# Metals in the Twin Transition

## Regional Emissions in EU metal-technology pathways

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# Contents

# Executive summary

The EU's twin transition, coupled with the Critical Raw Materials Act, will drive a sharp increase in metal use and industrial activities related to these sectors. Five value chains (electric vehicles, electricity networks, solar photovoltaics, wind power and electronics) will be responsible for over 90% of the increase in metal demand in Europe by 2030. The growing demand for metals may increase associated environmental impacts, including potentially harmful metal water emissions. The understanding and regulation of industrial water emissions is a critical priority in the EU due to their potential widespread environmental and public health impacts.

This report aims **to assess the additional water metal emissions from the increase in demand for key metals driven by the Twin Transition and CRM Act by 2030**. It also analyzes **the relevance (magnitude) of such water emissions in the regional EU context**.

To that end, TNO (Dutch Organization for Applied Research) developed a multi-step approach while considering relevant characteristics of the (non-ferrous) metals industry and key value chains in the twin transition. This assessment focuses on Battery Electric Vehicles (EV), wind turbines, databases and servers, solar Photovoltaics (PV) and electricity networks, given their importance in achieving EU climate and digital targets and their role in current and future metal demand. Within these value chains, copper, nickel, zinc, lithium, gallium and Rare Earth Elements are considered. For the metal demand, this report builds mainly on the previous work: "Metals for Clean Energy (MCE): Pathways to solving Europe's raw materials challenge report". Metal emissions are assessed under a value chain perspective while considering the most relevant metal emissions to the value chains in scope and their relevance to the EU (non-ferrous) metal sector and industry. This report focuses on the increase in domestic activities and associated water metal emissions in Europe (the European Union + 8 countries) by 2030 driven by the value chains in scope.

The EU+8 domestic **additional water metal emissions** from the increase in metals demand for EVs, wind turbines, database and servers, PV and electricity networks between 2020 and 2030 are 0.28 $t_{emitted}$/year for copper, 1.13 $t_{emitted}$year for nickel, 1.53 $t_{emitted}$/year for zinc, 0.002 $t_{emitted}$/year for gallium and 95.8 $t_{emitted}$/year for lithium. EVs contribute the largest to the increase in water metal emissions. For Rare Earth Elements, there is insufficient data available to estimate additional metal water emissions.

The increase in emissions (releases) from the additional metals demand for the value chains in scope compared to major industrial activities across Europe is 0.4% for copper, 1.0% for nickel and 0.3% for zinc. No emissions (releases) data are registered for lithium and gallium for a consistent comparison.

The increase in **regional concentrations compared to the natural background concentrations, and the measured reasonable worst-case environmental concentrations** is in all cases less than 0.1% for copper, nickel and zinc. Lithium's regional increase in freshwater concentrations is 17.9% compared to the **natural background concentration** and 6.5% for the measured **reasonable worst-case concentration**. **The added risk from the additional metal's predicted environmental concentrations** compared to the predicted no-effect environmental concentration of the four metals is lower than 0.01 for copper, nickel, lithium and zinc. For gallium, there is no data available for such a consistent assessment.

We conclude that the increase in metal emissions driven by the value chains in scope is low for copper, nickel and zinc when compared to the annual metal emissions from the industrial activities related to the metals in scope. Lithium emissions are expected to increase as there are currently no lithium-related activities in the EU + 8. The increase in regional concentrations driven by the value chains in scope is low for copper, nickel and zinc. For lithium, the increase in regional concentrations exhibits a higher increase. However, the added risk from the predicted environmental concentration is lower than 0.01 for all metals, suggesting a limited risk increase to the environment under the assessed conditions. For gallium, there is no data available for a consistent assessment.

# 1 Introduction

The European Union (EU) is prioritizing digital and green transitions in many sectors (including the metal sector) to overcome climate change, reduce energy dependence, and enhance economic and strategic resilience. The European Green Deal and the EU's Digital Strategy are central to this effort, collectively known as the "Twin Transition" (Salvi et al., 2022). This initiative aims to foster innovation in digital technologies while accelerating the adoption of sustainable technologies like renewable energy generation. Critical Raw Materials (CRMs) are key to enabling the Twin Transition. CRMs are the foundation of renewable energy technologies and digital innovations. For example, copper is used in solar panels, while Rare Earth Elements (REEs) such as neodymium are crucial for wind turbines and gallium for semiconductors (Carrara et al., 2023; IEA, 2024).

The supply of CRMs (mostly metals) poses challenges due to their scarcity, limited supply chain diversification in sourcing and refining, geopolitical dynamics, and environmental impacts from extraction and processing. The EU has established the CRMs act (European Commission, 2024) to overcome the above-mentioned challenges and ensure a secure and sustainable supply of CRMs. In addition, the CRM Act has set the following benchmarks to reduce dependency on external sources and promote sustainable practices:

- The EU extraction capacity is capable of extracting the ores, minerals or concentrates needed to produce at least 10 % of its annual consumption of strategic raw materials, to the extent possible in light of the EU's reserves;
- The EU processing capacity, including for all intermediate processing steps, is capable of producing at least 40 % of the EU annual consumption of strategic raw materials;
- The EU recycling capacity, including for all intermediate recycling steps, is capable of producing at least 25 % of the Union's annual consumption of strategic raw materials and is capable of recycling significantly increasing amounts of each strategic raw material from waste;
- Diversify the EU imports of strategic raw materials to ensure that, by 2030, the annual consumption of each strategic raw material at any relevant stage of processing can rely on imports from several third countries or overseas countries or territories (OCTs) and that no third country accounts for more than 65 % of the EU's annual consumption of such a strategic raw material.

Implementing the CRM Act will likely increase the industrial activities related to its benchmarks. It is suggested that five value chains (electric vehicles, electricity networks, solar photovoltaics, wind power and electronics) will be responsible for over 90% of the increase in metal demand in Europe by 2030 (Gregoir & van Acker, 2022). The growing demand for metals to support key value chains in the EU may increase associated environmental impacts, including potentially harmful emissions. While these activities aim to strengthen the EU's industrial base and support the green transition, they could inadvertently conflict with the EU's zero pollution vision for 2050. The EU has established the Zero Pollution Plan to regulate harmful industrial emissions, promoting cleaner practices and sustainability in the metals and critical raw materials industry (European Commission, 2021). This plan has provided specific targets for 2030 and a recent evaluation of the Industrial Emissions Directive (IED), focusing on revising the EU rules on industrial emissions. This includes relevant EU industrial sectors such as the production and processing of the (non-ferrous) metals industry and their related metal (and their compounds) emissions.

The regulation of industrial water emissions is a critical priority in the EU due to their potential widespread environmental and public health impacts, as well as to assure the proper functioning of ecosystem services. Water metal emissions can spread widely through freshwater ecosystems, reaching regions beyond the release source. This contrasts with other compartments such as soil, where metal emissions typically bind to particles and remain localized, or air, where they eventually settle out into other compartments (Weldeslassie et al., 2018). Metals in water are more bioavailable, potentially creating a risk to biodiversity and human health (de Paiva Magalhães et al., 2015). Generally, there is also often greater regulatory scrutiny about industrial water emissions than in other compartments. The EU has implemented strict legislation in the last decades, including the Water Framework Directive (WFD), which mandates member states to prevent and reduce pollution in water bodies and achieve good chemical and ecological status. Additionally, water emissions-related data on a European level is consistently better documented, particularly for freshwater systems (Santos et al., 2021). Hence, this report focuses on water emissions.

Therefore:

This report aims to *assess the additional water metal emissions from the increase in demand for key metals driven by the Twin Transition and CRM Act by 2030.* In addition, *it also analyzes the relevance (magnitude) of such water emissions in the regional EU context*.

To that end, TNO (Dutch Organization for Applied Research) developed a multi-step approach while considering relevant characteristics of the (non-ferrous) metals industry and key value chains in the Twin Transition. This assessment focuses on Battery Electric Vehicles (EV), wind turbines, databases and servers, solar Photovoltaics (PV) and electricity networks, given their (1) importance in achieving EU climate and digital targets and (2) their role in current and future metal demand. The selection of metals and, consequently, metal water emissions is carried out based on (1) the metals relevant to the value chain mentioned above and (2) their relevance within the EU (non-ferrous) metal sector and industry.

This assessment is commissioned by Eurometaux. Eurometaux is the European industry association that represents the non-ferrous metals industry. Its members include companies and national associations involved in producing, processing, and recycling of non-ferrous metals such as aluminium, copper, zinc, nickel, cobalt, lithium, Precious metals, REEs and lead. The association serves as a platform for data collection, dialogue and advocacy, aiming to promote the interests of the non-ferrous metals sector within the EU. Eurometaux's purpose is to ensure that the European non-ferrous metals industry remains competitive, sustainable, and resilient, contributing to the region's overall economic growth and development.

# 2 Research approach

## 2.1 General Approach

The multi-step approach consists of six consecutive steps, each building upon the previous one (see Figure 2.1). The following sections describe each step in detail. The assessment scope focuses on the most relevant technologies driving metal demand, three production stages and seven metals. The selection of key technologies, products and strategic metals is based on the 2030 metal demand (Gregoir & van Acker, 2022) and alignment with industrial expertise (Eurometaux) on metal relevancy for the EU non-ferrous metal sector. A summary of the technology/product/metal scope is depicted in Table 2.1. The temporal scope of the assessment is up to 2030, and the geographical scope includes the EU – 27, with the addition of Albania, Bosnia and Herzegovina, Cyprus, Montenegro, North Macedonia, Norway, Serbia and the United Kingdom (UK). The geographical scope is selected based on the location of relevant projects and operations related to the non-ferrous metal sector and twin transition. The geographical scope is referred to in this report as EU + 8.

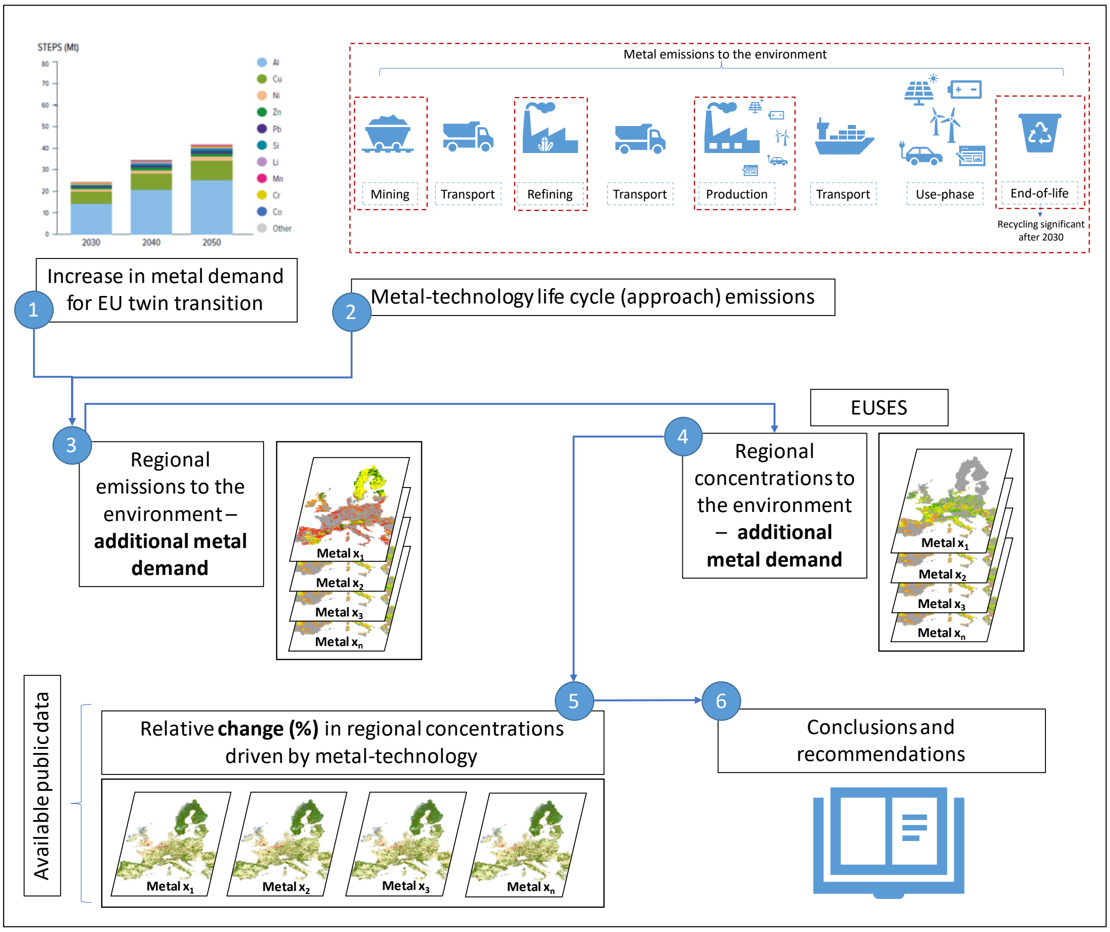


Figure 2.1: Multi-step approach.

Table 2.1: Technologies, products and metals included in the assessment

| Technology[1] | Reference product | Metals in scope |
|---|---|---|
| EVs | Battery cathodes | Copper (Cu) |
| Wind turbines | Permanent magnets (mainly NdFeB) | Nickel (Ni) |
| Database and servers | Semiconductors | Zinc (Zn) |
| PV | | Lithium (Li) |
| Electricity networks | | Gallium (Ga) |
| | | Dysprosium (Dy) |
| | | Neodymium (Nd) |

[1] These five value chains account for more than 90% of the increase in metal demand anticipated for 2030, driven by renewable and digital technologies.

This assessment focuses on a value chain perspective in which metal emissions to freshwater (further called water) are assessed under a life cycle approach for the selected metal-technology pathway combination. Note that in this report, the "life cycle approach" refers to the scope that covers multiple stages across the technology value chains, specifically focusing on the metal emissions to water from the activities within the defined scope. Metal emissions to water are accounted for only the activity in itself (e.g., mining or processing). Other potential sources of metal water emissions, such as machinery production for mining activities or processing, are outside the scope (for more information, see section 2.1.2.). Results are provided holistically while considering the main steps of each technology value chain from mining up to (reference product) production. For example, the wind turbine value chain included the mining and processing of rare earth elements (e.g., dysprosium) and the production of permanent magnets. The composition of each metal technology pathway is presented in Table 2.2. The Li-ion battery recycling stage is also considered for the EV value chain. Results are also presented from a metal activity-related and regional contribution perspective.

