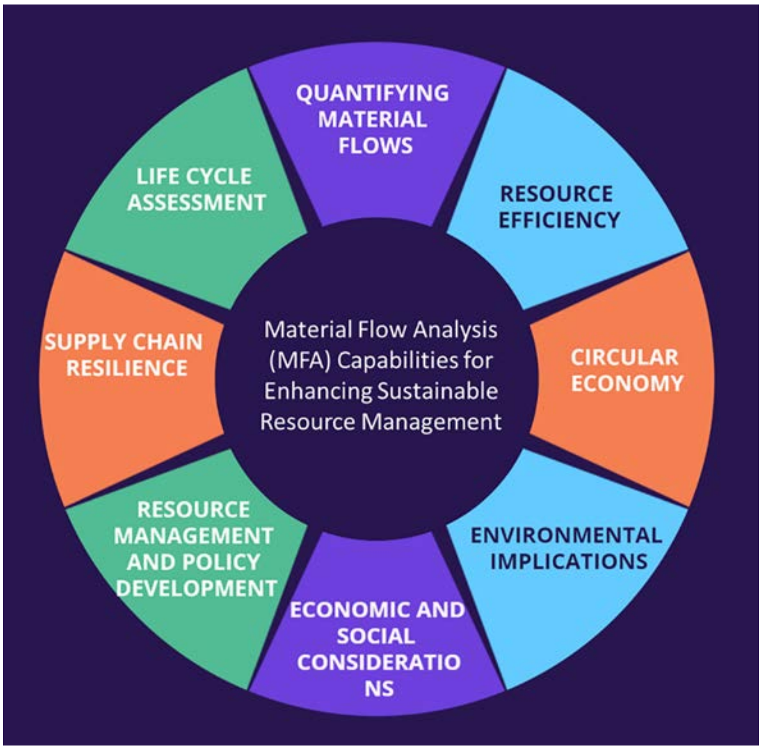

Figure 5.5. Navigating sustainable resource management: MFA and its powerful capabilities.

activities, such as excessive resource consumption, CO_2 emissions and pollutant hotspots. MFA can also help in the identification of ways to improve resource efficiency, reduce environmental impact and transition to a circular economy.

Economic and social considerations. In addition to environmental aspects, MFA can also provide insights into the economic and social aspects of material flows. It can aid in evaluations of the economic value and contribution of various materials and industries, determination of job prospects and study of the material performance related to economic performance. MFA promotes the assessment of the social importance and EI of resource use, waste generation and recycling operations.

Resource management and policy development. MFA provides important information for resource management and policy development and helps in the identification of physical dependencies, vulnerabilities and potential bottlenecks in the supply chain. An MFA can drive policies and strategies related to resource conservation, waste management, recycling and sustainable production. It can also help in the setting of relevant goals, evaluation of progress and identification of areas for action.

Supply chain resilience. Supply chain resilience refers to the ability of a system to withstand and recover from disruptions or uncertainties while continuously maintaining operations and meeting demand. In the context of MFA, supply chain resilience examines the robustness and vulnerability of the material supply chain, from the extraction of raw materials to their final use and disposal. By understanding the flow of materials and potential bottlenecks within the supply chain, MFA enables policymakers and industries to strengthen supply chain networks and ensure the stable and efficient flow of critical resources.

LCA. The LCA is a systematic analysis that evaluates the environmental impacts of a product, process or service throughout its entire life cycle. This assessment considers all stages: raw material extraction, manufacturing, transportation, product use and end-of-life disposal or recycling. In the context of MFA, LCA becomes a complementary tool, enabling the detailed data on material flows obtained through MFA to be utilised so that a comprehensive understanding of a product's environmental footprint can be gained. By integrating MFA data into the LCA, decision-makers can obtain a more accurate and holistic view of the environmental impacts associated with material utilisation and waste generation. This integration helps in the identification of hotspots in the life cycle of a product, which are the stages in a product's life cycle at which resource inefficiencies or environmental burdens are at their most significant. Armed with this knowledge, policymakers and industries can make informed decisions to optimise material choices, production processes and end-of-life options, with the aim of producing more sustainable and environmentally friendly products.

5.4 Considerations for the Knowledge Base, Similar to the European Raw Materials Knowledge Base and Raw Materials Information System

The EU Raw Materials Knowledge Base (EURMKB) is a part of the European Innovation Partnership's strategic implementation plan. Its primary objective is to serve as a comprehensive and centralised platform for accessing all relevant information on raw materials within the EU (EC, undated a). The EURMKB aims to be a one-stop shop, serving as a valuable source of data for industry stakeholders and policymakers. It works in collaboration with EU Member States to gather data from various sources and store, maintain, upgrade, analyse and disseminate information related to raw materials. It acts as a repository of knowledge, providing data on raw materials that is easily accessible and up to date. By centralising this information, the EURMKB facilitates efficient and informed decision-making for policymakers. The EURKMB stores data pertaining to a wide range of raw materials and relevant data associated with them. It includes geological surveys, exploration reports, production statistics, reserves estimates and other relevant information (EC, undated a). The data it provides helps in understanding the availability, characteristics and potential uses of raw materials within the EU. The EURKMB conducts analyses and provides insights on raw materials, supporting evidence-based decision-making and strategic planning. It also contributes to the development of better policies, fosters innovation and promotes resource efficiency within the EU.

