Resources, Conservation & Recycling 235 (2026) 109111

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.sciencedirect.com/journal/resources-conservation-and-recycling

Review

Science-based targets for material use: A systematic review of analytical concepts and approaches in Europe

Philip Nuss[a,1,*], Susanna Paleari[b], Veronique van Hoof[c], Andrea van Acker[c], Jens Günther[a,1], Beatriz Vidal[d,2], Peder Jensen[d,2]

[a] German Environment Agency (UBA), Unit I1.2 – Capacity Building, Sustainable Resource Use, Security, Woerlitzer Platz 1, 06844, Dessau-Rosslau, Germany
[b] Research Institute on Sustainable Economic Growth (IRCrES-CNR), Via Alfonso Corti, 12 20133, Milano, Italy
[c] Flemish Institute for Technological Research (VITO), Materials Management & Sustainable Chemistry, Boeretang 200 2400 Mol, Belgium
[d] European Environment Agency (EEA), Unit – Circular economy, finance and indicators, Kongens Nytorv 6, 1050, Copenhagen K, Denmark

ARTICLE INFO

Keywords:
Science-based targets
Sustainable resource use
Circular economy
Raw material targets
Science-policy interface

ABSTRACT

Science-based targets (SBTs) are increasingly proposed to align raw material use with environmental and societal goals, yet no consensus exists on what constitutes sustainable levels of material use. This paper reviews the scientific literature on material-use targets (2000–2025) and combines it with a dedicated review of resource-use and circular-economy targets in European policy documents. Three main approaches to setting material targets are identified: *retrospective boundaries* based on historically “safe” extraction levels; *materials availability* focusing on the accessibility and availability of resources; and *impact-based* approaches that derive targets from planetary boundaries or from the material requirements of sustainability scenarios. Impact-based approaches have become most prominent, supported by advances in scenario analysis, while retrospective boundaries remain influential in policy debates. The European policy inventory reveals widespread but highly heterogeneous material and wider resource targets. Most targets are strategic and non-binding, centered on economy-wide indicators (e.g., material footprints or circular use rates), with fewer sectoral or sub-national targets and substantial variation in baselines, reference years, and accounting perspectives. We find that the scientific basis behind these targets is often not clearly articulated. We argue that SBTs for materials should rely on transparent analytical frameworks explicitly linked to one of the three approaches.

1. Introduction

The use of raw materials (metals, non-metallic minerals, biomass and fossil energy carriers) has become a central concern in environmental policy, as current extraction and consumption patterns drive environmental degradation (Cabernard et al., 2019; UNEP IRP, 2024) and collectively push humanity beyond the planet’s safe operating space, particularly in high-income regions such as the EU (Christis et al., 2024).

Against this background, several countries have already put forth absolute raw materials reduction targets in their national policies, e.g., Austria (BMK, 2022), Belgium (Circular Flanders, 2025), Finland (ETC CE, 2025), Germany (BMUV, 2024), or the Netherlands (ETC CE, 2022a) (or e.g. Australia (DCCEEW, 2024) as an example outside Europe). The European Parliament has emphasized the need for quantifiable materials use targets that align with sustainability objectives (European Parliament, 2021). In the 8th Environment Action Programme (EAP), the European Union (EU) aims to significantly decrease its material and consumption footprints to bring them into planetary boundaries (EU, 2022). Civil society actors increasingly call for absolute reduction targets (Friends of the Earth Europe et al., 2020; IEEP, 2022). The 2020 Circular Economy (CE) Action Plan commits the EU to a regenerative growth model within planetary boundaries, with goals to reduce the EU consumption footprint and double the circular material use rate in the coming decade (EC, 2020). However, no absolute EU reduction targets for materials exist yet.

Setting quantifiable targets in policy making helps to create directionality and focused action, and allows governments to check progress

* Corresponding author.
E-mail address: philip.nuss@uba.de (P. Nuss).
[1] Disclaimer: This paper does not necessarily reflect the opinion or the policies of the German Environment Agency (UBA).
[2] Disclaimer: This paper does not necessarily reflect the opinion or the policies of the European Environment Agency (EEA).

https://doi.org/10.1016/j.resconrec.2026.109111
Received 14 January 2026; Received in revised form 2 July 2026; Accepted 31 July 2026
Available online 14 August 2026

over time. A *science-based target (SBT)* has three characteristics, namely that (1) achieving it is a biophysical possibility within a specified time frame, (2) it can be quantified and, hence, progress can be measured in absolute or relative terms, and (3) it is underpinned by a transparent analytical rationale for deriving at the specific target value (e.g., a relation to planetary boundaries, avoiding a negative outcome, and ethical imperative, etc.) (Andersen et al., 2021). While SBTs have been applied, e.g., in climate policy, such as the two-degree target tied to a maximum atmospheric concentration of 450 ppm CO_2 (IPCC, 2018), no such consensus exists for raw materials use.

Determining an optimal threshold for materials use remains challenging due to the complexity of material flows, varying socio-economic contexts, and the interplay between primary and secondary resource markets, among other factors. Efforts to define SBTs for raw materials use have been initiated by researchers (e.g., see (Dudka et al., 2025; Thomassen et al., 2024)) and by a number of organizations such as, e.g., the UNEP International Resource Panel (IRP) (UNEP IRP, 2014; 2011; UNEP IRP, 2025), SYSTEMIQ (Potočnik, 2025; Potočnik and Teixeira, 2025) or the German Environment Agency (Dittrich et al., 2024, 2021). Nevertheless, a lack of international consensus and differences in analytical approaches for deriving at sustainable levels of raw materials use remain an obstacle to derive SBTs for materials use (WEF, 2019).

This paper investigates (1) existing scientific methods for deriving material use targets and (2) current materials-related and broader resource targets in European policy, including differences in scope, resource focus, implementation status, policy domain, and accounting perspective. It assesses the state of the art in material use and related resource targets in Europe for both policy and academic audiences, with the aim of summarizing the current scientific debate on material target setting and providing an initial overview of broader resource targets in Europe. It is structured in two parts: Sections 3.1–3.2 review science-based target-setting approaches for raw materials by classifying them according to the analytical methods used and mapping the main approaches in the literature, while Section 3.3 screens European national policy documents, using a country questionnaire, to identify material use and broader resource use targets.

2. Methods

2.1. Literature review on material reduction targets

Only one systematic literature review on material reduction targets for metal and mineral resources from 2002 to 2022 appears available by (Dudka et al., 2025) who used Scopus to search for articles in English defining absolute boundaries for mineral resource use. In addition, (Thomassen et al., 2024) provide an overview of selected studies with a focus on the net accessibility of mineral, metal, and fossil resources within a CE setting.

Our paper aims to complement this previous work by (1) identifying additional relevant literature between 2000 and 2025 based on a systematic literature review of both the scientific and grey literature (using a broader Google Scholar search as described below) (Sections 3.1–3.2) and (2) classifying material reduction targets into different approaches (Section 3.3).

The focus is on both biotic (biomass) and abiotic raw materials (metals, non-metallic minerals, fossil energy carriers) as often times they are all together examined and captured e.g. in indicators such as the material footprint (raw material consumption (RMC)) or figures on domestic material use (e.g., domestic material consumption (DMC)) (Eurostat, 2018; Wiedmann et al., 2015).

We used Google Scholar (Google, 2025) via Publish or Perish (PoP) (Harzing, 2025a) to capture both peer-reviewed and policy-oriented grey literature. Google Scholar's broad coverage across disciplines and document types complements more traditional scientifically oriented searches (e.g., by (Dudka et al., 2025)) using engines such as Scopus or Web of Science, which focus more narrowly on high-impact, peer-reviewed journals (Haddaway et al., 2015; Harzing and Alakangas, 2016). A key word search was performed using the key terms and synonyms (i.e., alternative terms to refer to the keyword) shown in Table 1.

We use the PoP-software (Harzing, 2025) to extract keyword search results of the top-20 papers as ranked by the Google Scholar rank algorithm (Beel and Gipp, 2009) for each year from 2000 to March 29th 2025. A total of 500 potentially relevant papers were then manually screened based on their title and abstract (Supplementary Information 01). This resulted in a short-list of 60 publications which were subject to a manual in-depth screening using the following criteria: (1) the study provides a review, analysis, development, or application of raw materials targets, (2) the study covers either global targets or examines targets at regional, country, or sectoral level, and (3) the study is available in English or at least includes an extensive English summary. After this, a final list of 16 publications remained solely from the Google Scholar analysis.