Table 2.2: Text Metals-technologies pathways composition based on (Carrara et al., 2023; Gregoir & van Acker, 2022)

| Technology | Reference product | Metals in scope |
|---|---|---|
| EV[1] | Battery cathodes | Copper (Cu), Nickel (Ni), Zinc (Zn), Lithium (Li), Gallium (Ga), Dysprosium (Dy) and Neodymium (Nd) |
| Wind turbines | Permanent magnets (mainly NdFeB) | Copper (Cu), Nickel (Ni), Zinc (Zn), Dysprosium (Dy) and Neodymium (Nd) |
| Database and servers | Semiconductors | Copper (Cu), Nickel (Ni), Zinc (Zn), Gallium (Ga), Dysprosium (Dy) and Neodymium (Nd) |
| PV | N.A | Copper (Cu), Nickel (Ni), Zinc (Zn), Lithium (Li) and Gallium (Ga) |
| Electricity networks | N.A | Copper (Cu) and Zinc (Zn) |

[1] Zinc in EVs is primarily used in the car's body structure and battery housing, not in the batteries themselves. As a result, the demand for zinc in EVs is more related to a substitution demand for the zinc used in internal combustion engine (ICE) cars rather than potentially creating additional demand for new battery technologies.

### 2.1.1 Step 1: Metal demand for the twin transition.

The technologies metal demand is retrieved from the "Metals for Clean Energy (MCE): Pathways to solving Europe's raw materials challenge report" (Gregoir & van Acker, 2022). This report contains the metal requirements to achieve two different energy transition scenarios as described by the International Energy Agency (IEA)[1]. The Sustainable Development Scenario (SDS) is a reference for this step as it largely aligns with Europe's clean energy technology requirements (Gregoir & van Acker, 2022) and offers a medium energy demand scenario. The medium energy scenario reflects that the announced political ambitions are successfully met. Despite the uncertainty in how the energy transition may develop, the largest difference between energy demand scenarios occurs after 2030 (beyond the temporal scope of this study). All technology's metal demands are present in the MCE study except for databases and servers. For database and servers, the metal demand is retrieved from the "Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study by the European Commission Joint Research Center (JRC)" (Carrara et al., 2023). Given that the JRC study provides only a low and high-demand scenario, an average scenario between low and high is assumed to align with the SDS medium energy MCE scenario.

Note that this study builds strictly on the MCE and JRC studies for metal requirements and compositions across each selected energy technology/product by 2030; refer to the studies mentioned above for more information about metal requirements and compositions. It is worth noting that given recent events and market trends, the demand for these metals and end-use estimates in the MCE and JRC studies may vary from the starting reference points.

In order to understand the effect of additional metal emissions from the increase in demand for key metals driven by the Twin Transition and CRM Act, it is required to analyze the current and potential (2030) locations of mines, processing facilities (smelter and refining) and production sites (cathodes[2] for batteries, permanent magnets and semiconductors) in the EU + 8. This process is crucial to understanding the relationship between EU capacity for the mentioned activities, metal demand in 2030 and current and potential metal emissions to water. The EU + 8 current (2020-2021) and potential (2030) capacity for mining and processing of copper, nickel, zinc and lithium is retrieved from the MinesSpans database (McKinsey, 2021). Potential sites and capacities in 2030[3] for mining, processing of dysprosium, neodymium and gallium (a by-product of mining and processing of other metals) and production/capacity facilities of batteries cathodes, batteries recycling, permanent magnets and semiconductors are retrieved under an extensive (literature/news/data portals) review of announced projects and data available on the MCE (Gregoir & van Acker, 2022) study. The data on potential facilities for all metals are corroborated with each project owner's webpage and experts from the industry (Eurometaux and Eurometaux members). To illustrate the extent of this review, more than 200 web sources, such as the "Battery atlas" and the "Copper Production and Trade mapping system," were double-checked for the metals and value chain steps (projects) in scope.

### 2.1.2 Step 2: Life cycle approach water metal emissions.

Value chain metal emissions to water are assessed on a ton/year basis while considering a life cycle approach including mining, processing (smelting and refining), reference product

[1] For more information see IEA (2021), World Energy Outlook 2021, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2021
[2] In this report, the use of cathodes strictly refers to cathodes for batteries
[3] Note that for these metals there are currently no mining or processing operations in the EU

production (e.g., battery cathodes) and end-of-life (recycling) activities (see Figure 2.2. Other value chain steps, such as transport and use-phase, are not considered. Metal emissions to water from the different activities are limited to copper, nickel, zinc, lithium, gallium, dysprosium and neodymium; and are only considered for the freshwater compartment as emissions to other compartments can be, in comparison, limited. Furthermore, metal emissions are considered only for the domestic (EU + 8) activities incurred (current and planned) to meet the metal supply for these technologies. Other potential sources of metal water emissions related to the activities, such as machinery production, fall outside the assessment scope. Note that currently (and up to 2030), the actual recycling of metals is carried out within the same metal manufacturing facilities (Forsén et al., 2017; Kania & Saternus, 2023). To illustrate, the smelting and refining of copper, depending on the facility, is carried out with an input of primary (concentrate) material, secondary (scrap) material, or both. Therefore, in the metal sector, the end-of-life (recycling) for the metals in scope occurs within the manufacturing-refining (processing) step, and thus, it is addressed as such, except for the recycling of Li-ion batteries, which is considered a separate step.

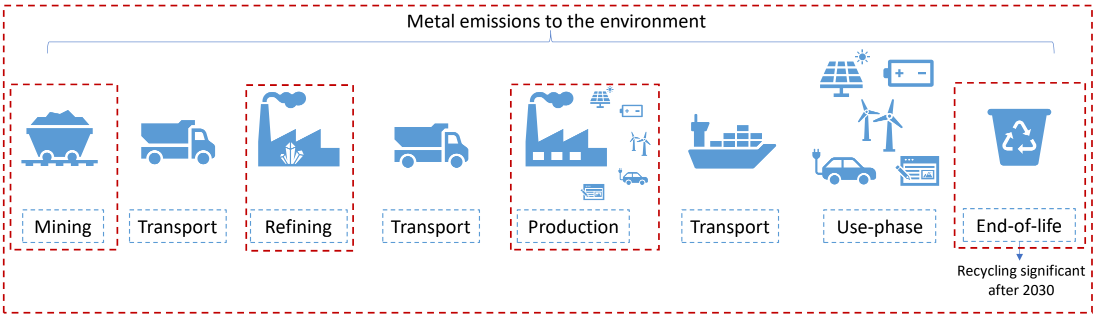


Figure 2.2: Value chain steps considered in this assessment for each technology/metal pathway combination.

Metal Emissions Factors (EFs) are selected following a hierarchical approach, and EFs are selected based on industry representatives' data. A preference is given to publicly available EFs provided by the industry, given that those represent (to a larger extent) the current technologies and value chain activities carried out (or to be implemented) in the EU +8. When EFs are not publicly available from the industry, life cycle inventory databases are used.

### 2.1.2.1 Industry Emissions Factors

The industry has provided EFs for the EU + 8 representative zinc mining and processing characteristics (Four Elements Consulting, 2023) battery cathode production (**further called cathodes**), lithium hydroxide production, and gallium-related activities. For cathodes, the EFs are indicative proxies from pilot cathode plants outside the EU, which are expected to improve further with the maturing of the plant and plant management experience (Umicore, 2024). For lithium hydroxide, EFs are representative of Lithium Hydroxide Monohydrate (LHM) production from spodumene in Albemarle's Australia and China facilities, and similar technology is expected to be applied and improved in the EU + 8 projects, leading to potential lower EFs (Albemarle, 2024). Figure A 1 in Appendix a presents a scheme of this process.

There are no specific gallium EFs related to semiconductor production. However, the semiconductor production industry requires ultrapure quality substrates (e.g., gallium arsenide - GaAs). Due to its unique properties, gallium arsenide (GaAs) is a crucial material in semiconductor production, and only a few producers can produce ultrapure GaAs quality globally. Therefore, gallium EFs are considered from the ultrapure quality of GaAs substrate (**further called Ga substrate**) production required for producing semiconductors rather than the production of the semiconductors (EU gallium sector, 2024).

The industry has also provided measured emissions for copper mining and processing and zinc mining and processing (International Copper Association, 2024; International Zinc Association (IZA), 2024). These emissions are measured and reported under the national Pollutant Release and Transfer Register (PRTR) scheme on an annual basis within EU (and some outside EU) related operations. Note that a few operations related to the mining and processing of copper and zinc in the EU + 8 are not covered.

## 2.1.2.2 Life cycle inventory database Emissions Factors

The remaining EFs are retrieved from ecoinvent. This database is selected since it is considered one of the world's most consistent and transparent life cycle inventory databases (Wu & Su, 2020) and for data accessibility/licensing motives. The ecoinvent database supports environmental assessments of products and processes worldwide, covering a diverse range of sectors with more than 20,000 datasets modeling human activities and processes. Ecoinvent includes a wide geographical representation of activities (European, country-specific and worldwide). In addition, the ecoinvent database contains specific activities related to mining, metal processing (smelting and refining), reference product production and recycling.

Compared to other databases, such as the Specific Environmental Release Factors (spERCS) used in the European Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), ecoinvent offers EFs for metals outside the specific scope of each metal-related activity. For example, in spERCS, only the EF of copper is available for copper processing. However, copper production can also result in water emissions of other metals such as nickel and zinc.

The selection of ecoinvent activities is based on an extensive review of each activity's data availability, description and scope. A detailed list of the activities and their description considered in this study is presented in Table b.1 in Appendix b. For mining activities, they rarely occur for one specific mineral, and ores generally come with different shares of metallic elements. The ecoinvent metals mining processes involve ores with different mineral content and average metal-specific metal content. Therefore, emissions factors are rescaled to consider the metal content described in each ecoinvent mining activity to reflect emissions on a metal content level. For example, the mining activity of copper contains an average of 26.7% of copper concentrate. The ecoinvent database contains relevant activities such as cathodes, permanent magnets, semiconductors production, and battery recycling, but it lacks any EF for the metals in scope, except for copper and nickel from batteries recycling (hydrometallurgy process).

GaBi (developed by Sphera) is another widely applied LCI inventory database. GaBi offers detailed and region-specific data, often sourced directly from industrial partners. GaBi offers updated data for compliance and market-specific assessments. Nevertheless, in some cases, the close link to industries can limit the flexibility of data applications given the proprietary nature of the data. This can make it challenging for users to understand the assumptions behind specific data points (Hauschild et al., 2018). To overcome this, the industry has directly shared the EFs representative of their activities (present in the GaBi database but not yet updated in the ecoinvent database, e.g., zinc-related processes).

### 2.1.2.3 Specific Environmental Release Factors

Another method to estimate metal emissions is by applying release factors to estimate the water emissions of metal processing as done by spERCS. However, these release factors are only for the processing step and can be applied to the metal in the scope of the activity. The methods and EFs from spERCS are present in Appendix c.

Given the data availability and differences in EFs between databases, and to maintain consistency, the regional contribution to water emissions is presented, mainly following the EFs shared by the industry and when an EF is not available from the industry, EFs from ecoinvent are applied. It is assumed (as a proxy) that all Li-ion battery recycling facilities carry out the hydrometallurgy process for the batteries recycling stage, given that it is the only EF available. However, battery recycling facilities can go through other pyrometallurgy or dry processes. Note that despite the selected EFs scope, there are still data gaps that cannot be currently assessed in terms of the scoped value chain stages, technologies, and metal emissions. For example, there are no EFs available for the mining of dysprosium, neodymium gallium or lithium in the EU from the metals in scope. Partially explained by the current lack of related activities domestically. Table 2.3 includes the EFs applied in this assessment. A comparison and discussion between EFs from the different sources and measured emissions is carried out and presented in Appendix d.

Table 2.3: Emission factors according to activity type and database. The green activities are included in this study.

| Source | Activity type in the database | Emission/Release Factor (EFs) $kg_{emitted}/kg_{produced}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Cu | Ni | Li | Zn | Ga | Dy | Nd |
| Industry data | Lithium hydroxide production | | | 1.00E-03 | | | | |
| | Zinc mining | 1.51E-07 | 1.67E-07 | | 8.59E-07 | | | |
| | Zinc smelting and refining | 8.11E-08 | 1.63E-08 | | 3.57E-06 | | | |
| | Cathodes production (pilot - average) | | 5.50E-07 | 5.05E-05 | | | | |
| | Ultrapure quality of Ga substrate production | | | | | 2.00E-03 | | |
| | | | | | | | | |
| Ecoinvent[1] | Copper mining | 2.37E-07 | 7.29E-07 | | 2.27E-06 | | | |
| | Copper smelting and refining | 2.5E-07 | 9.9E-08 | | 4.0E-07 | | | |
| | Nickel mining | 2.82E-07 | 1.72E-05 | | 2.82E-07 | | | |
| | Nickel smelting and refining | 5.87E-07 | 2.36E-07 | | 9.46E-07 | | | |
| | Lithium mining/brine extraction | | | | | | | |
| | Lithium hydroxide production | | | 1.54E-02 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zinc mining | 1.06E-05 | 3.20E-07 | | 4.99E-04 | | | |
| | Zinc smelting and refining | 2.63E-07 | 3.67E-10 | | 3.68E-06 | | | |
| | Gallium mining | | | | | | | |
| | Gallium processing | | | | | | | |
| | Rare earth element mining | | | | 3.64E-05 | | | |
| | Rare earth element refining | | | | | | | |
| | Cathodes production | | | | | | | |
| | Permanent magnet production | | | | | | | |
| | Semiconductors production | | | | | | | |
| | Li-ion battery recycling (Hydrometallurgy) | | | | | | | |
| | Li-ion battery recycling (Hydrometallurgy) | 1.65E-08 | 1.65E-08 | | | | | |
| | | | | | | | | |
| Industry measured emissions | Copper mining (average) | 1.02E-06 | | | | | | |
| | Copper smelting and refining (average) | 4.55E-06 | | | | | | |
| | Zinc mining (average) | | | | 3.19E-06 | | | |
| | Zinc smelting and refining (average) | | | | 8.58E-06 | | | |
| [1] Note that ecoinvent EFs are rescaled and presented to metal content | | | | | | | | |

### 2.1.3 Step 3: Regional contribution.

Following Step 1, the location of current and potential (2030) facilities for mining and processing (smelting and refining) of copper, nickel, zinc, lithium, dysprosium, neodymium and gallium are processed and mapped under a geographic information system environment to derive location-specific emissions. The same process is applied to facilities related to battery cathode production, battery recycling, and permanent magnet production. For semiconductors, only the locations that process ultrapure quality gallium substrates for semiconductor production are considered. Other facilities that process gallium or GaAS wafers are not included. The location of each facility is corroborated and approximated spatially explicitly with databases (e.g., the battery atlas[4]), each project owner's webpage, and industry experts (Eurometaux and Eurometaux members).