The Raw Materials Information System (RMIS) is a comprehensive database that provides information on raw materials, their availability and utilisation, and other relevant data. It serves as a centralised platform for stakeholders to access accurate and up-to-date information related to raw materials, enabling informed decision-making and resource management. The RMIS collects and stores data on various raw materials and information on their geological characteristics, reserves, extraction methods, processing techniques and potential applications. It also provides data on the availability of raw materials, including their reserves globally and nationally. The RMIS tracks supply and demand dynamics, import/export patterns and consumption trends. It provides information on recycling initiatives, circular economy practices and waste management strategies (EC, undated b). The RMIS helps in the visualisation of data in interactive maps and graphs. It also helps facilitate data sharing and fosters partnerships among government agencies, researchers and relevant stakeholders.

The national database for Ireland is predicted to be a vast source of knowledge that can help researchers in better understand the criticality of raw materials and their availability to various industries and also enable the use of consistent standards throughout Europe.

6 Conclusions

The CIRCLE project marks a significant advancement for Ireland, as it entailed the compilation of the first critical raw materials list by assessing 42 raw materials important to Ireland's industrial sectors. The identification of the raw materials that hold critical importance for a country empowers policymakers and industries to develop effective strategies for enhancing resource efficiency. The information collected and provided by the CIRCLE project's criticality assessment has unlocked valuable insights that could be used to advance Ireland's progress towards a sustainable future.

The methodology adopted for the criticality assessment was largely based on the European Commission's 2017 framework, which incorporates two major indicators: SR and EI. This approach enabled a comprehensive evaluation of each candidate raw material's significance in the context of Ireland's economy, industrial needs and risks associated with the supply of material. It is considered that each material is important for a country's economic sustainability. Therefore, the CIRCLE project has taken a holistic approach and presented the critical raw material list through three methods, all of which are regularly used in different regions and countries in the world. The first method, identifying raw materials as critical when both EI and SR values surpass a specific threshold, offers a straightforward categorisation. Considering the relatively small size of Ireland's economy, its EI threshold value was set as 0.4 (compared with the European Commission EI threshold value of 2.8). The SR threshold remained unchanged at 1, as the SRs were similar for the EU region and Ireland. Out of the 42 raw materials, 20 were identified as critical for Ireland. The second method entailed materials being assigned to one of three criticality categories based on the crossing of threshold values for EI and SR, designating 20 raw materials as having high criticality status (both EI and SR threshold crossed), 18 as having elevated criticality status (either the EI or SR threshold crossed) and four as having low criticality status (neither the EI nor SR threshold crossed). The third method, the ranking approach, was used to sort materials according to the sum of their calculated EI and SR values, offering a clear hierarchy from the most critical to the least critical.

The CIRCLE project sets the stage for a proactive, informed and sustainable resource management approach by introducing the critical raw material list for Ireland. This list is a valuable tool for decision-makers, fostering a dynamic interplay between economic development and environmental sustainability. As industries in Ireland are moving towards digital transformation, these criticality assessments gain even greater significance. The ability to leverage data-driven insights, coupled with circular economy principles, will enable Ireland to optimise material use, reduce waste and promote a more resilient and climate-friendly society.

In conclusion, the CIRCLE project is a pioneering initiative that will enable Ireland to be a leader in sustainable resource management. Armed with the knowledge of critical raw materials, Ireland is equipped to forge a path towards a truly resilient and circular economy. By embracing these insights and coupling them with digital transformation, Ireland is well positioned to build a future in which economic prosperity and environmental consciousness can coexist harmoniously, ensuring a better world for generations to come.

7 Future Recommendations

Looking ahead, the CIRCLE project's insights offer valuable directions for future research, driving Ireland's resource efficiency and sustainability pathway. One crucial recommendation is to establish a national database on critical raw materials. This comprehensive database should be accessible to industries, academia, the Government of Ireland and the public, with a dedicated section on critical raw materials. By facilitating strategic decision-making and reducing IR, this database will enhance Ireland's resource security and economic resilience. Another significant recommendation is the integration of CMUR data into this national database. This metric is essential for tracking progress towards Ireland's ambitious greenhouse gas emission reduction targets, waste reduction targets and overall climate change targets. Understanding the circularity of materials and its impact on resource efficiency will inform targeted circular economy initiatives, fostering a greener future. Integrating MFA within the national database will also provide valuable insights into material flows and resource consumption. Informed decision-making based on MFA findings will drive effective waste reduction strategies and promote optimal resource utilisation across supply chains. In addition, the establishment of knowledge bases similar to the EURMKB and the RMIS is recommended. Such knowledge bases will enable Ireland to share best practices, exchange knowledge and collaborate with other Member States on European-level initiatives. By leveraging this collective expertise, Ireland could accelerate its progress towards a circular and resilient economy. Considering the existing responsibilities of the CSO in providing raw materials import and export data to Eurostat, we suggest that the CSO takes the lead in establishing and maintaining the national database on critical raw materials. With its established infrastructure and expertise, the CSO is well positioned to manage the data integration seamlessly.

Incorporating these recommendations into research efforts will empower Ireland to progress towards a more sustainable and resource-efficient future. By promoting data accessibility, circular practices and collaborative research, Ireland can emerge as a leader in global sustainability efforts, and leave a lasting positive legacy for future generations.

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Abbreviations

BGS	British Geological Survey
CIRCLE	Critical Raw Materials for Ireland for a Resource-Efficient Economy
CMUR	Circular material use rate
CSO	Central Statistics Office
EI	Economic importance
EURMKB	EU Raw Materials Knowledge Base
GVA	Gross value added
HHI	Herfindahl–Hirschman index
IR	Import reliance
LCA	Life cycle analysis
MFA	Material flow analysis
NACE	Statistical Classification of Economic Activities in the European Community
NRC	National Research Council
RMIS	Raw Materials Information System
SR	Supply risk

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
> Sceitheadh fuíolluisce uirbigh;
> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
> Foinsí radaíochta ianúcháin;
> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
> Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
> Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
> Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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