During the screening process, additional literature was identified through citation linking (i.e. backward and forward citation tracking of key articles identified in the initial search) and by consulting existing literature overviews (Dudka et al., 2025; Thomassen et al., 2024). Next to peer-reviewed literature, also "grey literature" (non-peer-reviewed, e.g., reports) was added to the literature list. These additional literature sources are highlighted as "relevant (manually added)" in the accompanying *Supplementary Information 01 (Excel file)*.

The final list of literature includes **31 publications** (Table 2). For the selected literature, information on the methods was collected and the studies classified into different approaches to target setting.

2.2. Inventory of European resource-use targets

We compiled data from national policy programs, legislation, and strategies, and validated it through consultation with European Environment Information and Observation Network (Eionet) representatives (EEA, 2025a). The analysis covers the EU-27 plus Iceland, Norway, Switzerland, Kosovo, and Turkey; Belgium was analyzed at regional level (Flanders, Wallonia, Brussels). No information was reported by Liechtenstein.

While focusing primarily on raw materials, we also include targets related to waste, products, water use, and environmental footprints as these are of particular relevance for resource and CE policy in Europe (see a justification of this scope and additional methods details in Supporting Information 02). We therefore refer to "resource use targets". Energy-related targets are excluded as they generally fall under climate and energy policy; however, water-use targets reported as part of CE strategies are included. Environmental footprint targets – in addition to territorial targets – are included to capture life-cycle and consumption-based impacts, consistent with CE monitoring approaches (EEA, 2024; Eurostat, 2025; Helander et al., 2019; Nuss et al., 2021).

The analysis followed a two-step approach: compiling targets from European Topic Centre on Circular Economy and Resource Use (ETC CE)

Table 1
Keywords used for the literature search on materials targets.

Keyword	Synonyms
material(s)	raw material(s) resource(s) mineral(s) metal(s)
target(s)	planetary boundary limit(s) threshold(s) budget(s)
Sustainable	environment ecologic circular economy

Table 2
Results of the literature review highlighting studies with a focus on material targets.

Target Type	Material focus	Geographical scope	Temporal scope	Target (if applicable)	Methodological Details	Authors
Retrospective	Building materials	Germany	2045	Resource use in life-cycle impact assessment (LCIA) compared to downscaled planetary boundaries (PBs)	Application of the LCIA-PB (planetary boundary) concept by (Sala et al., 2020) to the construction sector. Sala and colleagues used the factor 2 concept by (Bringezu, 2015) and (Buczko et al., 2016).	(Binz and Jäger, 2024)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global and individual countries	1970–2017	A target of 25 Gt/a to 50 Gt/a was set as the boundary based on (Bringezu, 2015)	Safe operating space based on (Bringezu, 2015) and allocated by population to individual countries.	(Hickel et al., 2022)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	6–12 tons per person primary extraction in 2050 (abiotic raw materials)	Return to half to a full level of extraction in 2000 (Bringezu, 2015).	(Bringezu, 2019)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2030	Global Total Material Consumption (TMC) of 45 billion tons, or 5 tons per person (this would mean a factor 2 reduction at the global level and by a factor 10 for the industrialized countries	Safe operating space based on the TMC value in 1970. The year 1970 was taken as a sustainable level for the TMC, which was at 45 billion tons or 5 tons per capita.	(Buczko et al., 2016)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	Total Material Consumption (TMC) = 6–12 tons per person and year (<2 tons per person for biotics). Raw Material Consumption (RMC) = 3–6 tons per person until 2050	Return to 2000 levels (high target), half 2000 level (low target)	(Bringezu, 2015)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	Total Material Requirement (TMR) of 8 tons per person and year in Finland	Based on work of (Bringezu, 2009)	(Lettenmeier et al., 2014)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2030 and 2050	Various targets discussed (e.g. 5.6–6.1 tons per capita Total Material Consumption (TMC) (abiotic).	Inspired e.g. by work of Schmidt-Bleek and others.	(Bringezu, 2014)
Retrospective	Aggregated and for individual groups (biomass, fossil fuels, metal ores, non-metallic minerals)	EU	2050	Return to 2000 level annual mineral extraction rate (= 6 tons per capita Raw Material Consumption (RMC))	Assumed return to extraction levels of the year 2000 globally.	(Bringezu, 2011)
Materials availability	Individual materials	Only conceptual examples	Only conceptual examples	Conceptual discussion. No quantitative targets given	Includes an overview with classification into four target types, namely (1) reserves vs. extraction, (2) historical primary resource extraction rate, (3) relationship with other planetary boundaries, and (4) scenario analysis.	(Thomassen et al., 2024)
Materials availability	Various (review)	Various (review)	Various (review)	Various (based on literature)	Review of life cycle impact assessment (LCIA) methods examining resource depletion or dissipation.	(Beylot et al., 2024)
Materials availability	Metal-specific (Fe, Al, Cu, Mn)	Global	time-dependent (scenarios until 2100)	Varies depending on the year and raw material	Maximum dissipation rate that allows to maintain resource availability in the future.	(Baabou et al., 2022)
Materials availability	Individual materials (Dy, Nd, Cd, Te, Se, In)	Global	2050	To meet the 1.5 °C target, Te, Se, and Dy in nearly all scenarios may face physical shortage based on present mineral reserve.	Minerals shortage to meet demand in SSP scenarios is assessed by comparing total cumulative demand to present production capacity.	(Wang et al., 2022)
Materials availability	42 metals	Global	2050	Varies depending on the metal	Sustainable extraction rates for metals between 2010 and 2050 based on extractable global resources.	(Henckens et al., 2014)
Materials availability	Various materials (Cu, Al, Au, Fe, Pb, Sn, Zn)	Global	ca. 2200	Various (depending on material)	Carrying capacity defined as the total quantity of existing accessible reserves divided by a specified time horizon (200 years).	(Yossapoll et al., 2002)

(continued on next page)

Table 2 (*continued*)

Target Type	Material focus	Geographical scope	Temporal scope	Target (if applicable)	Methodological Details	Authors
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2023	To provide a Decent Living Standard (DLS) globally, a material footprint (MF) of 6 t/(cap*yr) (lower and upper bound of 3 and 14 t/(cap*yr)) is required.	Use of decent living standards (DLS) concept to derive at minimum material requirements per person to alleviate poverty.	(Vélez-Henao and Pauliuk, 2023)
Impact-based	Individual materials (Fe, Al, Cu, Zn, Pb, Ni)	Global	time-dependent (scenarios until 2100)	Global in-use metal stocks need to converge around 7 tons per capita. High income countries need to contract from ca. 12 tons per capita to 7 tons per capita.	Allocation of the carbon emissions budget for "well below 2C" to each metal sector based on the RCP 2.6. Method: Material Flow Analysis (MFA) and Life-Cycle Assessment (LCA) emissions intensities (van der Voet et al., 2019). A world with the same per-capita metal stock is assumed.	(Watari et al., 2021b)
Impact-based	Individual materials (crude oil, Cu, Li-ion batteries, Co, metals (aggregated)	Germany	differs depending on the raw material	Varies depending on the year and raw material	Linkage of planetary boundary concept (e.g., climate change, land system change, water use, P and N emissions) to derive material targets.	(Dittrich et al., 2021)
Impact-based	Metal-specific (Al, Cu, Fe, Zn, Pb, Sn, Ni, Au, Ag, Pt, Ti, Cr)	Global	differs depending on the raw material	Varies depending on the raw material. For major metals, the ecological resource availability (ERA) budgets are 40 times smaller than production volumes in 2016.	Estimation of the ecological resource availability based on down-scaled planetary boundaries and allocation according to current emissions shares.	(Desing et al., 2020)
Impact-based	Individual materials (Fe, Al, Cu, Zn, Pb, Ni)	Global	time-dependent (scenarios until 2100)	7 tons per capita of metal stock - roughly half the current level in high-income countries.	Requirements for six metals aligned with global climate goals were examined. Method: Dynamic material flow analysis (MFA) model with life-cycle assessment (LCA) emission intensities.	(Watari et al., 2020)
Impact-based	not specified	Global	not specified	no target proposed	Recommends to base targets on scenarios analysis of future materials demand and sustainable supply e.g. in SSPs.	(Graedel, 2019)
Impact-based	Phosphorus (P)	Various countries	2011	All countries transgress P planetary boundaries	Phosphorus (P) exceedance footprint based on consumption-based P requirements of countries compared to the respective planetary boundary.	(Li et al., 2019)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Canada, Spain	1995–2009	Stabilization of consumption-based resource flows and stocks.	Biophysical accounting framework including three measures of physical stocks, three measures of aggregate consumption (incl. material footprint), and four indicators of sustainable scale.	(Fanning and O'Neill, 2016)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2030	Raw material consumption (RMC) of 8 tons per capita and year by 2030 based on (Dittrich et al., 2012)	Assuming medium population growth, current best practices, and no rebound between different material uses as described in Dittrich et al., 2012.	(Hoekstra and Wiedmann, 2014)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	Raw material consumption (RMC) of 6–8 tons per capita in 2050	Based on decoupling analyses (UNEP IRP, 2011). Using assumptions of the IPCC SRES scenarios.	(UNEP IRP, 2014)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	EU	2020 and 2050	Domestic material consumption (DMC): 2020: −30%, 2050: −70% (reduction varies by raw material category)	Chapter 4 describes possible reduction potentials per raw material category building on the target on greenhouse gas (GHG) emissions and energy use and assumed best practices.	(BIO Intelligence Service et al., 2012)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2030 and 2050	8 tons per capita and year by 2030 and 10 tons per capita by 2050	Assuming medium population growth, current best practices, and no rebound between different material uses.	(Dittrich et al., 2012)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	Raw material consumption (RMC) of 6–8 tons per capita in 2050	Decoupling analysis. Using assumptions of the IPCC SRES scenarios.	(UNEP IRP, 2011)
Impact-based	Aggregated (biomass, fossil fuels, metal ores, non-metallic minerals)	Global	2050	Raw material consumption (RMC) of 6–8 tons per capita in 2050	Based on three forced future scenarios for 2050 under e.g., climate protection considerations.	(Fischer-Kowalski et al., 2010)