[4] See more in https://battery-news.de/en/battery-atlas/

The regional water emissions contribution is obtained by multiplying each facility's current and potential (2030) capacity by the corresponding emission/release factor from Step 2. Note that only one facility in EU + 8 produces ultrapure quality gallium substrate for semiconductor/wafer applications. In addition, the domestic increase in production to meet demand is challenging to forecast given market shits, efficiency gains, new applications, etc. The European domestic production (capacity) of gallium substrates for semiconductor/wafer applications is expected to increase by 50% between 2020 and 2030 (EU gallium sector, 2024), and this increase is considered in the assessment.

The regional water emissions contribution is related to the total output of each facility, which can be related to different sectors. Therefore, the expected shares of metal use (as determined in step 1) per value chain, as well as the Global Critical Minerals Outlook 2024 (IEA, 2024) and the MCE (Gregoir & van Acker, 2022), are utilized to attribute the share of water emissions ascribed to the value chains in scope.

Table 2.4 shows the metal demand shares applied to allocate the share of water emissions to the value chains in scope. It is assumed that all (potential) projects and current facilities across the geographical scope supply the technologies and base demand with the same share regardless of location. This is assumed given the unfeasibility of gathering information on the end user for each metal facility in the EU + 8. Note that for ascribing specific shares while considering market dynamics, imports/exports of (semi) intermediates and competition between sectors fell outside this assessment's scope and were therefore not considered.

For gallium, there is no specific share (%) data on a European level for the manufactured semiconductors/wafers containing gallium substrates. In addition, the demand data provided in the MCE (Gregoir & van Acker, 2022) and JRC (Carrara et al., 2023) did not consider European base demand. Therefore, the shares in Table 2.4 for gallium are spread over the European demand data for the manufactured semiconductors/wafers containing gallium substrates value chains in scope as provided in the MCR and JRC studies.

Table 2.4: Shares of Europe metal demand for the considered technologies over time.

| Technology | Copper (%) | | Nickel (%) | | Lithium (%) | | Zinc (%) | | Dy and Nd (%) | | Gallium (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2020** | **2030** | **2020** | **2030** | **2020** | **2030** | **2020** | **2030** | **2020** | **2030** | **2020** | **2030** |
| PV | 0 | 0.9 | 0 | 0.004 | | | 0 | 1.6 | | | 0 | 3.9 |
| Wind | 0.8 | 1 | 1.4 | 1.6 | | | 0.1 | 0.1 | 51.7 | 34 | | |
| E. networks | 2.9 | 3 | 0 | 0 | | | 0.1 | 0.1 | | | | |
| EVs | 2.6 | 20.8 | 0 | 17.7 | 100 | 100 | 0.7 | 7 | 39.7 | 63.7 | 94.5 | 95.3 |
| Data storage and serves | 0.1 | 0.1 | 0.2 | 0.2 | | | <0.1 | <0.1 | | | 5.5 | 0.8 |
| Base demand + other [1] | 93.6 | 74.2 | 98.4 | 80.5 | | | 99.2 | 91.2 | 8.6 | 2.3 | | |

[1]Base demand includes other sectors such as infrastructure, transport and construction. For more information, see Metals for Clean Energy: Pathways to solving Europe's raw materials challenge.

### 2.1.4 Step 4 and 5: Regional concentrations and relative change

Two main steps are carried out to put the additional water metal emissions from the increase in demand for copper, nickel, zinc and lithium in 2030 in an EU regional context; gallium is not included, given insufficient data to assess concentrations (see below):

- Step 1: The predicted Environmental Concentrations (PECs) in the freshwater compartment, caused by additional water metal emissions from the increase in demand for copper, nickel, lithium and zinc in 2030, are quantified with the European Union System for the Evaluation of Substances (EUSES) model for the generic regional scale. The generic regional scale scenario in EUSES assumes as a worst-case scenario that emissions are not spread well over the EU, allocating 10% of all additional emissions at the regional scale.

- Step 2a: The additional metal-specific regional PECs are compared with empirical metal concentrations in Europe via three scenarios. In the first scenario (scenario 1), the empirical concentrations are assumed to resemble the natural background situation. In the second scenario (scenario 2), the empirical concentrations are assumed to resemble a reasonable worst-case situation. In the third scenario (scenario 3), PECs are compared with Predicted No-Effect Concentration (PNEC) values.

- Step 2b: Extra water emissions due to the increase in demand for the selected metals in Europe are compared with current point source emissions to freshwater from major industrial activities across Europe.

Results from steps 2a and 2b are presented as a percentage increase compared to the current situation. Furthermore, a sensitivity scenario is presented in Appendix e, in which the regional PEC was calculated for a specific country with the highest contribution to the additional water metal emissions.

#### 2.1.4.1 Predicted Environmental Concentrations

The EUSES framework is applied to quantify the PEC of the additional water metal emissions from the increase in demand for metals in 2030. The European Commission designed the EUSES framework to conduct risk assessments posed by chemical substances to human health and the environment. It is a widely used framework that helps perform environmental risk assessments of chemical substances within the EU, ensuring that the evaluation of chemical substances aligns with EU regulations (Mazmudar et al., 2022). EUSES integrates a series of parameters that simulate the behavior of chemical substances in various environmental compartments such as air, water, soil, and sediment (European Commission, 2004). It performs a tiered risk assessment that can range from basic screening to more detailed evaluations depending on the data availability and the risk profile of the substance[5]. However, the tiers do not include a bio-availability correction as an option foreseen in REACH and applied in the REACH registration files for copper, nickel and zinc.

In EUSES, Kd values (the partitioning coefficients) are key parameters to quantify the PEC of metals. Kd values describe the metal partition between water and suspended solids or sediment. Furthermore, they steer the transport and fate of a chemical substance in the freshwater compartment (water column). Kd values for suspended solids and sediment for

[5] For more information see EUSES - European Union System for the Evaluation of Substances - ECHA

copper, nickel, zinc and lithium were retrieved from the European Chemicals Agency (ECHA)[6] database and are present in Table e.1 in Appendix e. There are no Kd values available for gallium.

EUSES generally applies the "10% rule", assuming that 10% of the total emission of a substance is emitted to the regional scale (and the remaining 90% to the continental scale). The 10% rule is the default reasonable worst case in the EUSES framework. It is an approach widely applied for initial screenings for risk assessments when chemical substance emissions are new and distribution data is not available. It provides a baseline for comparing different chemical substances under the same assumptions (Kim et al., 2024). In this assessment, the PECs for copper, nickel, zinc and lithium are simulated considering the default 10% rule. EUSES provides output on regional and continental scales. The regional assessment is used by default in chemical risk assessment. Given the scope of the assessment, continental PECs are only presented present in Table e.1 in Appendix e.

### 2.1.4.2 Comparison with relevant databases

*2.1.4.2.1 Concentrations*

The simulated PECs of the additional water metal emissions from the increase in demand for key metals in 2030 are compared with concentrations from the Forum of European Geological Surveys (FOREGS)[7] database (scenario 1), with concentrations from the Metal Environmental Exposure Data (MEED)[8] (scenario 2) and with PNEC values in the ECHA database (scenario 3). All databases provide empirical concentrations and PNECs for total (none bioavailability corrected) copper, nickel, zinc, and lithium, presented in Table e.1 in Appendix e.

**Natural background concentrations**

The FOREGS database provides information on the distribution of various chemical substances in Europe. It provides a baseline on (geochemical) natural background concentrations of chemical substances in the environment without significant influence from human activities (Salminen et al., 2005). These concentrations are essential for distinguishing between naturally occurring and elevated levels due to anthropogenic sources. We assumed that the geometric mean of all the country-specific median concentrations of a specific metal in FOREGS represents a reasonable value for the natural background concentration of that metal. The natural background concentration refers to a concentration with no or limited human activities in Europe.

**Reasonable worse-case concentrations**

MEED provides the regional PEC based on recent and historical monitoring data that are publicly accessible (Heijerick et al., 2023). The MEED derives Reasonable Worst-Case (RWC) ambient PEC values for specific regions considering the geometric mean value of all 90$^{th}$ percentiles that have been derived for individual European countries. The 90$^{th}$ percentile is the value below which 90% of the data falls. It provides a central measure of the upper value across datasets and helps to understand typical high-end values across locations. This value was derived for the purpose of risk assessment. Ideally, for this study, PEC regional values could be derived from the geometric mean of all 50$^{th}$ percentiles, as it would provide the central tendency of the concentrations caused by a combination of natural background conditions and human activities. However, data is not available for the 50$^{th}$ percentile, and PEC values are only present for the RWC.

[6] For more information see ECHA CHEM, data was acceced on 18-11-2024
[7] For more information see Foregs - Geochemical Baseline Database: Instructions
[8] For more information see MEED (Metals Environment Exposure Data ) program - REACH Metals Gateway

The quantified PECs of the additional water metal emissions from the increase in demand for key metals are compared with both databases as they provide a better context. To illustrate, if the comparison is only carried out with FOREGS, it can lead to an overestimation of the relevance of the additional concentrations for the metals in scope, given that FOREGS provides natural background concentrations in the environment without significant influence from human activities, which is not typical for European freshwater bodies (Wolfram et al., 2021). In contracts, comparing the additional concentrations for the metals in scope only to MEED could lead to an underestimation as, currently, MEED provides the RWC (based on empirical concentrations).

**Predicted no-effect concentration**

The PNEC is a parameter used in environmental risk assessment to estimate the concentration of a substance below which it is expected to pose no adverse effects on the environment. It is commonly used in regulatory frameworks such as REACH and guidance is provided by organizations like ECHA. The PNEC is typically derived from ecotoxicological data, and it is compared with PEC to calculate a Risk Characterization Ratio (RCR = PEC/PNEC). An RCR > 1 indicates a potential risk. Here, we compared the increase in the PEC caused by the additional activities with the PNEC as a risk-oriented indicator (ΔRCR = ΔPEC/PNEC). PNECs for copper, nickel, lithium and zinc are retrieved from the ECHA database (ECHA chemicals database, 2020, 2022, 2023, 2024).

##### *2.1.4.2.2 Releases from point sources*

The additional water metal emissions (releases) for the metals in scope are also compared to the European Pollutant Release and Transfer Register (E-PRTR) database[9]. The E-PRTR is a public database that provides detailed information on major industrial activities across Europe, focusing on the release and transfer of pollutants. The E-PRTR is the EU's official database for tracking the release of pollutants into air, water, and land (EEA, 2022). It covers the release data of substances for major industrial sectors such as energy, metals and chemical sectors. Data is (historically) available for copper, nickel, and zinc and is presented in Table e.1 in Appendix e. There is no data available for lithium and gallium. The comparison is done with the most recent (2022) data entry for water emissions of copper, nickel and zinc of all large point sources in Europe.

### 2.1.5 Step 6: Conclusions and recommendations.

In the final step, conclusions and recommendations are provided and discussed.

[9] For more information see European Industrial Emissions Portal

# 3 Results and discussion

## 3.1 Metal demand for the Twin Transition

Figure 3.1 shows the increase in metal demand for the selected metal technology combination in Europe. EVs production is the main driver of overall metal demand between 2020 and 2030, followed by electricity networks and PV. EVs account for approximately 83% of the total metal demand increase. Regarding a single metal demand and absolute mass, copper increases significantly from 237 kton in 2020 to 1276 kton in 2030. Zinc and lithium also show an increase between 2020 and 2030, with both metals' demand surpassing 200 kton on an annual basis. Note that the demand for zinc in EVs is related to some extent to a substitution demand for the zinc used in ICE cars rather than potentially creating additional demand for new battery technologies. In terms of relative change, dysprosium and neodymium exhibit the largest increase. Dysprosium shows a 92-fold increase, while neodymium shows a 38-fold increase between 2020 and 2030. In 2020, data storage and servers drive the demand for dysprosium and neodymium, while in 2030, the majority of the demand is driven by EVs and wind (permanent magnets). Gallium demand increases from 0.002 kton in 2020 to 0.024 kton in 2030 (a 12-fold increase). While gallium is present in PV, data storage and servers, the largest share of gallium demand in 2030 is driven by EVs. Copper showed the largest increase in metal demand on an absolute mass basis; however, it exhibits a 5-fold increase on a relative basis. It should be highlighted that the material intensity (mass/installed capacity) of dysprosium, neodymium, and gallium within the selected technologies is considerably lower than that of base metals such as copper and zinc.

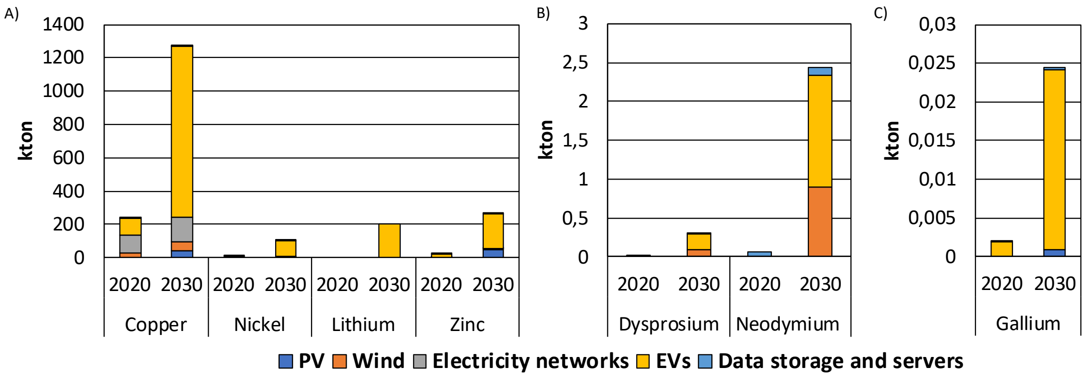


Figure 3.1: EU overall metal demand for 2020 and 2030 is for A) copper, nickel, lithium, and zinc, B) dysprosium and neodymium, and D) gallium. The figure is split into three graphs for display purposes to account for the differences in magnitude between metals.