(*continued on next page*)

Table 2 (*continued*)

Target Type	Material focus	Geographical scope	Temporal scope	Target (if applicable)	Methodological Details	Authors
Target review	Various (review)	Various (review)	Various (review)	Various (based on literature)	Literature review. Distinction between three target types, namely (1) retrospective, (2) reserve-oriented, and (3) ecosystem-oriented.	(Dudka et al., 2025)
Target review	Individual materials (Fe, Al, Cu, Zn, Pb, Ni) (review)	Global	2100	Discussion of metal scarcity concerns in scenarios and how metal scenarios could be related to planetary limits.	Review of metal scenarios showed that most major metal supplied could be constrained by physical availability. Results depend on assumptions of ultimately recoverable resources. Only a limited link between major metal scenarios and planetary limits could be found in the literature.	(Watari et al., 2021a)
Target review	Various (review)	EEA countries	2013	various targets assessed such as Raw material consumption (RMC), resource efficiency, waste management, etc.	Literature review for European countries	(Bahn-Walkowiak and Steger, 2015)

country profiles (ETC CE, 2022b, 2024a), and validating them with national representatives. The finalized country compilations (*Supplementary Information 02, Word*) underpin the assessment (*Supplementary Information 03)*.

We focus on quantitative targets with implementation deadlines between 2020 and 2050 that exceed EU-level ambitions, including draft and regional targets (cut-off: 31 May 2025). Targets are classified as *binding* or *non-binding* and grouped into eight categories, further subdivided into **64** more specific sub-categories (types) (Supplementary Information 03). To avoid double counting, each national target was classified only under the most appropriate and specific ‘type’. Due to limited policy detail, systematic mapping to analytical approaches identified in the literature was not possible.

3. Results and discussion

3.1. Approaches to materials reduction target setting

Of the 31 publications examined in depth (Table 2), three studies included literature overviews for material target setting (Bahn-Walkowiak and Steger, 2015; Dudka et al., 2025; Watari et al., 2021a) while the remaining 28 studies discussed or applied different approaches for target setting (Fig. 1).

From the studies providing target literature reviews, Dudka and colleagues (Dudka et al., 2025) reviewed publications between 2000 and 2022 and distinguished the following three boundary typologies: (1) retrospective (a reduction target relative to a reference state in the past), (2) reserve-oriented (comparing demand for raw materials with remaining reserves), and (3) ecosystem-oriented (where the boundary for materials is indirectly defined by examining the impact on other planetary boundaries). Complementary, (Thomassen et al., 2024), focusing on materials-availability targets rather than offering a full literature review, distinguish four approaches to defining a safe operating space for raw material extraction: (1) relating material reserves to annual extraction, (2) assuming a safe historical raw materials extraction rate, (3) linking raw materials related environmental impacts to other planetary boundaries, and (4) scenario analysis, e.g., based on climate protection or wider sustainability transition pathways. Furthermore, (Bahn-Walkowiak and Steger, 2015) review resource policy targets, while (Watari et al., 2021a) reviewed metal scenarios in the context of science-based targets for material use but do not distinguish them regarding different scientific approaches for target setting.

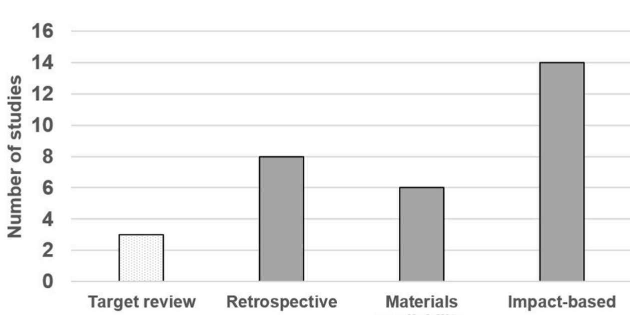

Fig. 1. Analytical approaches to material target setting according to the literature review.

Based on our literature review and following the target typologies discussed by (Dudka et al., 2025; Thomassen et al., 2024), we classified the targets found in the literature review into the following three types of material target approaches (see also Table 2):

(1) Retrospective approach (safe historical raw materials extraction rates)

Retrospective target-setting approaches define material use boundaries by referencing past levels of extraction or consumption, without incorporating considerations such as accessible reserves or environmental thresholds. These targets typically propose a reduction relative to a selected historical benchmark year.

Such methods set targets based on historical extraction rates considered environmentally "safe". In other words, they estimate a point in time when total global resource extraction (both abiotic and biotic) remained at a level that the Earth system could still tolerate – without causing unacceptable environmental degradation or triggering tipping points. The underlying rationale is precautionary: material flows throughout their life cycles create environmental and social stresses at multiple locations, and these cumulative pressures should therefore be limited (Bringezu, 2015).

However, the literature refers to a wide range of different baseline years for materials use (which in turn directly influences the absolute material target). For instance, (Buczko et al., 2016) argue that, from an environmental perspective, 1970 may be used as a global baseline year for material use (citing (Wiedenhofer et al., 2013) but without providing further reasoning regarding this choice), while noting that other authors instead propose 1950 as a baseline because the sharp fall in fossil-fuel prices relative to labor and capital around that time triggered the surge in resource and energy use – and associated environmental pressures – in industrialized countries (Pfister, 1995). (Wiedenhofer et al., 2013) analyzed structural breaks in the metabolism of industrialized countries and found a stabilization of per-capita energy and resource use around

1970. However, it remains unclear why this year was chosen by (Buczko et al., 2016) as a baseline for a resource target. The target values proposed by (Buczko et al., 2016) was subsequently taken up by the European Commission in benchmarking resource use in the EU consumption footprint (Sala et al., 2020). On the other hand, (Dittrich et al., 2012) refer to 1992 as a possible year at which to freeze global resource extraction (the year of the first Rio Summit) at around 50 billion tons.

(Hickel et al., 2022) evaluate the level of materials use in different countries and regions based on the work by (Bringezu, 2015), who outlines a possible target corridor of 3–6 tons per person (RMC) until 2050 by assuming a necessary halving of global resource consumption (resulting in a low target value) or returning to the level of 2000 (resulting in a high target level). A level of 5 tons per capita (RMC) is suggested for "long-term orientation towards 2050″ (Bringezu, 2015) (the same paper also provides an overview of typical per-capita raw materials use levels found in the literature using this approach). Similarly, (Bringezu, 2011) suggests capping total material consumption in 2050 at the 2000 level of 55 billion tons per year. An overview of the material target proposals by Bringezu is also given in (Bringezu, 2022). However, according to Thomassen and colleagues, it remains unclear why, e.g., the 2000 level is considered a sustainable level (Thomassen et al., 2024).

For example, Schmidt-Bleek (cited in (Bringezu, 2014)) suggested that, to achieve a fair and sustainable global distribution of natural resource use, industrialized countries would need to reduce their resource consumption by about a factor of ten so that developing countries could substantially increase their use while overall global resource extraction declines (Schmidt-Bleek, 1994, 1992). This factor was presented as an estimated yardstick for the scale of dematerialization needed rather than as a precisely derived threshold. Since then, global trends did not follow this path: global material use has almost doubled since 2000 and staying rather stable (and at very high values) for high income countries (UNEP IRP, 2024).

Critiques of the above approaches highlight that such attempts (1) do not link material use to specific environmental impacts and the exceedance of associated thresholds), (2) make no connections to the transition to a more circular and climate-neutral society including the specific countermeasures to resource use this entails, and (3) lack a systemic view of the scale of these necessary countermeasures, resulting in insufficient policy proposals (Watari et al., 2021b), which points to a gap relative to core SBT criteria such as biophysical feasibility, quantifiability, and a transparent analytical rationale (Andersen et al., 2021).

Indeed, the rationale for selecting a specific point in time in the past is not always clear and might lack explicit environmental justification. (Dudka et al., 2025) find that such retrospective approaches are *"not science-based but rather based on an arbitrary choice"*.

The level of material aggregation using the retrospective approach is usually high (i.e., at the level of four raw material categories, biomass, fossil energy carriers, metal ores, and non-metallic minerals). However, such approaches are widespread in the literature and we identified a total of **8 studies** using the retrospective approach (Table 2).

(2) Materials availability and accessibility approach

Several studies regard the availability and accessibility of raw materials as a distinct area requiring protection – referred to in life cycle assessment (LCA) terminology as an Area of Protection (AoP) (Dewulf et al., 2015). Depletion-based assessment methods (i.e., methods that estimate the impact related to the reduction of the availability of mineral resources) have been widely used in life-cycle impact assessment (LCIA) (Beylot et al., 2024). More recently, several methods were developed to address issues of reduced mineral resource accessibility and dissipation in LCIA (Beylot et al., 2024). There is no scientific consensus of how to assess abiotic resource depletion in LCA (Berger et al., 2020; Sonderegger et al., 2020).

In our literature review, we identified a total of **6 studies** examining approaches for assessing materials availability and accessibility in the context of target setting (Table 2). In this context, availability is the total amount of resources that exist, whereas accessibility is the sustainably usable portion of resources and rate at which these can be provided – limited by extraction constraints, technological/energy requirements, and losses/dissipation (Thomassen et al., 2024). However, we note that our assessment did not include a detailed review of the LCA literature as such reviews are provided elsewhere (e.g., see (Berger et al., 2020; Sonderegger et al., 2020)).

For example, (Thomassen et al., 2024) examine how much extraction of minerals, metals, and fossil resources could be considered environmentally sustainable within a CE. The authors quantify extraction limits by assessing the net accessibility rate considering available resources in both the eco- and technosphere. Similarly, (Baabou et al., 2022) examine the maximum dissipation rate that allows to maintain resource availability in the future. Dissipation is the portion of a material flow (after extraction, recycling, reuse, etc.) that is not recoverable, so it becomes permanently unavailable (e.g., because it is dispersed, degraded, locked into products or processes, or otherwise lost in ways that users cannot retrieve or use it (Baabou et al., 2022). In (Baabou et al., 2022), building-sector dissipation rates for iron (+70%), copper (+56%), and manganese (+68%) exceed the carrying capacity (CC) (defined as the maximum sustainable dissipation rate that preserves long-term resource availability and services), while aluminum (−90%) remains well below it. Several studies looked at the demand for raw materials compared to available reserves or ultimately extractable resources (Henckens et al., 2014; Wang et al., 2022; Yossapoll et al., 2002).

The reviewed studies vary widely in their coverage of raw materials, ranging from analyses of individual elements (e.g., Dy, Nd, Cd, Te, Se, In) (Wang et al., 2022) and metal-specific assessments (Fe, Al, Cu, Mn) (Baabou et al., 2022) to broader reviews encompassing multiple materials (e.g., Cu, Al, Au, Fe, Pb, Sn, Zn) (Yossapoll et al., 2002) and even comprehensive evaluations covering up to 42 metals (Henckens et al., 2014) (Table 2).

The quantitative insights reported in the literature are highly heterogeneous, with many studies offering only conceptual discussions without or only with a few examples of specific numerical targets (Beylot et al., 2024; Thomassen et al., 2024), while others provide material- or year-dependent estimates; notably, some analyses project that, to meet the 1.5 °C climate target, elements such as tellurium (Te) (e.g., cadmium-tellurium (CdTe)/ Copper Indium Gallium Selenide (CIGS) solar cells), selenium (Se) (e.g., CIGS, photovoltaic glass/coatings), and dysprosium (Dy) (e.g., neodymium-iron-boron (NdFeB) magnets in wind turbines/electric vehicle motors) could face physical shortages under most modeled scenarios (Wang et al., 2022).

(3) Impact-based approaches (material use linked to other planetary boundaries)

This category includes approaches that define the boundary for raw materials use indirectly, i.e., through the impacts that material use has on other planetary boundaries or environmental and/or socio-economic goals (thereby estimating the material demand required to stay within a specific boundary). This covers also studies that, based on this approach, investigate the demand for raw materials in target-scenarios to achieve other goals such as climate protection, address the triple planetary crisis, and the Sustainable Development Goals (SDGs). This category was found to be most prominent in the literature with a total of **14 literature sources** identified during the scientific review (Table 2).

Impact of raw materials use on other planetary boundaries:

This approach sets material targets by linking them to other planetary boundaries, such as, e.g., climate change or freshwater use (Desing et al., 2020; Dittrich et al., 2021). It allocates a share of the global environmental space to a country, e.g., based on population (equal per capita) or another downscaling approach (e.g., grandfathering (i.e., allocating emissions allowances or resource shares in proportion to historical levels)) (Christis et al., 2024), and then assigns a portion of that share to specific resource uses using current emission shares.

For example, Germany's metal extraction budget was calculated using this method (Dittrich et al., 2021) which yielded drastically lower resource budgets compared to current production and consumption levels. In one case study, the maximum allowable use of copper was estimated at 5040 kt, assuming equal per-capita allocation for downscaling the carbon budget (climate change planetary boundary) and constant per-unit impacts; at 2010 use levels (when copper had a share of 0.75% of total GHG emissions), this budget would be exhausted in roughly four years (Dittrich et al., 2021). Another approach belonging to this assessment type is by (Li et al., 2019) who examined the phosphorus consumption footprint and compared this with the current phosphorus planetary boundary.

Raw materials use in sustainability scenarios:

This approach defines sustainable resource use through sustainability scenario analysis that stays within existing planetary boundaries. This method models future production and consumption patterns to determine safe extraction rates. Examples include work by (Watari et al., 2020) to derive at metal extraction figures to stay within climate targets, work by (Vélez-Henao and Pauliuk, 2023) to use the concept of decent living standards for calculating respective material requirements, or decoupling scenarios by the UNEP International Resource Panel aligned with climate targets (UNEP IRP, 2011).

(Dittrich et al., 2012) argue that based on current best practices in countries to lower their raw materials consumption (RMC) and assuming the complete substitution of fossil fuels without increases of other materials might result in a level of **8 tons per capita by 2030**. This limit was also used in work by (Hoekstra and Wiedmann, 2014; O'Neill et al., 2018) to benchmark resource footprints.

The UNEP International Resource Panel (IRP) sketches out a possible material target (RMC) of **6–8 tons per capita and year in 2050** based on different decoupling analysis conducted (UNEP IRP, 2014, 2011). This presents a target under which there would be convergence in raw materials use, i.e., developing countries would achieve a rising consumption of raw materials, while industrialized countries would need to reduce the intensity of the raw materials use (equitable use of natural resources).

The global sustainability transition scenario of the 2024 Global Resource Outlook, estimates a global material footprint of around 12 tons per capita, in 2060 (UNEP IRP, 2024). Lower-income societies see stronger raw material extraction growth than higher-income groups to build essential stocks like infrastructure – already achieved historically by the Global North. Per capita resource use in low-income countries rises to ~7 tons (aligning with decent living standards) narrowing material footprint disparities to higher income countries. However, this scenario exercise did not intend to estimate a sustainable level of material use but it is rather an exploration of the possible impact of policy options to curb material use, noting that this scenario does not account for the full potential of CE policies which are expected to deliver larger improvements in resource efficiency.

Advances in integrated scenario analysis increasingly enable the incorporation of material considerations into global climate and sustainability assessments (Pauliuk et al., 2017). For instance, (Deetman et al., 2021; Van der Voet et al., 2019) proposed an analytical framework that links life cycle assessment (LCA) with material flow analysis (MFA) to evaluate the comprehensive environmental impacts of metal supply and demand scenarios. In a similar vein, (UNEP IRP, 2024) has developed material outlooks aligned with climate and sustainability goals, allowing the quantification of potential material corridors for use in future target setting. The Global Environment Outlook (GEO-7) (UNEP, 2025) also includes a dedicated assessment of material requirements for achieving the UN Sustainable Development Goals (SDGs). Scenario modeling targeting specific materials such as plastics exist (OECD, 2022). EU projects such as CircEUlar (CircEUlar, 2025) and CIRCOMOD (CIRCOMOD, 2025) also integrate material aspects into climate modeling. Collectively, these approaches provide scenario-based estimates of future material demand, environmental impacts, and mitigation potential, thereby identifying material corridors and leverage points for aligning resource use with climate and sustainability goals.