As shown in Figure 3.2, demand for all metals and sectors (base demand[10] and selected technologies) is expected to increase between 2020 and 2030. The current domestic supply deficit is also expected to continue and increase by 2030 for most metals, given the lack of sufficient metal production facilities/projects. Note that Figure 3.2 is directly related to processing capacity and not mining capacity, given the lack of data to connect (local) mine supply (and secondary feedstock) with processing locations. In addition, the supply of these

[10] Base demand includes other sectors such as infrastructure, industry and transport. For more information see Metals for Clean Energy: *Pathways to solving Europe's raw materials challenge.*

facilities can follow complex value chains, with feedstock being sourced not only from European sources but also from global mines. The metal demand for the selected technologies is expected to add pressure to the base demand (all sectors besides transition technologies) for copper, zinc and nickel. Base demand includes sectors such as infrastructure, trasnport and industry, and it increases over the years, especially for copper and nickel. Between 2020 and 2030, the share of copper demand from the selected technologies over the total demand increases from 6.5% to 25%, and for nickel, it increases from 1.5% to 20%. There is a considerable demand increase for the other metals, lithium, dysprosium, neodymium, and gallium, which are mostly driven by EVs.

Concerning metal domestic supply, there are currently no concrete plans for new projects for refining copper and zinc, only expansions to some extent. In recent years, European smelters and refineries, especially for zinc, copper and nickel, have been squeezed by high energy prices and global competition (Ma et al., 2022; Regueiro & Alonso-Jimenez, 2021; Sgaravatti et al., 2023). This has led to (temporary) shutdowns or holding operations, such as the zinc smelter and refinery in Budel, The Netherlands. A similar trend is seen for mining operations. Most announced projects expected to be online by 2030 are related to battery and wind supply chains, lithium and nickel, and rare earth minerals (dysprosium and neodymium) mining and refining for permanent magnet production. For example, there is only one project expected to be online for the production of rare earth elements in Europe (Sweden), providing 720t neodymium/praseodymium oxides and 250t dysprosium annually for the production of permanent magnets (Gregoir & van Acker, 2022). The current and potential supply of gallium for the production of semiconductors/wafers will depend upon imports, as there are no domestic projects in the pipeline to extract it. The current domestic production related to gallium value chains focuses on processing ultrapure quality GaAs substrate for semiconductors/wafers applications.

Lithium is the only metal in which the domestic supply could meet the demand by 2030. However, the supply of lithium by 2030 is uncertain, given that several processing facilities are linked to the opening of domestic mining operations (e.g., the Jadar mining project, Echassieres mining project, or Zinnwald mining project). Most of these mining operations are currently being debated, and it is uncertain whether they will become operational before 2030.

The EU will continue to rely on imports of metals and products to satisfy the energy and digital transition. Note that, for example, the demand for dysprosium and neodymium is directly related to the production of permanent magnets, and such supply chains occur at a product level rather than at a metal level. To illustrate, Europe imports permanent magnets and not refined REEs (Rizos et al., 2022). The additional demand for some metals and, consequently, new domestic projects is mainly directly related to the selected value chains. For example, the production of lithium for EV batteries and the production of dysprosium and neodymium for permanent magnets. Meeting the metals demand for copper, nickel and zinc for the selected technologies with EU metal production is complex as they compete with other sectors. For example, EVs and electricity networks are already produced domestically, and this trend is expected to continue in the following years (Gregoir & van Acker, 2022); therefore, a shift in metal supply for specific sectors can occur. This progression in demand between sectors is considered for the allocation of regional water emissions driven by each value chain between 2020 and 2030.

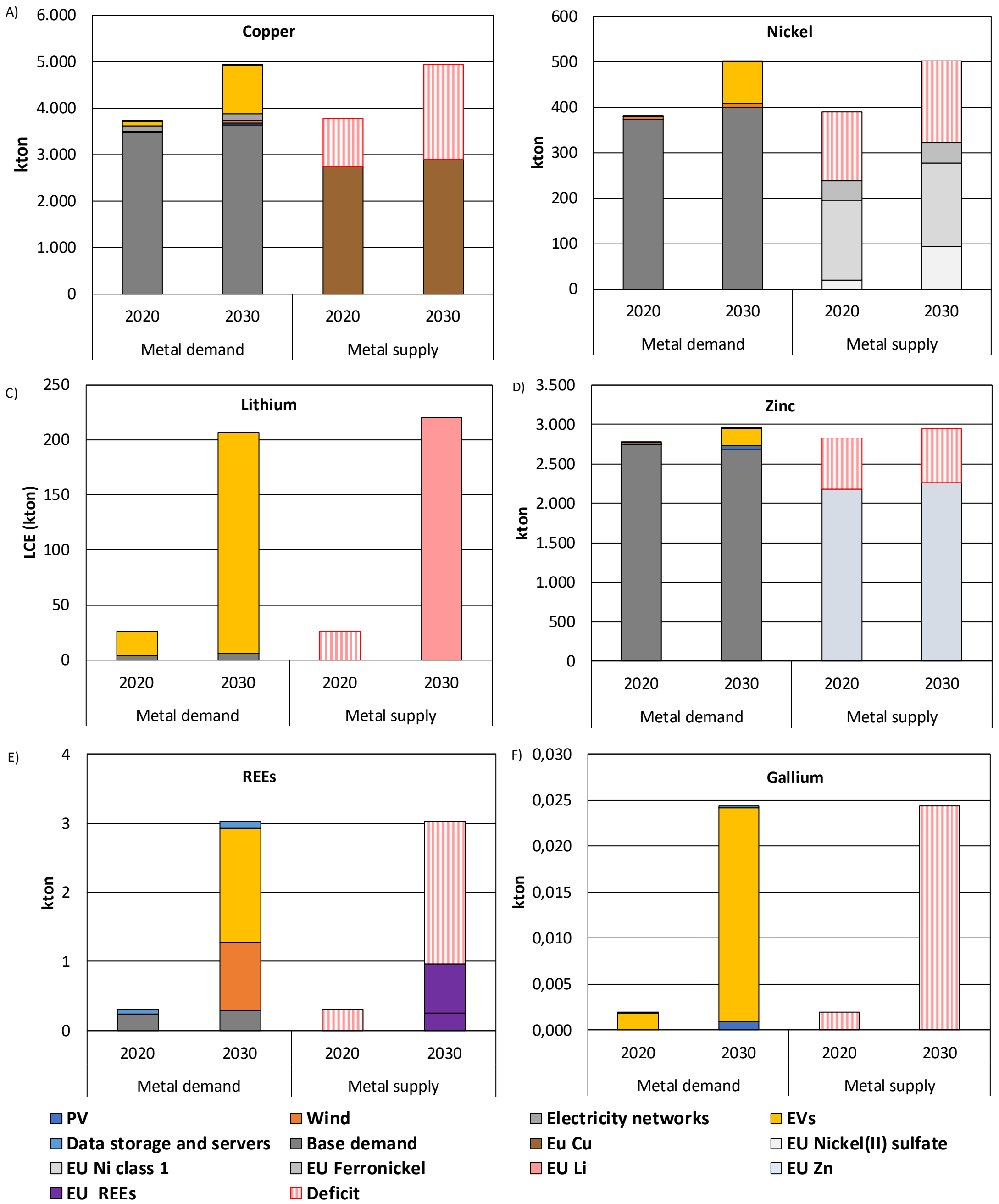


Figure 3.2: EU metal demand A) Copper, B) Nickel, C) Lithium, D) Zinc, E) Rare Earth Elements (Dysprosium and Neodymium) and F) Gallium for the selected technologies and base demand for 2020 and 2030; and EU metal supply (refined) for 2020 and 2030.

# 3.2 Life cycle emissions

## 3.2.1 Activity-related metal emissions (total domestic supply)

Figure 3.3 shows the overall metal water emissions in the EU + 8 disaggregated by metal-related industry and activity, and Figure 3.4 provides the contribution of each activity to the total. Note that these figures reflect the domestic (EU + 8) water emissions from the different activities related to the metal current and expected supply for the value chains in scope and base demand. Lithium emissions are considerably higher than any other metal and will increase by approximately 95.8 $t_{emitted}$/ year between 2020 and 2030. The share of lithium emissions is driven by cathode production and the processing of lithium to lithium hydroxide. No emissions have been reported from lithium mining. There is a general lack of information regarding water lithium emissions/releases (Bolan et al., 2021). However, lithium emissions can increase with the opening of new mines in the EU + 8 (as considered in this study) (Chow, 2022).

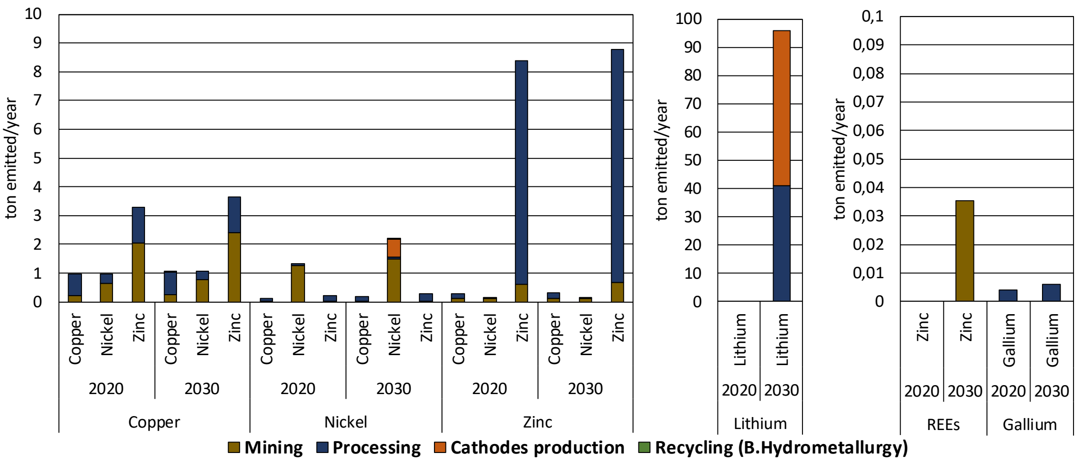


Figure 3.3: EU + 8 metal water emissions per metal-related industry disaggregated by activity for copper, nickel, REEs, and gallium, zinc and lithium. Note that three graphs with respective scales are presented for illustration purposes, given the unit difference. These figures reflect the domestic water emissions from the different activities related to the metal current and expected supply for the value chains in scope and base demand.

**Copper:** The water metal emissions for the copper (mining + processing + battery recycling) related industry increases by 0.06 $t_{emitted}$/ year for copper, 0.12 for nickel $t_{emitted}$/ year and 0.37 for zinc $t_{emitted}$/ year between. Although all mining and processing activities related to copper result in copper, nickel, and zinc water emissions, copper mining results in more zinc and nickel emissions in water than copper itself. For the copper-related industry, the share of copper water emissions is driven by the processing of copper (80%), while nickel and zinc water emissions, respectively, are driven more by mining activities (approximately 60%) (see Figure 3.4). The share of copper emissions in 2030 related to battery recycling is considerably low when compared to other activities (see Figure 3.4). Over time, the copper industry's water emissions increase are driven by the expansion and opening of a few copper mining projects, such as the expansion of the Altic mine in Sweden. There are no new projects in the pipeline for copper processing. EFs from copper mining are relatively similar between ecoinvent and average measured emissions reported by the industry (International Copper Association, 2024), while average reported copper emissions from copper processing are higher but in the same order of magnitude as the EFs from ecoinvent (see Figure d.1). Note that each industry metal sector only reports emissions for their metal in scope. Therefore, it is not feasible to compare other metal emissions besides the one in scope of each industry.

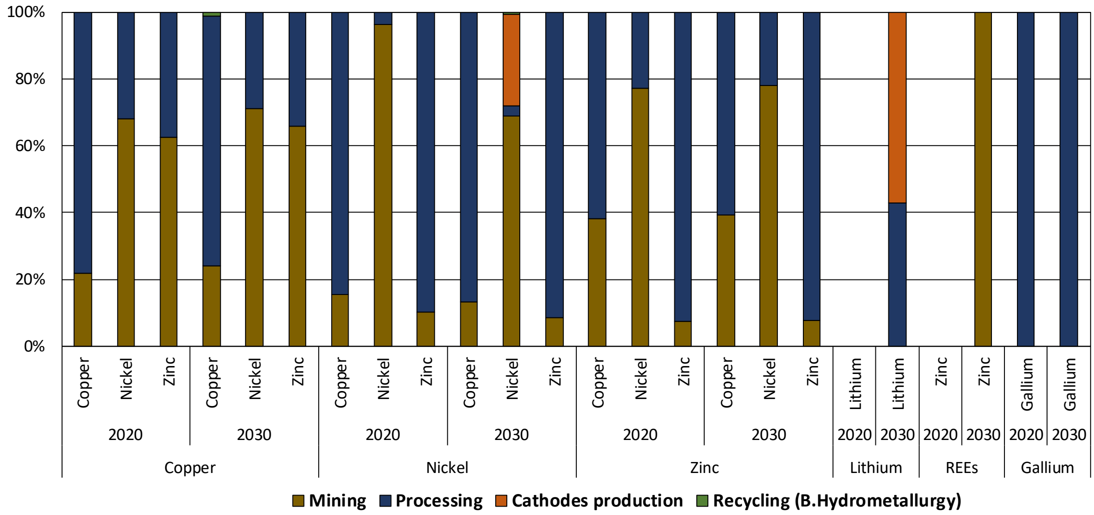


Figure 3.4: EU + 8 contribution of metal emissions per metal-related industry disaggregated by activity

**Nickel:** For the nickel-related industry, the increase in water metal emissions for copper (0.05 $t_{emitted}$/ year) and zinc (0.08 $t_{emitted}$/ year) is relatively low between 2020 and 2030 when compared to nickel (0.86 $t_{emitted}$/ year) (see Figure 3.3). The increase in nickel water emissions is mainly driven by the opening of new projects related to cathode production, which contribute to 0.6 $t_{emitted}$/ year of the total increase in nickel water emissions. By 2030 almost 30% of the total nickel water emissions are driven by cathode production, while the contribution of nickel emissions from battery recycling is minimal. On an absolute basis, most nickel water metal emissions are driven by activities related to nickel mining, while for copper and zinc water emissions, the contribution is higher from nickel processing (see Figure 3.4). There was no data available to compare industry-reported nickel mining and processing emissions in the EU + 8 with ecoinvent EFs.