Furthermore, an increasing number of studies examine the view of human needs (instead of purely focusing on ecological constraints) and utilize the concept of "decent living standards (DLS)" when developing minimum material thresholds (Vélez-Henao and Pauliuk, 2024, 2023) (instead of maximum levels e.g. when benchmarking against planetary boundaries). A recent study by (Streeck et al., 2025) demonstrates that moderate expansions in societal material stocks could universally achieve DLS. Notably, developed countries already possess adequate stocks for DLS, underscoring the feasibility of equitable resource distribution through optimized use rather than unchecked growth.

An overview of all short-listed studies is given in Table 2.

3.2. Authors and institutions involved in different target assessment frameworks

Different institutions and authors have been advancing discussions on the three different target setting approaches. Fig. 2 visualizes the collaboration network between authors, their institutions, and the methodological approaches they have contributed to. Each node represents a method (green), institution (orange), or author (blue). The node size indicates the level of engagement – how frequently an author or institution contributes to different methodological domains – while edge thickness (strength) represents the number of times a specific author or institution has published on a given method, reflecting the intensity of that relationship.

The network reveals distinct clusters centered around key methodological themes. The Wuppertal Institute for Climate, Environment and Energy (WI) stands out as a major hub in the "Retrospective" approach, showing repeated and strong linkages to its affiliated researchers, notably Bringezu and Lettenmeier. The thick connections between WI and this method reflect the institute's sustained leadership in this area. Other contributors such as the Sustainable Europe Research Institute (SERI), the Autonomous University of Barcelona (UAB), and the University of Kassel (Uni Kassel) also display meaningful connections within this cluster, though with less intensity.

In contrast, the Material Availability cluster – comprising the University of Antwerp (Uni Antwerp), the Bureau de Recherches Géologiques et Minières (BRGM), the International Reference Center for Life Cycle Assessment and Sustainable Transition (CIRAIG), the Chinese Academy of Sciences (CAS), and the New York Institute of Technology (NYIT) – appears disconnected from the rest of the network. This isolation suggests that research on material availability has developed along a more specialized trajectory, with limited overlap of authors or institutional collaborations across other methodological areas.

By comparison, the Impact-Based methods demonstrate greater interconnectivity. Institutions such as the National Institute for Environmental Studies (NIES) and the Wuppertal Institute (WI) act as bridges linking multiple methodological domains, highlighting their broad engagement across sustainability research. The International Resource Panel is a UNEP-hosted science–policy panel, so reports appear under 'UNEP IRP' in the author field of Fig. 2. Overall, the network illustrates how a small number of highly connected institutions function as interdisciplinary anchors, while others contribute to more focused and independent streams of methodological development. As highlighted above, the Impact-Based approaches, especially related to scenarios building, are also the most prominent in the literature indicated by its larger node size.

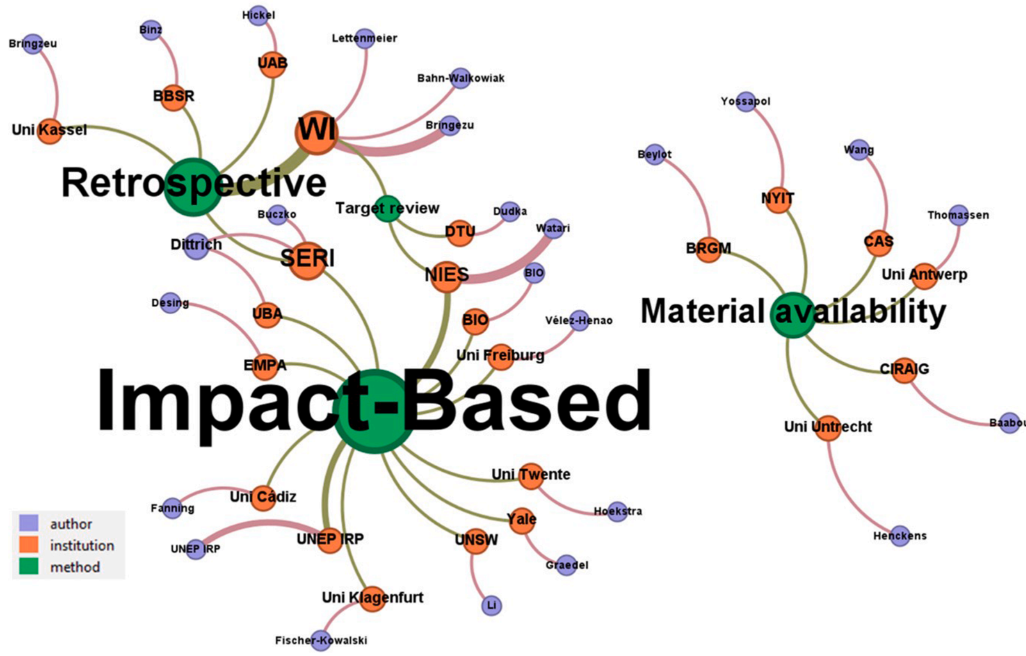

Fig. 2. Visualization of different authors and institutions contributing to three material target setting approaches (based on Supplementary Information 01). The node size reflects degree centrality. Figure created using Gephi v0.10 (Bastian et al., 2009). A list of institutional abbreviations can be found in Supporting Information 01.

3.3. Resource targets in European countries

All 32 European countries who participated in the validation process reported back on their resource targets. A total of 398 targets were analyzed across 20 different resources-/product-/ waste-types (e.g., mixed waste, raw materials, beverage containers, food waste, etc.) – in the following simply termed "resource focus"). The detailed country-level data are provided in the Supplementary Information.

Overall pattern of target adoption across Europe (Table 3).

Across Europe, most countries cover several target categories with at least one target per category, but there is considerable heterogeneity in whether these constitute binding legal targets (dark-orange shading) or merely non-binding commitments (Table 3). Product making, waste prevention and waste reuse (RU), recycle (RY), and recovery (RE) are the target categories that are most frequently addressed by European countries (in terms of the total number of targets found), and the highest number of targets is set for the 2026–2035 period (column F in *Supplementary Information S03*).

For instance, both Wallonia (Belgium) and France have adopted >20 targets addressing most of the categories in Table 3, while only a few targets have been set by e.g. the Czech Republic (CZ) and Denmark (DK). Wallonia (BE-WA) and Denmark (DK) have largely followed a non-binding approach, while the targets shaped by France (FR) and the Czech Republic (CZ) mainly are binding.

Most binding national targets are concentrated in the "product making" category and, in this domain, they predominate over non-binding commitments (Table 3). These binding targets typically include bans or quantitative limits on certain plastic items placed on the market, minimum recycled-content requirements in new products, and obligations for distributors to provide reusable and refillable packaging options.

By contrast, the "resource use/efficiency" category shows the opposite pattern: only two countries – France (FR) and Switzerland (CH) – have binding targets (Table 3). In France, Law No 2015–992 on the Energy Transition for Green Growth sets a target of a 30% reduction in resource consumption relative to GDP between 2010 and 2030 (ETC CE, 2022c), while the 2020 Anti-Waste Law for a CE aims to reduce the quantity of waste from economic activities per unit of value produced by 5% by 2030 compared with 2010 levels, with particular emphasis on the construction and public works sector (EEA, 2025b) (*Supplementary Information 02*). In Switzerland, Article 10 of the Federal Act on Climate Protection Targets, Innovation, and the Strengthening of Energy

Table 3
EU resource targets 2020–2050 per category. An "x" indicates that at least one (or more) target(s) within the respective policy category exists. Dark orange color coding indicates that at least one (or more) binding targets exist in that country.

Category	AT	BE-BX	BE-FL	BE-WA	BG	CH	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IS	IT	LT	LU	LV	MT	NL	NO	PL	PT	RO	SE	SI	SK	TR
Resource use and efficiency	x		x	x	x	x			x		x		x	x	x		x	x		x	x		x		x	x	x	x	x		x		
Product making	x		x	x	x		x		x		x	x	x	x	x	x	x		x	x		x	x	x	x	x		x	x	x		x	
Consumption				x					x	x	x	x			x	x		x		x	x					x		x			x	x	
Waste prevention	x	x	x	x	x	x			x		x	x	x		x	x	x	x	x	x	x	x	x		x	x		x	x	x			
Waste collection	x	x	x				x					x	x					x	x	x		x		x		x			x	x		x	
Waste RU/RY/RE		x	x	x		x		x	x	x	x		x	x	x	x	x	x		x	x	x	x		x	x		x		x		x	x
Waste incineration and landfill	x	x		x				x		x		x	x	x	x				x	x	x	x	x		x			x					
Other			x	x	x				x																		x			x			

Security sets a target of at least net-zero emissions by 2040, covering both direct and indirect emissions (Schweizerische Eidgenossenschaft, 2022) (*Supplementary Information 02*); footprint indicators are included in our assessment as these are considered central to broader resource-use and circular-economy monitoring (EEA, 2024; Helander et al., 2019; Nuss et al., 2021).

Target stringency, status and resource focus (Fig. 3).

A comparison of stringency (binding vs. non-binding) and adoption status (draft vs. adopted) shows that while almost all targets (>98%) inventoried are adopted (only 8 targets were found in draft policies), around 67% of all targets remain at proposal or strategy level (stringency: "non-binding") with only 32% having been translated into legally binding provisions ("binding") (for the remaining 1% relevant data on the target status could not be collected) (Fig. 3).

In terms of resources and waste focus, several targets address mixed waste streams (31%), followed by aggregate raw materials (14%) (e.g., targets focusing on indicators such as the material footprint, domestic material consumption, circular material use rate, etc.), and product-level targets (both cross-cutting (5%) and specific, such as beverage containers (13%)). Numerous targets also address specific material and waste streams (e.g., plastics (12%) food waste (5%), construction and demolition (C&D) waste (5%), biowaste (4%)), while others focus on particular materials (e.g., metals, biomass) (Fig. 3).

For instance, Portugal's National Waste Management Plan targets the decoupling of economic growth from material consumption (raw materials overall) by 2030 relative to 2016 (k€/t) (ETC CE, 2024b). Greece's Law 4819/2021 establishes a binding 30% reduction in per-capita food waste generation by 2030, relative to 2022, at retail and consumer levels (EEA, 2025c) (*Supplementary Information 02*).

Resource use and efficiency targets by target type (Fig. 4).

A particular interest of this paper is on absolute material reduction targets which are included in the "resource use & efficiency" category. Within this broader category, target types are dominated by productivity (ratio of output (e.g. GDP) to input (e.g. resources)) and efficiency (resource inputs for a given output) improvements (e.g., increase domestic resource productivity by year X) and by increases in the circular use of materials (with progress often measured via the circular material use rate (CMUR), followed by targets for absolute reductions in material use (Fig. 4). Few targets directly address productivity or efficiency for other resources (e.g., waste, water) and environmental footprints. This pattern indicates that macro-level decoupling remains a central policy

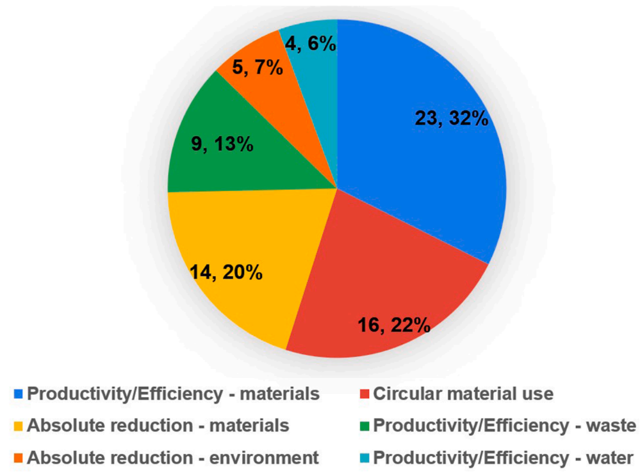

Fig. 4. European resource use and efficiency targets by target type. Absolute target numbers and percentages shown in the figure.

narrative, with relative decoupling metrics (productivity/efficiency) predominating over absolute reduction metrics.

Across the European country sample, **absolute material-reduction targets** make up ca. 20% (14 targets in total) of all resource use and efficiency targets and these are used mainly as strategic steering signals typically embedded in circular-economy strategies or sustainability plans, and only rarely as binding law (*Supplementary Information 03*). Many of these targets are closely aligned with, or build upon, existing EU policy frameworks, with countries in some cases increasing ambition levels, shortening timelines, or expanding sectoral and resource scope. Examples of such absolute reduction targets include consumption-based "material footprint" caps (e.g., Austria's 7 t/cap by 2050; Flanders −30% by 2030; Finland capping 2035 use at 2015 levels; Germany's 6–8 t/cap "guiding principle" by 2045; Netherlands −50% use of primary raw materials by 2030) and some targets focusing on domestic material use (e.g., domestic material consumption (DMC) and direct material input (DMI)) (e.g., Wallonia −25% by 2030).

Although absolute reduction targets are visible in European countries (Fig. 4), our reading of the underlying policy documents suggests that their scientific derivation is usually not spelled out in detail. In most

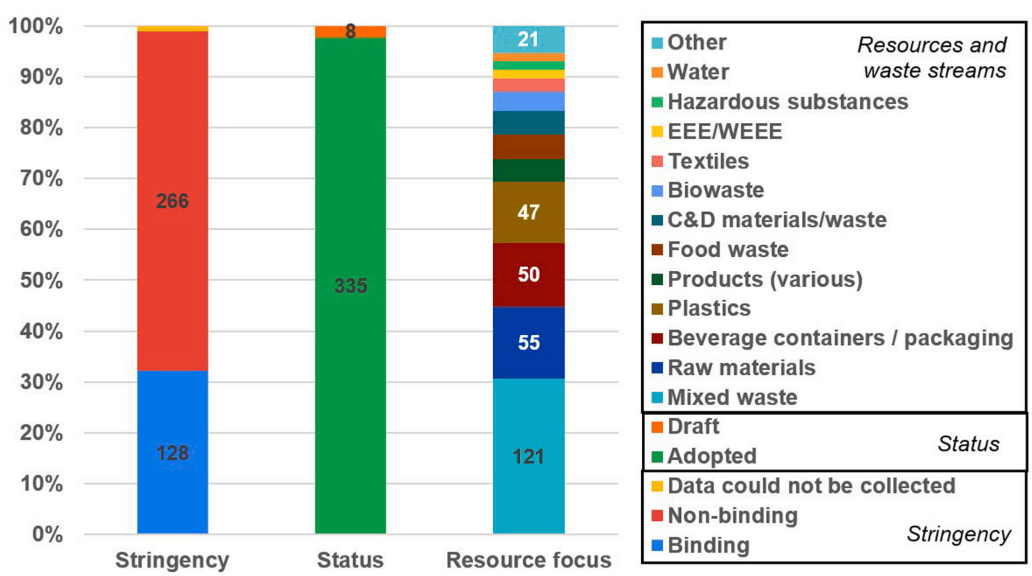

Fig. 3. EU resource targets 2020–2050 by level of stringency, level of adoption (status), and resources- and waste-type focus. Absolute target numbers shown in the figure.

cases, strategies set quantitative targets for the material footprint (RMC) or domestic material use (DMC/DMI) without explaining the rationale used to derive these reference values, i.e., whether they arise from a retrospective caps approach anchored in "safe" historical extraction rates, a materials-availability or accessibility constraints approach, or an impact-based approach grounded in planetary boundaries and / or sustainability scenarios (Sections 3.1–3.2). For example, Germany's National CE Strategy (NKWS) represents a partial exception, citing (UNEP IRP, 2014, 2011) decoupling research and thereby indicating an impact-based scenario rationale. Another example is the Swiss Sustainable Development Strategy (Swiss Confederation, 2022) which aims to reduce the material footprint "substantially and in harmony with the 1.5-degree target set in the Paris Climate Agreement", which also points to an impact-based rationale. However, its underlying sources additionally refer to equitable global distribution, citing a threshold of 5.2 ton of raw materials consumed per capita and per year (Bringezu and Schütz, 2014; UBA, 2015) which reflects a more retrospective approach, while also acknowledging the varying environmental significance of different raw materials (Müller et al., 2017) (cited in (Swiss Federal Council, 2018)).

For many of the material targets identified through the country consultations, however, the underlying scientific rationale is not clearly articulated, making it difficult to link these policy targets to the three scientific approaches outlined in Part 1 of this paper. Explicitly stating the rationale behind quantitative target values would enhance dialogue with the scientific community while preserving the important signaling function these targets already serve. Practical steps towards greater transparency could include brief annex notes indicating the chosen approach (retrospective / availability / impact-based), the baseline and data sources (e.g., environmentally extended multi-regional input output (EE-MRIO) analysis, life cycle assessment (LCA, etc.) variants for footprints), and a short sensitivity remark on the robustness of estimates to changes in underlying assumptions).