**Zinc:** The increase in water metal emissions in the zinc-related industry between 2020 and 2030 is 0.02 $t_{emitted}$/ year for copper, 0.01 $t_{emitted}$/ year for nickel and 0.37 $t_{emitted}$/ year for zinc (see Figure 3.3). Most of the zinc water emissions are related to zinc processing and a small share to zinc mining (see Figure 3.4). The opposite tendency is seen for nickel water emissions, in which mining-related activities contribute more. Zinc water emissions increase over time, given the potential expansion of processing facilities and opening of new mines such as the Matsa mine (Spain) and the Olympias - Phase 3 (Greece) mines. Figure d.1 shows that EFs for zinc mining and processing based on industry representatives' data (Four Elements Consulting, 2023) are slightly lower than the average reported zinc emissions from zinc mining and processing (International Zinc Association (IZA), 2024). EFs from ecoinvent related to zinc mining activities are considerably higher than those from other data sources, while the zinc processing EFs between data sources are similar.

**Rare Earth Elements:** As shown in Figure 3.3, zinc water emissions from REEs related industry increase by 0.04 $t_{emitted}$/ year between 2020 and 2030. There are no direct REEs (dysprosium and neodymium) EFs related to REE mining, processing and permanent magnet productions. The existing literature has emphasized the methodological challenges, significant uncertainty and general lack of knowledge regarding the potential environmental effects of REEs production over the entire value chain (Bailey et al., 2020; Golroudbary et al., 2022; Schreiber et al., 2021). Nevertheless, opening new mines and refining facilities in the EU + 8 could increase REEs water emissions.

**Gallium:** Gallium water emissions from the production of GaAs for semiconductors/wafer application increase by 0.0019 $t_{emitted}$/ year between 2020 and 2030 (see Figure 3.3). The increase in water emissions is driven by the potential increase in domestic production to meet end-user applications. Given the lack of data, there are no EFs for other gallium value chain stages. In addition, gallium is not typically mined directly because it is not found in large concentrations (Lu et al., 2017). Instead, it is a by-product of extracting other metals, particularly aluminum (bauxite) and zinc. Thus, deriving gallium EF to water from gallium extraction can be complex. Furthermore, no projects are currently or expected by 2030 for the extraction of gallium in the EU + 8.

### 3.2.2 Regional contribution

Figure 3.5 shows the aggregated shares (%) of overall metal water emissions on a county basis. Only countries with a representative contribution (equal or higher contribution than 5% for the relevant year) are presented in the graph. The countries with a lower contribution are grouped in "Others". The are small regional variations between 2020 and 2030 for copper and zinc. Few mining and processing projects in the pipeline are expected to be online before 2030. As shown in the previous section, the aggregated copper emissions were driven to a larger extent by processing activities (see Figure 3.4). This tendency is evident in countries with large copper processing activities, such as Germany, Poland, and Belgium. A similar tendency is seen for zinc, with countries characterized by large zinc processing operations (e.g., Spain and Norway) displaying a concentration larger than 5% for zinc aggregated water emissions. For Poland, zinc aggregated water emissions are partially driven by copper mining activities. EFs related to copper mining are higher for zinc than copper (see section 3.2.1), and Poland holds one of the largest operations related to copper mining in the EU + 8.

Countries with nickel mining activities, copper mining activities (large operations), or cathode production facilities drive the aggregated nickel emissions in 2020 and 2030. To illustrate, Poland holds large copper mining operations and no nickel mining operations. In addition, EFs related to copper mining are higher for nickel than copper (see section 3.2.1). The nickel water emissions from copper mining activities contribute to a large extent to Poland's aggregated water nickel emissions in 2020 and 2030. For other countries such as Greece and Finland (to some extent), the aggregated nickel emissions are driven more by nickel mining activities. Finland is expected to be the only country with nickel mining, processing, cathode production, and battery recycling activities (see Figure 3.6). The regional contribution to aggregated nickel emissions changes over time, particularly in countries with large battery cathode projects. For example, due to a (potential) significant cathode production, Poland's contribution to aggregated nickel water emissions is expected to increase from 13.8% in 2020 to 19.8% in 2030. In contrast, Sweden and Germany will see smaller aggregated nickel water emission increases due to their smaller-scale cathode projects. The cathode production capacity significantly influences the regional nickel water emissions. Note that given recent market developments, it is uncertain whether some of these projects will go on.

As shown in Figure 3.5, the regional contribution of aggregated lithium water emissions in 2030 is spread over a few countries. The largest contribution is reported for Poland, followed by Germany and France. The production of cathodes drives Poland lithium water emissions. For Germany and France, the aggregated lithium emissions to water are driven to a large extent by the production of lithium hydroxide. Germany and France are expected to hold lithium hydroxide production and cathode facilities. Many of the expected lithium hydroxide production projects are mines or brine lithium extraction from geothermal sources projects that include lithium processing up to lithium hydroxide. Therefore, the regional contribution (% basis) of lithium water emissions between countries, including mining emissions (when available), should not vary. Only a few locations, such as the Jadar mine in Serbia and the Mina do Barroso in Portugal, will mine lithium and not provide lithium hydroxide as a final product. Similarly, only a few locations will focus solely on lithium processing, such as the Guben and Bitterfeld/Wolfen refineries (Germany) and the Galp refinery in Portugal.

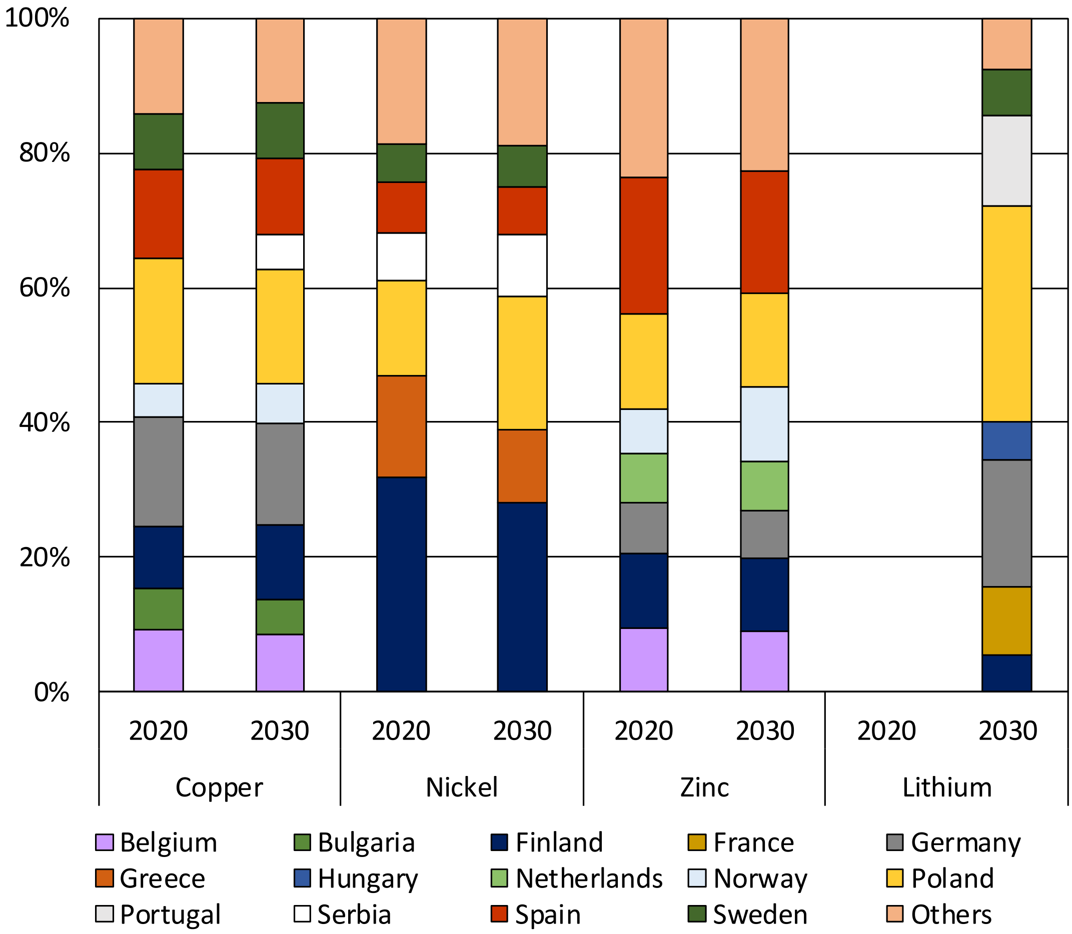


Figure 3.5: Regional water emissions contribution (%) aggregated per metal type in the EU + 8 for 2020 and 2030. Gallium regional contribution is not shown for confidential purposes. Only countries with a representative contribution (equal or higher contribution than 5% for the relevant year) are presented in the graph. The countries with a lower contribution are grouped in "Others".

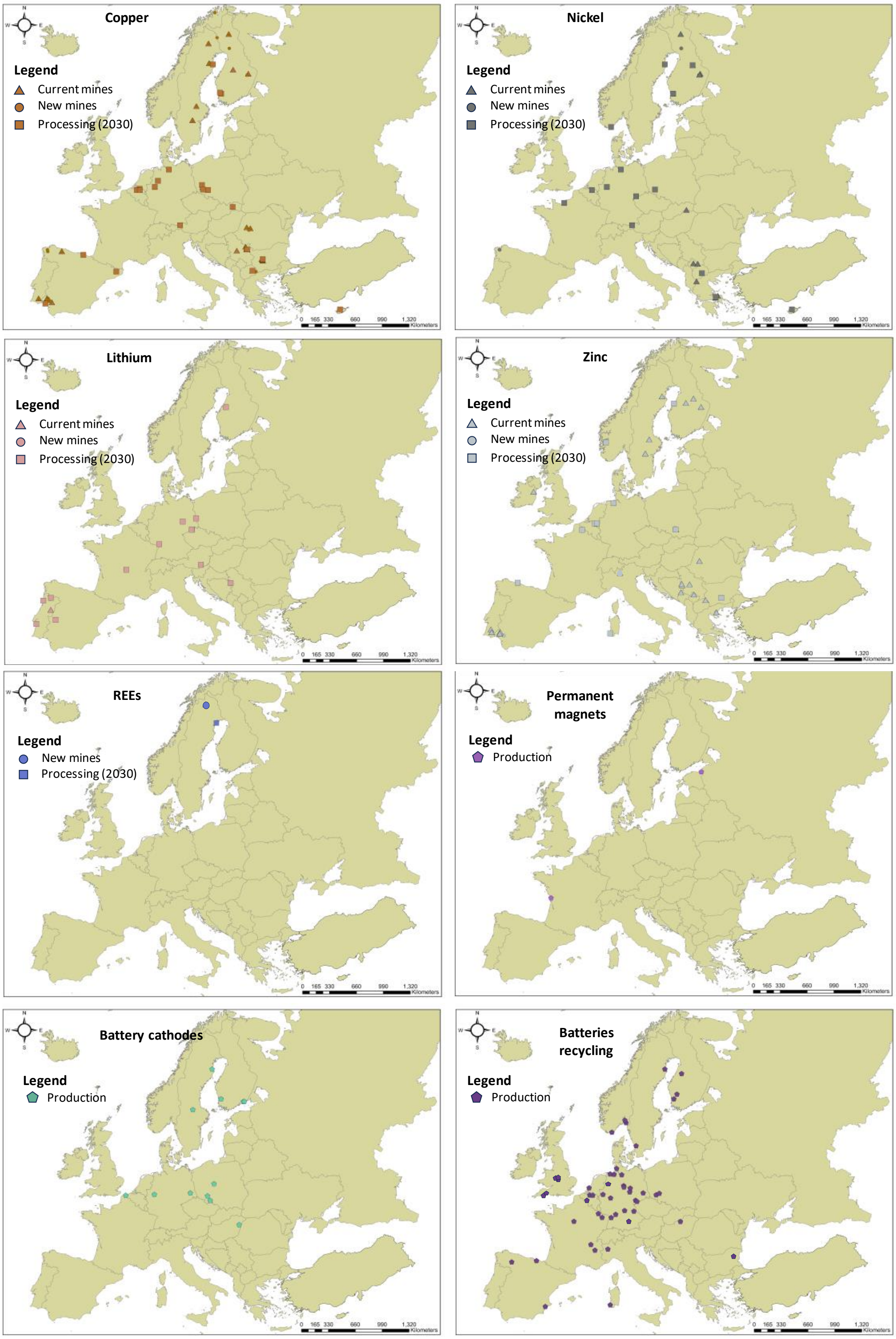


Figure 3.6: Geographical location of current and potential projects (2030) related to the metals and technologies in scope. Note that other processing facilities related to nickel are also shown. However, this is related to other nickel-related product processing facilities such as ferronickel and not high-quality nickel. Gallium related facilities are not shown for confidential purposes.

### 3.2.3 Technology value chain contribution

Figure 3.7 shows the aggregated additional metal water emissions per value chain without (A) and with (B) the base demand sectors. There is an increase in water metal emissions driven by the additional metal demand for strategic value chains. Copper water emissions increase by 0.28 $t_{emitted}$ /year, nickel water emissions increase by 1.13 $t_{emitted}$ /year, zinc water emissions increase by 1.53 $t_{emitted}$ /year, gallium water emissions increase by 0.002 $t_{emitted}$ /year and lithium water emissions increase by 95.8 $t_{emitted}$ /year between 2020 and 2030.

EVs contribute the largest to the increase in water emissions for all metals. The EVs large contribution compared to other value chains is determined by the opening of new facilities related exclusively to this value chain (e.g., bettery cathode facilities) and the assumption that market competition dynamics can occur between base demand sectors and the technologies in scope leading to a shift in water metal emission between sectors over time. For example, the EV demand for copper increases from 2.6% to 20.8% between 2020 and 2030, leading to a demand decrease in the base sectors from 93.6% to 74.2%. This results in copper water emissions shifting to some extent from the base sector to EVs (and other value chains) by 2030 (see Figure 3.7 – C).