Resource targets by accounting perspective, scope, policy focus, policy type (Fig. 5).

Fig. 5 characterizes resource-use and efficiency targets across European countries by perspective (territorial vs footprint), geographical scope, policy focus, and the policy document through which they are enacted.

Territorial framings (we include indicators such as e.g. DMC or the CMUR in this category as they have a territorial or geographic bound) remain with 76% more common, though several countries adopt footprint-style targets (24%) to better capture import-embedded material or wider resource (e.g., indirect GHG emissions)) requirements. Illustrative examples of that include Austria, which pairs an economy-wide footprint targets (RMC 7 t/cap/yr by 2050 (baseline 2015)) with a territorial target (DMC 14 t/cap/yr by 2030 (baseline 2015)) highlighting how both perspectives can be used in one national framework (*Supplementary Information 03*). Belgium shows intra-national diversity: Flanders sets a material footprint target (−30% by 2030) and even a sectoral footprint (mobility material footprint −60% by 2050), while Wallonia adopts territorial targets (DMC/DMI −25% by 2030 (baseline 2013)). Finland caps consumption of primary raw materials at its 2015 level by 2035 (footprint), and Germany signals a long-term RMC corridor of 6–8 t/cap/yr by 2045 (footprint) alongside a 2030 circularity target (circular material use rate (CMUR)).

Economy-wide scopes predominate (65%), with some sectoral targets (15%) – for example, Portugal's target to reduce the environmental footprint of footwear products by 15% by 2025 and France's target to reduce the material footprint of mobility by 60% by 2050. Regional-level examples (17%) include Wallonia and Flanders (Belgium), selected German Länder (Rhineland-Palatinate, North Rhine–Westphalia, Thuringia), and Spanish regions (Asturias, Basque Country).

For the sub-national level, Oslo articulates a city-level consumption cap ("compatible with global sustainable consumption" by 2030) and Zürich's (Switzerland) climate protection plan aims to reduce the city's carbon footprint by 30% by 2040 relative to 1990 levels.

Only one resource-use target focusing on private households was identified for Austria (a 10% reduction in material consumption in private households). However, because the country questionnaire did not explicitly target household-level measures, additional targets for European private households may not have been captured in our study.

CE is with 39% of all targets the dominant policy focus; and strategies are with 50% by far the most frequent policy types on which targets are embodied, followed by plans and programs (each 15%). Most targets remain strategic (e.g., embedded in policy strategies, plans, or programs) (total of 96%) rather than statutory (i.e., embedded in law) (4%).

4. Conclusions

Methods:

We identified three main approaches to setting global raw-material targets, i.e., retrospective, materials-availability, and impact-based – with impact-based, scenario-driven work emerging as the most prominent and interconnected approach (Section 3.1). This is in line with the

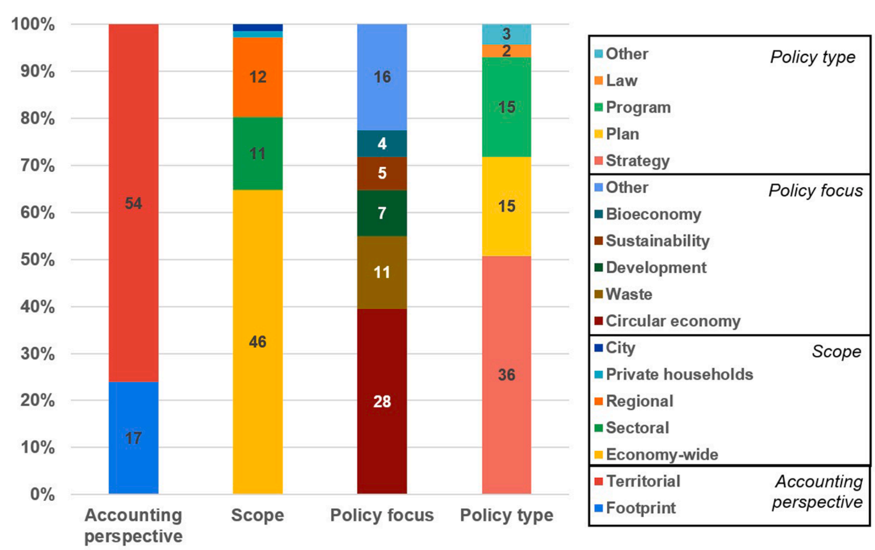

Fig. 5. European resource use and efficiency targets by accounting perspective, scope, policy focus, and policy type. Absolute target numbers shown in the figure.

broad analytical frameworks to material target setting found by other research groups (Dudka et al., 2025; Thomassen et al., 2024). The growing prominence of impact- and scenario-driven work – around half of which have been published since 2014 – highlights the importance to explicitly link overarching sustainability objectives (climate and biodiversity protection, decent living standards, and the UN Sustainable Development Goals (SDGs)) to their associated raw material requirements. Drawing these connections enables the development of future pathways of sustainable patterns of materials use.

While across approaches, there is still no agreed "science-based" material boundary, a growing toolbox of methods can be used to approximate targets for different material groups and policy contexts. Advances in integrated assessment modeling to incorporate material modules capturing material stocks and flows (Pauliuk et al., 2017) increasingly enable the systematic integration of material aspects into forward-looking sustainability pathways. These approaches can now express results across multiple impact categories (e.g., global warming potential, biodiversity loss, socio-economic implications), across different material groups (metals, non-metallic minerals, fossil fuels, biomass), for specific raw materials (e.g., Cu, Te, Li, Co, rare earth elements), and at the scale of individual world regions and countries. Examples include, e.g., the Global Resource Outlook (GRO) (UNEP IRP, 2024), GEO—Outlook (UNEP, 2025), OECD Global Material Outlook (OECD, 2019), several Horizon Europe projects (CircEUlar, 2025; CIRCOMOD, 2025), and scientific work streams (e.g., (Deetman et al., 2018; Schandl et al., 2016)). Overall, our assessment suggests that impact-based, scenario-driven approaches currently appear to offer the most promising route for developing and operationalizing science-based targets for material use in policy practice.

The UNEP IRP recommends setting targets for materials use by using such pathways at global, national and other governance levels that are explicitly linked to climate, biodiversity, land degradation and pollution goals, differentiated by country income and consumption patterns. This might be done, e.g., by operationalizing the GRO Sustainability Transition scenario (pages 116–117 in the GRO 2024 (UNEP IRP, 2024)) which would fall under the impact-based approach using sustainability scenarios in our analysis (Section 3.1). The IRP furthermore highlights the importance to develop internationally agreed pathways and differentiated national targets (using principles like common but differentiated responsibilities and material-footprint per capita), thereby also integrating aspects of equity, development contexts and "decent living standards" into target setting approaches.

We also find that research and institutional collaboration on SBT-setting for materials are so far clustered: retrospective targets are dominated by a few key actors (notably Wuppertal Institute), materials-availability work is comparatively isolated, and impact-based approaches act as a bridging, increasingly central domain.

Policy targets:

From the policy angle, European country-level policy documents already contain numerous resource-use and CE-targets, yet these remain highly heterogeneous across countries and policy domains and are usually not subject to a scientific assessment as described above. Across Europe, the target types most frequently addressed at national level often mirror those embedded in existing EU frameworks (*Supplementary Information 02 – Section 2*). Many national targets directly build on, or go beyond, EU commitments by adopting earlier implementation deadlines, raising ambition levels, or expanding the scope of sectors and resources covered. At the same time, several countries have introduced more innovative goal formulations, including targets for material and water productivity, waste-reduction goals spanning multiple waste types, dedicated reuse targets for specific product groups or waste streams, and objectives explicitly aimed at reducing littering. In other words, EU targets can stimulate counties to set more ambitious targets at national scale.

Target-rich jurisdictions coexist alongside countries with only a few commitments. Most targets are strategic (non-binding); binding targets are concentrated in specific domains (notably product-related measures) and in a small number of countries. Sub-national and sector- or product-specific targets are also emerging.

Territorial indicators (e.g., domestic material consumption, circular material use rate) dominate, but footprint-based and absolute cap-style targets (e.g., material footprints) have been introduced in several countries and sub-national entities. This indicates the importance of accounting frameworks that also capture global resource pressures and impacts.