The shift in water emissions between value chains and base sectors is also directly related to the total production of mining, processing, other activities and the specific metal demand for each value chain at a point in time. These dynamics result that after EVs, the largest increase in water emissions for copper (0.014 $t_{emitted}$ /year), nickel (0.012 $t_{emitted}$ /year) and zinc (0.175 $t_{emitted}$ /year $t_{emitted}$ /year) are related to PV (see Figure 3.7 – A). The same dynamics also have an opposite effect on other value chains, such as electricity networks. For electricity networks, the increase in copper and nickel water emissions is minimal over time. Note that by 2030, the base demand sectors will account for the largest share of water emissions for copper, nickel and zinc (see Figure 3.7 – B and C).

Lithium water emissions are exclusively driven by the EVs value chain, mainly for producing lithium hydroxide and cathodes. Note that the increase in lithium water emission from the EVs value chain could increase if other activities, such as domestic lithium mining (not included in this assessment, given the lack of data), are accounted for. The lithium mining projects in Europe are mainly related to establishing a resilient domestic EV supply chain (Alessia et al., 2021). For nickel, the increase in water emissions is dominated by the EVs value chain, directly related to opening new facilities for cathode battery production.

For gallium, the increase in water emissions is mainly attributed to EVs, with a small share increase driven by PV in 2030. Note that there was no data available for the base sector demand for gallium, and the difference in share demand across value chains directly represents the absolute metal demand of each sector in 2030. Therefore, the share of gallium water emissions related to databases and servers in 2030 decreases in function of the larger increase in absolute gallium demand for EVs and PV. Gallium emissions related to the value chains in scope only represent the ultrapure quality of GaAs substrate production required for the manufacturing semiconductors/wafers sector.

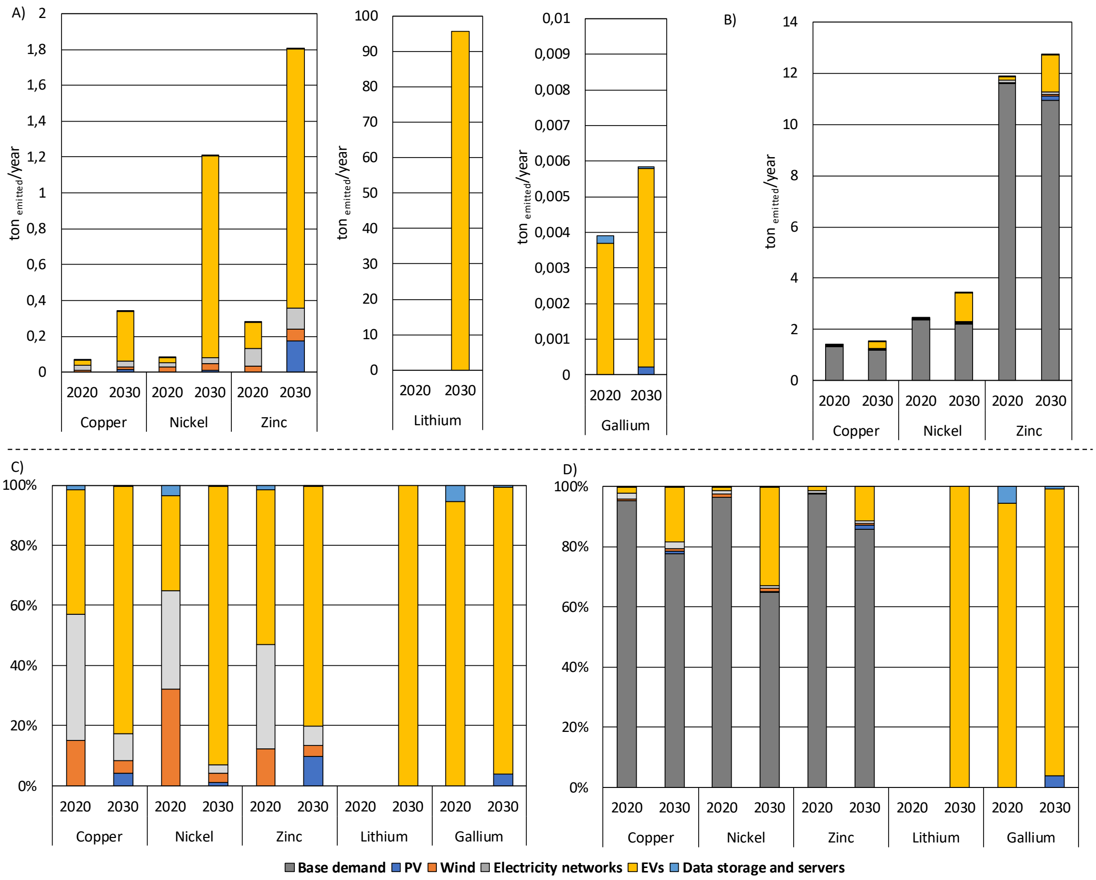


Figure 3.7. Aggregated metal water emissions in 2020 and 2030 per value chain type A) without the base demand sectors (Note that three graphs with respective scales are presented for illustration purposes, given the unit difference), B) with the demand base sectors, C) contribution of metal emissions per value chain without the base demand sectors and, D) with the base demand sectors.

## 3.3 Regional concentrations and relative change

The regional increase is smaller than <0.1% for copper, nickel and zinc, compared to natural background concentrations, while 17.9% for lithium. The increase in regional concentrations related to the additional water emissions driven by the 2030 metal demand for the value chains in scope is also less than <0.1% for copper, nickel and zinc compared to the RWC (reasonable-worst-case) background concentrations. For lithium, the regional relative contribution compared to the RWC is 6.5% (see Table 3.1). The risk increase in the RCR is for all four metals lower than 0.01 (see Table 3.1).

Table 3.1. % increase of the regional natural background concentrations, % increase of the regional reasonable worse case concentrations, % increase of the releases compared to major industrial activities and increase in risk characterization ratio from the increase in concentrations driven by the metal demand for the value chains in scope.

| | Unit | Cu | Ni | Zn | Li |
|---|---|---|---|---|---|
| **Comparison with EU regional PECs natural background in FOREGS** | | | | | |
| Increase | % | 0.034 | 0.076 | 0.039 | 17.9 |
| **Comparison with EU reasonable worse case regional PECs determined in MEED program** | | | | | |
| Increase | % | 0.013 | 0.076 | 0.014 | 6.5 |
| **Comparison with EU regional releases from major industrial activities in E-PRTR** | | | | | |
| Increase | % | 0.42 | 1.01 | 0.27 | NA |
| **Comparison with PNEC values in ECHA** | | | | | |
| Increase in risk characterization ratio | - | 0.000049 | 0.00022 | 0.000062 | 0.0022 |

The increase in regional concentrations from the country with the highest contribution (Appendix e - Table e.3) to the additional water metal emissions is also smaller than <1% for copper, nickel and zinc, while 17.4% for lithium compared to the RWC regional background concentrations. Compared to the regional natural background concentrations, the increase is smaller than <1% for copper, nickel and zinc, while for lithium the increase can be 48%. The risk increase in RCR for the country with the highest contribution is for all four metals lower than 0.01.

The increase in emissions (releases) from the additional metals demand for the value chains in scope follows a similar trend as with the increase in concentrations. Compared to major industrial activities across Europe, the increase in releases is 0.4% for copper, 1.0% for nickel and 0.3% for zinc (see Table 3.1).

## 3.4 Uncertainties

The results of this study should be interpreted with care due to the following uncertainties:

**Metal demand and regional contribution**

- The metal demand used in this report is largely based on the MCE study (Gregoir & van Acker, 2022). However, given current market dynamics, geopolitical drivers and efficiency gains in material use, metal demand may vary over time and between end uses by 2030.
- This report assumed the SDS scenario of the MCS study (as it largely aligns with EU clean energy targets) to estimate metal demand and additional metal water emissions. Using other available scenarios, such as the Stated Policies Scenario (STEPS), with different energy demand scenarios could result in lower overall metal demand and water metal emissions. However, scenario differences are more pronounced and expected after 2030 (beyond the temporal scope of the study).
- This report's results reflected the project announcements (relevant to the scoped value chains) at the moment of the assessment. Furthermore, it relied extensively on input from Eurometaux, Eurometaux members, and metal associations regarding the feasibility of those projects to be open before 2030. However, current market dynamics and development might change the feasibility of those facilities before 2030. Therefore,

changes in the fate of projects can bring differences in the overall additional water metal emission on a country, industry sector, and value chain level.
- Regional emissions were allocated to specific value chains on a general basis, assuming that all (potential) projects and current facilities across the geographical scope supply the technologies and base sector with the same share regardless of location. This was done given that companies deliver metals to intermediaries such as the London Metal Exchange (LME), from which consumers buy their metals and from that step in the value chain, they go to different sectors.

### Emissions factors
- EFs for the different value chain stages and related activities were assumed to be constant over time. However, they generally improve over the years, as shown in the E-PRTR database for copper, nickel and zinc releases (EEA, 2022).
- There are no EFs for other processes related to battery recycling besides hydrometallurgy. In the upcoming years, other processes for battery recycling will be deployed involving pyrometallurgy or dry techniques (Zanoletti et al., 2024).
- Some facilities process more than one metal at a time. For example, integrated facilities that process copper and nickel. However, there was no data on each specific facility process/technology to account for such integrated systems. Therefore, EFs were attributed only on an output basis of each metal independent of what a facility would incur in integrated metal processing. This assumption could result in an overestimation of water emissions for some facilities.

### Concentrations
- The FOREGS database is a valuable resource, offering extensive data on natural geochemical baselines across Europe. However, the database also has limitations. The data for FOREGS is collected over a specific period in the early 2000s and thus does not reflect temporal changes in geophysical conditions. Therefore, it provides a snapshot of the metal concentrations at that specific point in time. FOREGS is intended to represent natural baselines. However, some of the data might have been influenced by human activities, given the reach in contact of these activities across the continental scale. This might explain why the concentration value for nickel between FOREGS and MEED is approximately similar.
- There are differences in geographical scopes when comparing databases. The geographical coverage between this assessment FOREGS and MEED varies slightly. In MEED, there are not enough data points for a reliable estimation of Lithium PEC. The presented lithium regional PEC in MEED is based on the 83.5th percentile of FOREGS, which is considered a reliable estimate for the regional EU PEC when data is unavailable (Heijerick et al., 2023). MEED has compared this process with published scientific literature.
- PEC regional values could be derived from the geometric mean of all $50^{th}$ percentiles instead of the 90th percentile RWC value, as this would provide the central tendency of the concentrations caused by a combination of natural background conditions and human activities. However, data is not available for the $50^{th}$ percentile, and PEC values are only present for the RWC.
- While EUSES provides a standardized approach, this is often based on general assumptions that might not apply to specific cases; for example, a default setting for a chemical's release into water might not accurately represent localized conditions. To illustrate, soil and water characteristics in Mediterranean regions might not reflect those in Northern Europe, affecting the model's predictions in diverse areas.
- The PNEC value in the ECHA database for lithium (165 µg/L ) is different than reported in other assessments. For example, Oliver and Hewett have recommended for consideration in environmental regulation a PNEC limit of 15.2 µg/L for long-term exposure after

assessing 194 individual ecotox endpoints from global literature (Oliver & Hewett, 2024) . Using a different PNEC would increase the RCR for lithium assessed in this study.

# 4 Conclusions and recommendations

## 4.1 Main conclusion

This report aimed to **assess the additional water metal emissions from the increase in demand for key metals driven by the Twin Transition and CRM Act by 2030.** In addition, **it also analyzes the relevance (magnitude) of such water emissions in the regional EU context**.

The (EU + 8) **additional water metal emissions** from the increase in metals demand for EVs, wind turbines, database and serves, PV and electricity networks between 2020 and 2030 are:

- 0.28 $t_{emitted}$ /year for copper
- 1.13 $t_{emitted}$ /year for nickel
- 1.53 $t_{emitted}$ /year for zinc
- 0.002 $t_{emitted}$ /year for gallium
- 95.8 $t_{emitted}$ /year for lithium

EVs contribute the largest to the increase in water metal emissions (30 to 100% depending on metal).

The increase in emissions (releases) from the additional metals demand for the value chains in scope compared to major industrial activities across Europe is 0.4% for copper, 1.0% for nickel and 0.3% for zinc. No emissions (releases) data are registered for lithium and gallium for a consistent comparison.

The increase in regional concentrations compared to **natural background and RWC concentrations** is less than 0.1% for copper, nickel and zinc. Lithium's regional increase in freshwater concentrations is 17.9% compared to the natural background concentration and 6.5% for the measured RWC concentration. The **increase in the risk characterization ratio – RCR** is lower than 0.01 for copper, nickel, lithium and zinc. For gallium, there is no data available for a consistent assessment.

We conclude that the increase in metal emissions driven by the additional metal demand for EVs, wind turbines, database and serves, PV and electricity networks is low for copper, nickel and zinc when compared to the overall annual metal emissions from the industrial activities related to the metals in scope. Lithium emissions are expected to increase as there are currently no industrial lithium-related activities in the EU + 8. The increase in regional concentrations driven by the value chains in scope is low for copper, nickel and zinc. For lithium, the increase in regional concentrations exhibits a higher increase. However, the added risk from the predicted environmental concentration is lower than 0.01 for all metals, suggesting a limited risk increase to the environment under the assessed conditions. For gallium, there is no data available for a consistent assessment.

## 4.2 Secondary conclusions

- The EU will continue to rely on imports of metals (and products, e.g., permanent magnets) by 2030 to satisfy the energy and digital transition, as the domestic supply falls short under current and planned activities. Furthermore, the additional metal demand for specific value chains can be in competition with other sectors (e.g., infrastructure and transport).
- It is crucial to report and account for water metal emissions holistically and not only for a specific metal-related activity as there are interdependencies. For example, accounting for copper, nickel and zinc water emissions from copper mining instead of only accounting for copper water emissions. Failing to include this holistic approach can lead to underestimations of water metal emissions.
- It is crucial to compare EFs across databases and with reported data (if possible) to avoid an under/overestimation of metal water emissions. This is exemplified by the high EF for zinc related to zinc mining in ecoinvent when compared to industry representative data (present in Gabi) and measured water emissions.
- Significant data gaps exist in activities without a historical background in the EU + 8, such as the ones related to lithium mining, REEs mining and processing, gallium extraction or battery cathode production.

## 4.3 Recommendations

This report provides a first-of-a-kind assessment to understand the magnitude and relevance of the additional regional water metal emissions driven by the Twin Transition. However, more efforts in upcoming research should include:

- EFs for activities that will expand considerably in the EU + 8 related to values chains such as EVs and databases and servers (semiconductors production) in which there is a clear effort from the EU to position itself as a market competitor. For Example, EFs for lithium mining or geothermal brine extraction of lithium.
- Background concentrations comparison with PECs can be made at a river basin district level to avoid overseeing important location-specific dynamics that are difficult to identify at large scales. In addition, the comparison with background concentration can be done using the median concentration values when available (instead of only RWC) as they represent the central tendency of measured data.
- Industry data on metal emissions beyond their specific metal in scope.
- Regional differentiation on EFs, depending on each location-specific facility's technology and treatment processes, can increase the accuracy of the assessment.
- The assessment should be expanded beyond 2030 with additional value chains relevant to the EU, such as electrolyzers, to understand the effects of metal emissions from key value chains and domestic production of metals on longer temporal scopes.

# 5 Acknowledgments

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# Signature

TNO ⟩ Energy & Materials Transition ⟩ Utrecht, 19 December 2024

ValidSigned by Gerard van der Laan
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## Appendix A

# Spodumene Concentrate to Lithium Hydroxide Monohydrate scheme

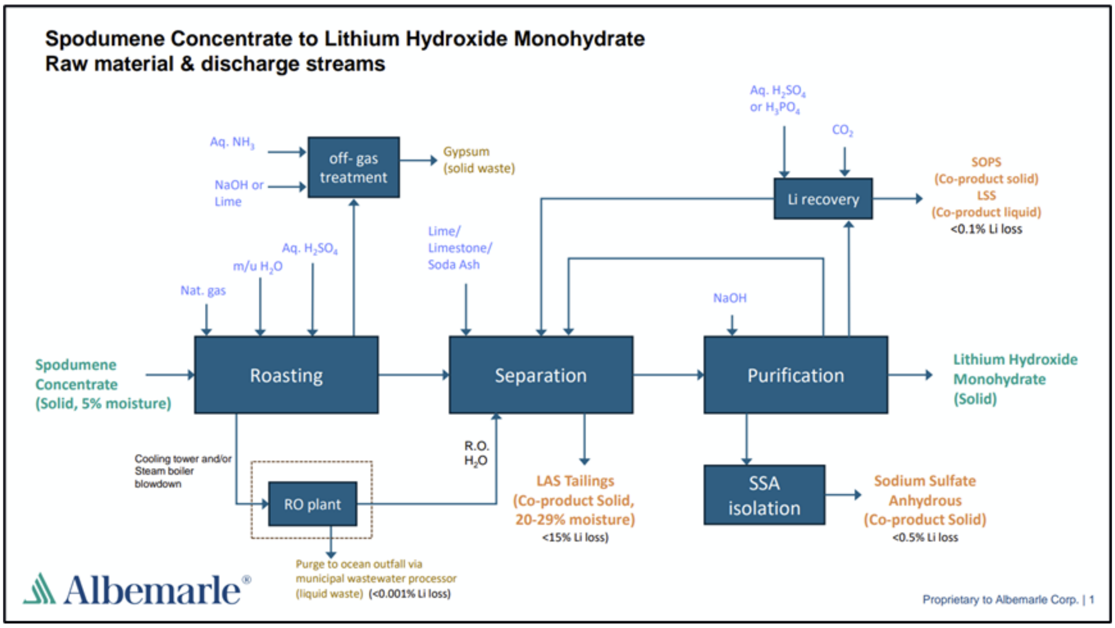


Figure A.1: Spodumene Concentrate to Lithium Hydroxide Monohydrate Raw material & discharge streams (Albemarle, 2024).

# Appendix B
# Ecoinvent activities

Table B.1: Ecoinvent activities.

| Metal - Product | Activity class | Activity - ecoinvent | Reference product | Description | Geography |
|---|---|---|---|---|---|
| Copper | Mining | Copper concentrate, sulfide ore {RoW}\| copper mine operation and beneficiation, sulfide ore \| Cut-off, U | Copper, concentrate | This activity includes constructing the mine site (including the mill), excavating the site and installing the facility. Based on typical current technology. Mining is done in 70% open pits and 30% underground | Rest-of-World {RoW] |
| | Manufacturing - refining (processing) | Copper, anode {RoW}\| smelting of copper concentrate, sulfide ore \| Cut-off, U | Copper, anode | This activity represents the smelting of copper concentrates to produce copper anodes at the global level; it starts with the delivery of copper concentrates and ends with the production of copper anode. | Rest-of-World {RoW] |
| | Manufacturing - refining (processing) | Copper, cathode {GLO} electrorefining of copper, anode Cut-off, U | Copper, cathode | Electrorefining of copper anodes to produce high grade copper cathodes | Global {GLO} |

| | | | | | |
|---|---|---|---|---|---|
| | Manufacturing - refining (processing) | Copper, cathode {GLO} copper production, cathode, solvent extraction and electrowinning process Cut-off, U | Copper, cathode | The dataset includes the ore's grounding, gravity concentration, pretreatment prior to hydrometallurgy, dump leaching step for copper recovery, solution cleaning step, and separation step. | Global {GLO} |
| Nickel | Mining | Nickel concentrate, 16% Ni {CA-QC}\| nickel mine operation and benefication to nickel concentrate, 16% Ni \| Cut-off, U | Nickel concentrate, 16% Ni | This dataset represents the production of 1 kg of nickel ore, beneficiated to 16% Ni in Quebec (Canada) for the year 2010. The dataset includes the extraction of nickel ore in an underground mine and it's benefication, management of tailings and waste rocks and wastewater treatment. | Canada, Québec {CA-QC} |
| | Manufacturing - refining (processing) | Nickel, class 1 {GLO}\| smelting and refining of nickel concentrate, 16% Ni \| Cut-off, U | Nickel, class 1 | This dataset represents the joint smelting and refining of 1 kg of nickel, 99.5% and 0.243 kg of copper, the former being the reference product. This dataset is created only to complete mining and benefication of nickel ore, QC dataset in order to provide a useful product (nickel). | Global {GLO} |
| Zinc | Mining | Zinc concentrate {GLO} zinc mine operation \| Cut-off, U. | Zinc, concentrate | The multi-output "zinc mine operation" process includes all steps required to produce zinc concentrate (59% Zn by mass), namely mining, comminution, and flotation. | Global {GLO} |

| | | | | | |
|---|---|---|---|---|---|
| | Manufacturing - refining (processing) | Zinc {RoW}\| primary zinc production from concentrate \| Cut-off, U | Zinc, high grade | The multi-output "primary zinc production from concentrate" process includes all steps required to produce special high grade zinc from zinc concentrate using the electrometallurgical and pyrometallurgical (less common) processes. | Rest-of-World {RoW] |
| Lithium | Mining | Lithium brine, 6.7 % Li {GLO}\| lithium brine inspissation \| Cut-off, U | lithium brine, 6.7 % Li | This dataset includes the inspissation of lithium containing brine to a concentrated lithium brine by sun energy in the desert of Atacama (Chile) | Global {GLO} |
| | Mining | Spodumene {RoW}\| spodumene production \| Cut-off, U | Spodumene | This dataset represents the production of 1 kg of milled spodumene in the World. | Rest-of-World {RoW] |
| | Manufacturing - refining (processing) | Lithium carbonate {GLO}\| lithium carbonate production, from concentrated brine \| Cut-off, U | lithium carbonate | This dataset represents the production of 1 kg of lithium carbonate from concentrated brine. The dataset can be used for preparing electrode base material for batteries. | Global {GLO} |
| | Manufacturing - refining (processing) | Lithium carbonate {RoW}\| lithium carbonate production, from spodumene \| Cut-off, U | lithium carbonate | This dataset represents the production of 1 kg of refined lithium carbonate (Li2CO3), with 99.9% purity. It is a copy of the Chinese dataset, as China represents the world main producer of lithium carbonate from spodumene. | Rest-of-World {RoW] |

| | | | | | |
|---|---|---|---|---|---|
| Gallium | Mining | Gallium, in Bayer liquor from aluminium production {GLO}\| gallium, in Bayer liquor from aluminium production \| Cut-off, U | Gallium, in Bayer liquor from aluminium production | This data set describes the simultaneous extraction of gallium together with aluminium in the Bayer process of the aluminium production. | Global {GLO} |
| | Manufacturing - refining (processing) | Gallium, semiconductor-grade {GLO}\| gallium production, semiconductor-grade \| Cut-off, U | Gallium, semiconductor-grade | The module includes the production and purification of high grade gallium (99.9999%) by hydrometallurgical processes | Global {GLO} |
| Rare earth elements | Mining | Rare earth oxide concentrate, 70% REO {CN-SC}\| rare earth element mine operation and beneficiation, bastnaesite ore \| Cut-off, U | Rare earth oxide concentrate, 70% REO | This dataset refers to the mining (open pit mining) and beneficiation activities (two step beneficiation process in-cluding ball milling and magnetic seperation) of bastnäsite minerals taking place in the Sichuan region in order to produce rare earth oxide (REO) concentrate, 70% beneficiated. | {China – Sichuan} |
| | Manufacturing - refining (processing) | Dysprosium oxide {CN-FJ}\| rare earth oxides production, from rare earth carbonate concentrate \| Cut-off, U | Dysprosium oxide | This dataset refers to the extraction (calcination) and refining (solvent extraction) of individual rare earth oxides, obtained from mined rare earth carbonates. "After drying and calcination, 90-92% mixed REOs are produced. The REO mixture from the leaching process undergoes a combined solvent extraction process at a facility in Southern China. | {China-Fujian} |

| | | | | | |
|---|---|---|---|---|---|
| | Manufacturing - refining (processing) | Neodymium oxide {CN-FJ}\| rare earth oxides production, from rare earth carbonate concentrate \| Cut-off, U | Neodymium oxide | This dataset refers to the extraction (calcination) and refining (solvent extraction) of individual rare earth oxides, obtained from mined rare earth carbonates. "After drying and calcination, 90-92% mixed REOs are produced. The REO mixture from the leaching process undergoes a combined solvent extraction process at a facility in Southern China. | {China-Fujian} |
| Cathodes | Reference product | Cathode, NMC111, for Li-ion battery {RoW}\| cathode production, NMC111, for Li-ion battery \| Cut-off, U | Cathode, NMC111, for Li-ion battery | This dataset represents the production of 1 kg nickel-manganese-cobalt (NMC) cathode for Li-ion batteries, with nickel manganese and cobalt in ratio 1:1:1 (NMC111) | Rest-of-World {RoW] |
| | Reference product | Cathode, NMC811, for Li-ion battery {RoW}\| cathode production, NMC811, for Li-ion battery \| Cut-off, U | Cathode, NMC811, for Li-ion battery | This dataset represents the production of 1 kg nickel-manganese-cobalt (NMC) cathode for Li-ion batteries, with nickel manganese and cobalt in ratio 8:1:1 (NMC811) | Rest-of-World {RoW] |
| Permanent magnets | Reference product | Permanent magnet, for electric motor {GLO}\| permanent magnet production, for electric motor \| Cut-off, U | Permanent magnet, for electric motor | Neodymium Magnet, produced out of Neodymium, Iron and Boron Alloy. | Global {GLO} |

| | | | | | |
|---|---|---|---|---|---|
| Semiconductors | Reference product | Wafer, fabricated, for integrated circuit {GLO}\| wafer production, fabricated, for integrated circuit \| Cut-off, U | wafer, fabricated, for integrated circuit | This dataset represents the production of 1 m2 of an electronic-grade silicon wafer used for integrated circuit or chip fabrication.The original input data for chemicals and elemental gases represents measures in grams per cm2 of input wafer. | Global {GLO} |
| Li-ion battery recycling | Value chain stage | Used Li-ion battery {GLO}\| treatment of used Li-ion battery, hydrometallurgical treatment \| Cut-off, U | Used Li-ion battery | This dataset represents the treatment of Li-Ion batteries from electric and electronic devices by a hydrometallurgical process. | Global {GLO} |
| Li-ion battery recycling | Value chain stage | Used Li-ion battery {GLO}\| treatment of used Li-ion battery, pyrometallurgical treatment \| Cut-off, U | Used Li-ion battery | This dataset represents the treatment of Li-Ion batteries from electric and electronic devices by a pyrometallurgical process | Global {GLO} |

# Appendix C
# spERCS database

spERCS provides a method for assessing the environmental releases of metals and metal compounds from manufacturing, processing, and downstream uses in the EU. A database of over 1,300 (1993-2010) site-specific measured release factors for 18 different metals and their compounds from various EU member states was compiled. Release factors are also generally applied to estimate the water emissions of metals processing, for example, in compiling the dossiers of chemicals needed under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation (REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 December 2006 Concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), 2023). The release factors estimate how much of a substance is released to a certain environmental compartment dependent on the nature of the process application and the properties of a substance (e.g., water solubility). The industry has compiled tables related to the release factors as part of the European Union System for the Evaluation of Substances (EUSES)(European Commission, 2004). These tables are a component of the above-mentioned spERCs. As shown in Figure c.1, the solid water partition coefficient (Kd), also called the suspended solids partition coefficient (Kpss), is the determining factor for metals.

<table>
<tr><th>Kd* (L/kg)</th><th colspan="2">Release factor</th><th>Justification</th></tr>
<tr><td>< 1,000</td><td colspan="2">6% (before on-site STP)</td><td>Assessment default as set by ERC 1</td></tr>
<tr><td>1,000 – 10,000</td><td colspan="2">0.2% (after on-site STP)</td><td>Reasonable worst-case (90th percentile) (available data too limited to develop robust regression)</td></tr>
<tr><td rowspan="8">10,000 – 400,000</td><td>Kd</td><td>Release factor**</td><td rowspan="8">Realistic worst-case regression line (RF = 10^(1.59 – 1.14 x log(Kd)) of the metal-specific 90th percentile reported site-specific release factors to wastewater for 201 sites from the production of massive metal and metal powder</td></tr>
<tr><td>10,000 – 25,000</td><td>0.2%</td></tr>
<tr><td>25,000 – 60,000</td><td>0.04%</td></tr>
<tr><td>60,000 – 100,000</td><td>0.01%</td></tr>
<tr><td>100,000 - 190,000</td><td>0.005%</td></tr>
<tr><td>190,000 – 250,000</td><td>0.002%</td></tr>
<tr><td>250,000 - 400,000</td><td>0.001%</td></tr>
<tr><td colspan="2">** after on-site STP</td></tr>
<tr><td>> 400,000</td><td colspan="2">6% (before on-site STP)</td><td>Assessment default as set by ERC 1</td></tr>
</table>

* Kd = Solid water partition coefficient for suspended matter

Figure C.1: Release factors to freshwater for manufacture of metal compounds (Eurometaux, 2021).

When Kd (Kpss) are not known, they can be estimated as a function of the relationship between the distribution coefficient (Ka) and Kd (Kpss) (Veselý, Majer, Kučera, & Havránek, 2001) for more information. Only for copper, nickel and zinc is the Kd (Kpss) known. For the other scoped metals, the Kd (Kpss) is not available, and thus, the mentioned function between Ka and Kd (Kpss) is applied with data from (Veselý et al., 2001) to obtain Kd (kpss) factors (see Figure c.2). Table c.1 shows each metal's Ka and Kd (Kpss) values, which are applied to obtain metal-specific release factors. These release factors are to be seen as realistic worst-case values. Dy is treated as the same as Nd.

Table C.1: Metal-specific Ka and Kd/Kpss coefficients.

| Metal | logKa | Kd/Kpss | EFs (%) |
|---|---|---|---|
| Cu(II) | | 3.02E+04 | 0.04 |
| Ni(II) | | 2.63E+04 | 0.04 |
| Zn(II) | | 4.68E+04 | 0.04 |
| Ga | 1.74 | 1.23E+02* | 6 |
| Li | -0.93 | 2.02E-01* | 6 |
| Nd (III) | 2.03 | 2.39E+00* | 6 |

* derived from logKa

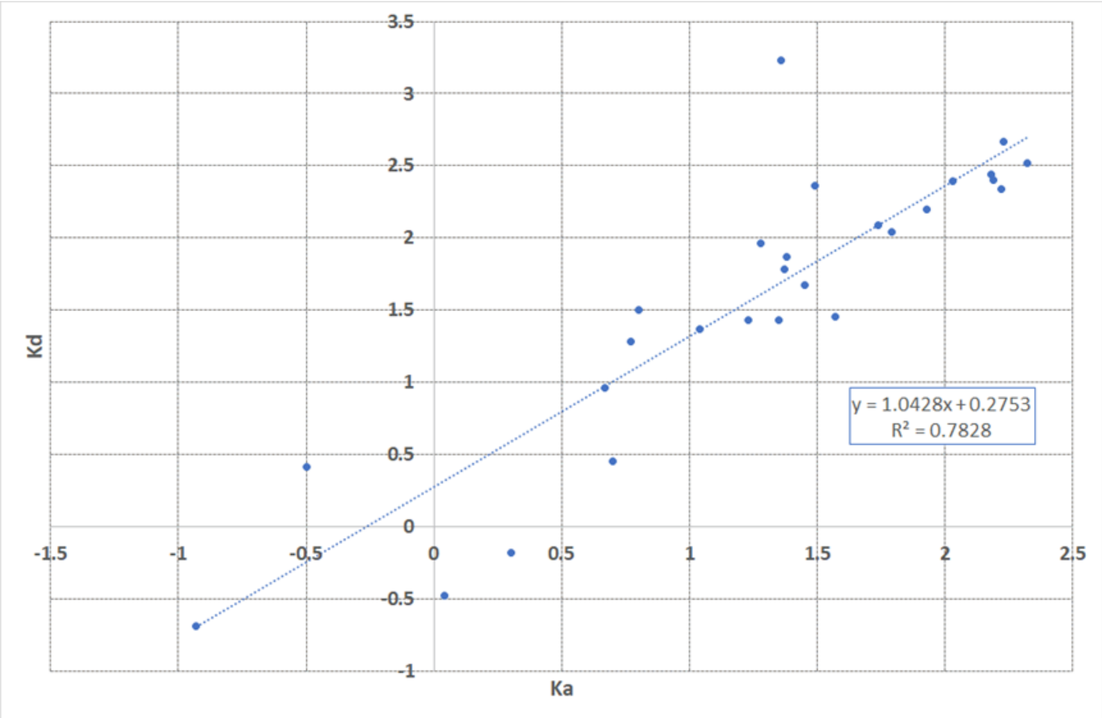


Figure C.2: Relation between log Ka en log Kd based on data from (Veselý et al., 2001).

# Appendix D
# Comparison of EFs across databases

Figure d.1 shows the difference in emissions factors across databases and reported industry emissions data. There is a strong difference between databases. EFs from the spERCS database are considerably higher than those reported by ecoinven, the industry annual emisisons and GaBi. EFs for processing in the spERCS database are several orders of magnitude larger. To illustrate, the spERCS EF for copper processing corresponds to 4E-4 $kg_{Cu\ emitted}$ / $Kg_{Cu\ produced}$ , while the EF in ecoinvent is 2.5E-7 $kg_{Cu\ emitted}$ / $Kg_{Cu\ produced}$ and the industry-measured emissions range between 1E-7 and 9E-6 $kg_{Cu\ emitted}$ / $Kg_{Cu\ produced}$ . Similarly, it occurs for the processing EFs related zinc. Regarding copper mining, the EF in ecoinvent is relatively similar to the emissions reported by the industry, and there is no large difference in the order of magnitude. Conversely, the EF for zinc mining in ecoinvent is considerably higher than the industry's reported emissions and GaBi representative data. While there are strong differences in zinc mining EFs between ecoinvent and GaBi, EFs from processing are similar. The industry has reported no emissions for nickel mining and processing. However, there is a large difference between the EF for nickel processing between ecoinvent and spERCS. Reported emissions from the industry are shown as an average from the locations that report such emissions.

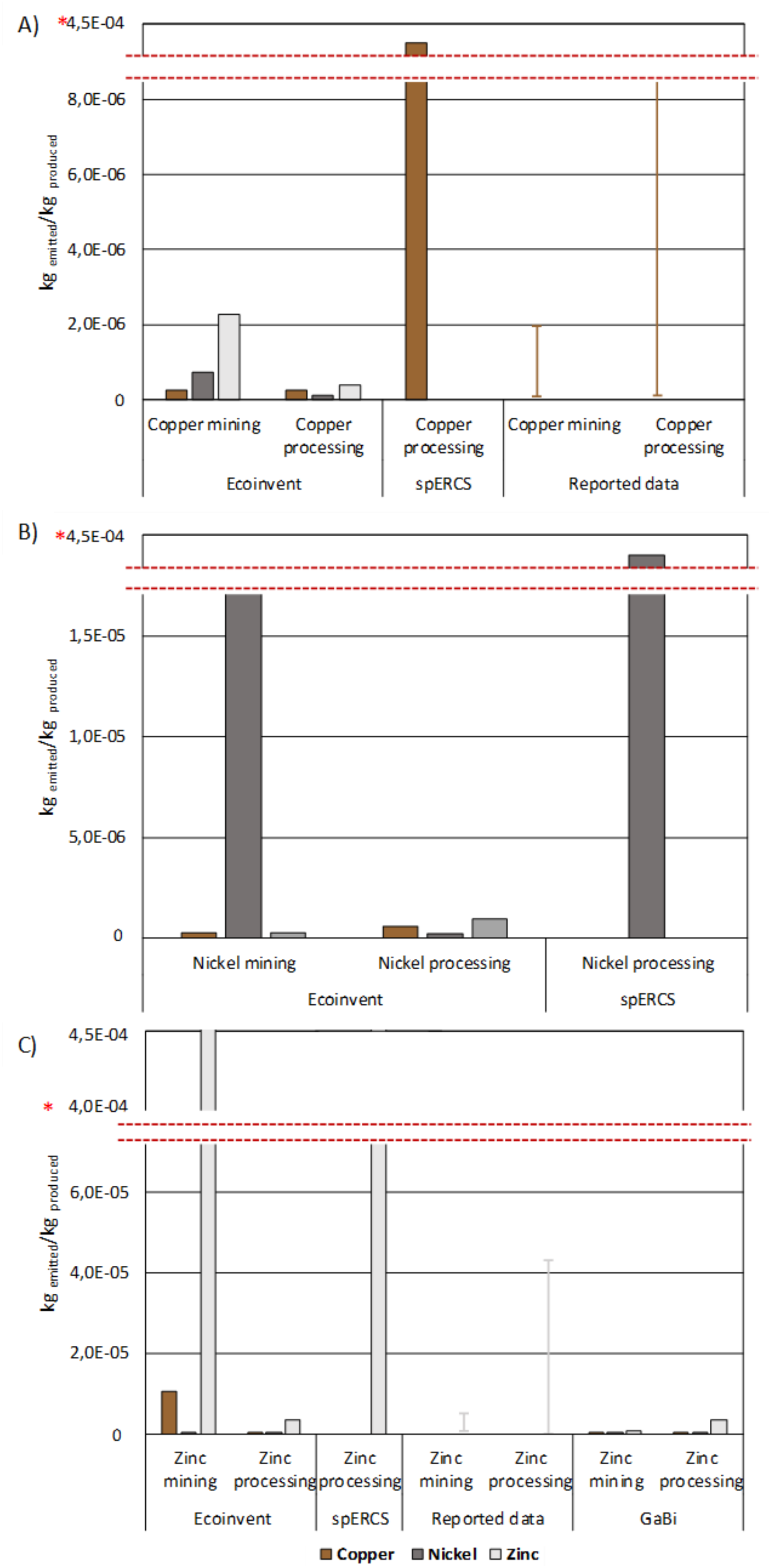


Figure D.1: EFs between ecoinvent, spERCS and reported by industry.

# Appendix E
# Relative change data and sensitivity

Table E.1: parameters used to estimate regional concentrations and relevant databases.

| | Unit | Cu | Ni | Zn | Li |
|---|---|---|---|---|---|
| **EUSES key input parameters** | | | | | |
| Kd sediment | l/kg | 24547[1] | 7079[2] | 3090[3] | 525[4] |
| Kd suspended soils | l/kg | 30200[1] | 26303[2] | 46774[3] | 776[4] |
| **Simulated PEC** | | | | | |
| Regional PEC in surface water (dissolved) | (µg/L) | 3.09E-04 | 1.38E-03 | 1.23E-03 | 0.376 |
| Continental PEC in surface water (dissolved) | (µg/L) | 4.73E-05 | 2.16E-04 | 1.77E-04 | 0.11 |
| **FOREGS[5]** | | | | | |
| Background concentration: 50-percentile | (µg/L) | 0.92 | 1.82 | 3.15 | 2.1 |
| **MEED[6]** | | | | | |
| EU-PEC (updated): 90-percentile | (µg/L) | 2.29 | 1.81 | 8.97 | 5.8 |
| **E-PRTR[7]** | | | | | |
| 2022 (release) | t/year | 67.2 | 112.5 | 579.1 | NA |
| 2020-2022 average (release) | t/year | 67.3 | 104.7 | 532.4 | NA |
| **ECHA** | | | | | |
| Predicted No-Effect Concentration | (µg/L) | 6.3[1] | 6.1[2] | 19.7[3] | 165[4] |

(ECHA chemicals database, 2022) accessed on 18-11-2024, the date is provided as dossiers can be updated over time
(ECHA chemicals database, 2023) accessed on 18-11-2024, the date is provided as dossiers can be updated over time
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(ECHA chemicals database, 2020) accessed on 18-11-2024, the date is provided as dossiers can be updated over time
(Salminen et al., 2005)
(Heijerick et al., 2023)
(EEA, 2022)

### Relative increase in continental concentrations
The increase in continental concentrations related to the additional water emissions driven by the 2030 metal demand for the value chains in scope is 0.0021% for copper, 0.012% for nickel, 0.002% for zinc and 1.9% for lithium compared to the RWC regional background concentrations (see Table e.2). When compared to the natural background concentrations, the increase is 0.0051% for copper, for nickel is 0.012%, for zinc 0.0056% and for lithium 5.2%. The increase in continental concentrations is lower compared to the regional one, given that the geographical scope of continental PEC evaluations is carried out on a European continental scale.

Table E.2: % increase of the continental background concentrations for the additional water emissions driven by the metal demand for the value chains in scope.

| | Unit | Cu | Ni | Zn | Li |
|---|---|---|---|---|---|
| **Comparison with EU continental PECs natural background in FOREGS** | | | | | |
| Increase | % | 0.0051 | 0.012 | 0.0056 | 5.2 |
| **Comparison with EU reasonable worse case continental PECs determined in MEED program** | | | | | |
| Increase | % | 0.0021 | 0.012 | 0.002 | 1.9 |

**Sensitivity scenario with the highest contribution country to the additional water emissions.**

The increase in regional concentrations from the country with the highest contribution (Appendix Table e.3) to the additional water metal emissions is 0.023% for copper, 0.26% for nickel, 0.024% for zinc and 17.4% for lithium compared to the RWC regional background concentrations. When compared to the regional natural background concentrations, the increase is 0.057% for copper, for nickel is 0.26%, for zinc 0.068% and for Lithium 48%. The difference in increase between regional concentrations and the country with the highest contribution to the additional water metal emission from the increase in the use of key metals is low except for lithium. This country exhibits a higher increase in concentrations of lithium, given the potential cathode facilities to be open before 2030.

Table E.3: % increase of the regional background concentrations, % increase of the releases compared to major industrial activities and risk characterization ratio from the increase in concentrations from the country with the highest contribution driven by the metal demand for the value chains in scope.

| | Unit | Cu | Ni | Zn | Li |
|---|---|---|---|---|---|
| **Comparison with EU regional PECs natural background in FOREGS** | | | | | |
| Increase | % | 0.057 | 0.26 | 0.068 | 48 |
| **Comparison with EU reasonable worse case regional PECs determined in MEED program** | | | | | |
| Increase | % | 0.023 | 0.26 | 0.024 | 17.4 |
| **Comparison with PNEC values in ECHA** | | | | | |
| Increase in risk characterization ratio | - | 0.000083 | 0.00076 | 0.00010 | 0.0061 |

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