The dominant policy narrative still centers on relative decoupling, reflected in a strong focus on productivity, efficiency, and circular-use indicators, while absolute material-reduction targets are less frequent and are rarely embedded in law. A number of countries have introduced absolute material or broader resource-reduction targets, including environmental footprint targets that are crucial for achieving environmental goals and avoiding burden shifting to other countries, yet the derivation of these quantitative levels is often not well documented. The material reduction targets identified in policy documents (e.g. Austria: RMC of 7 tons per capita in 2050; Germany: RMC of 6–8 tons per capita in 2045; Netherlands: 50% reduction in the use of primary abiotic materials by 2030 relative to 2016; Switzerland: RMC consistent with the 1.5 °C climate target) are already largely consistent with the ranges reported in the scientific literature reviewed in this study.

Outlook:

We suggest that – where feasible – European material targets should be explicitly linked to one of the three analytical approaches found in the literature for resource target setting – retrospective (safe historical rates), availability/accessibility (stocks, grades, recycling, dissipation), or impact-based (scenarios and downscaled planetary-boundary budgets), and be accompanied by brief consistency and sensitivity checks to key assumptions. Work on the science–policy interface to better link scientific approaches with policy and decision-making is of particular importance here. Future research should focus on in-depth analyses, including surveys with national policymakers, to systematically link absolute material reduction targets to scientific approaches. Furthermore, better integrating raw material aspects into EU model-based scenario quantifications (EU, 2025) would further support science-based target setting for materials, particularly in climate protection pathways and in combination with SDG monitoring, while global modeling and data collection efforts such as those of the UNEP IRP can help align European targets with international efforts and enhance their consistency and comparability.

Funding

The authors of this study acknowledge the financial support from the European Environment Agency (EEA) under the European Topic Centre on Circular Economy and Resource Use (ETC CE) (Framework Partnership Agreement (FPA) n° OCP/EEA/CAS/21/006-ETC CE).

Declaration of generative AI use

During the preparation of this work the authors used Perplexity GPT 5.1 in order to carry out final English language editing. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Philip Nuss: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Susanna Paleari:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Veronique van Hoof:** Validation, Investigation, Data curation. **Andrea van Acker:** Validation, Investigation, Data curation. **Jens Günther:** Validation, Investigation, Data curation.

Beatriz Vidal: Writing – review & editing, Validation, Conceptualization. **Peder Jensen:** Validation, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank representatives of all Eionet countries involved in the validation exercise of country-level targets. We also thank Matthias Koller and Hans-Joachim Hermann at UBA as well as the three peer-reviewers for commenting on the draft manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2026.109111.

Data availability

All data and literature sources used in the analysis are available in the supporting information.

References

Andersen, I., Ishii, N., Brooks, T., Cummis, C., Fonseca, G., Hillers, A., Macfarlane, N., Nakicenovic, N., Moss, K., Rockström, J., Steer, A., Waughray, D., Zimm, C., 2021. Defining 'science-based targets'. Natl. Sci. Rev. 8, nwaa186. https://doi.org/10.1093/nsr/nwaa186.

Baabou, W., Bjørn, A., Bulle, C., 2022. Absolute environmental sustainability of materials dissipation: application for construction sector. Resources 11, 76. https://doi.org/10.3390/resources11080076.

Bahn-Walkowiak, B., Steger, S., 2015. Resource targets in Europe and worldwide: an overview. Resources 4, 597–620. https://doi.org/10.3390/resources4030597.

Bastian, M., Heymann, S., Jacomy, M., 2009. Gephi: an open source software for exploring and manipulating networks. In: Int. AAAI Conf. Weblogs Soc. Media.

Beel, J., Gipp, B., 2009. Google Scholar's ranking algorithm: an introductory overview. Presented at the. In: Proceedings of the 12th International Conference on Scientometrics and Informetrics (ISSI'09).

Berger, M., Sonderegger, T., Alvarenga, R., Bach, V., Cimprich, A., Dewulf, J., Frischknecht, R., Guinée, J., Helbig, C., Huppertz, T., Jolliet, O., Motoshita, M., Northey, S., Peña, C.A., Rugani, B., Sahnoune, A., Schrijvers, D., Schulze, R., Sonnemann, G., Valero, A., Weidema, B.P., Young, S.B., 2020. Mineral resources in life cycle impact assessment: part II– recommendations on application-dependent use of existing methods and on futuremethod development needs. Int. J. Life Cycle Assess. 25, 798–813. https://doi.org/10.1007/s11367-020-01737-5.

Beylot, A., Dewulf, J., Greffe, T., Muller, S., Blengini, G.-A., 2024. Mineral resources depletion, dissipation and accessibility in LCA: a critical analysis. Int. J. Life Cycle Assess. 29, 890–908. https://doi.org/10.1007/s11367-023-02278-3.

Binz, S., Jäger, J., 2024. Planning and building within planetary boundaries. From the singular target of climate neutrality towards a holistic climate and resource-saving building design - a case study. IOP Conf. Ser. Earth Environ. Sci. 1363, 012001. https://doi.org/10.1088/1755-1315/1363/1/012001.

BIO Intelligence Service, Tan, A., Fischer-Kowalski, M., Lockwood, S., Mudgal, S., Brucker, M., Eisenmenger, N., Giljum, S., 2012. Generaldirektoratet För Miljö (Europeiska Kommissionen). Institute of Social Ecology, Sustainable Europe Institute. Assessment of resource efficiency indicators and targets: final report. EU:s publikationsbyrå.

BMK, 2022. Austrian Circular economy strategy. Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility. Innovation and Technology, Vienna.

BMUV, 2024. The National Circular Economy Strategy (NCES). Federal Ministry for the Environment, Nature Conservation. Nuclear Safety and Consumer Protection, Berlin.

Bringezu, S., 2022. The World Budget: safe and fair resource use for global survival and well-being.

Bringezu, S., 2019. Toward science-based and knowledge-based targets for global sustainable resource use. Resources 8 (3), 140. https://doi.org/10.3390/resources8030140.

Bringezu, S., 2015. Possible target corridor for sustainable use of global material. Resources 4, 25–54. https://doi.org/10.3390/resources4010025.

Bringezu, S., 2014. Targets for global resource consumption. In: Angrick, M., Burger, A., Lehmann, H. (Eds.), Factor X: Policy, Strategies and Instruments for a Sustainable Resource Use. Springer, Netherlands, Dordrecht, pp. 41–64. https://doi.org/10.1007/978-94-007-5706-6_3.

Bringezu, S., 2011. Key elements for economy-wide sustainable resource management. Une Croissance verte? Responssabilite & Environnement, Ann. Mines, Special Edition, pp. 78–87.

Bringezu, S., 2009. Chapter 4: visions of a sustainable resource use. In: Bringezu, S., Bleischwitz, R. (Eds.), Sustainable Resource Management: Global Trends, Visions and Policies. Greenleaf Publishing, Sheffield, UK, pp. 155–215.

Bringezu, S., Schütz, H., 2014. Indikatoren und Ziele zur Steigerung der Ressourcenproduktivität (No. Arbeitspapier 1.4. im Projekt Ressourcenpolitik: Analyse der ressourcenpolitischen Debatte und Entwicklung von Politikoptionen (PolRess)). https://doi.org/10.17169/FUDOCS_document_000000020107.

Buczko, C., Hinterberger, F., Stricks, V., 2016. Towards SDG implementation: the role of global resource policy and resource targets. Brief GSDR–2016 Update 4.

Cabernard, L., Pfister, S., Hellweg, S., 2019. A new method for analyzing sustainability performance of global supply chains and its application to material resources. Sci. Total Environ. 684, 164–177. https://doi.org/10.1016/j.scitotenv.2019.04.434.

Christis, M., Fonteyn, P., Sangers, D., Nuss, P., Nicolau, M., Günther, J., 2024. Drivers of Consumption and Sustainable Consumption Levels (No. ETC CE Report 2024/10). European Topic Centre Circular Economy and Resource Use (ETC CE).

CircEUlar, 2025. Developing circular pathways for an EU low-carbon transition [WWW Document]. URL. https://circeular.org/. Accessed 11.11.25.

CIRCOMOD, 2025. Circular economy modelling for climate change mitigation [WWW Document]. URL. https://circomod.eu/. Accessed 11.11.25.

Circular Flanders, 2025. Material footprint of Flemish consumption (RMC) [WWW Document]. URL. https://cemonitor.be/en/indicator/effects/materials/material-footprint-of-flemish-consumption-rmc/. Accessed 6.23.25.

DCCEEW, 2024. Australia's Circular Economy Framework. Australian Government Department of Climate Change. Energy, the Environment and Water, Canberra.

Deetman, S., de Boer, H.S., Van Engelenburg, M., van der Voet, E., van Vuuren, D.P., 2021. Projected material requirements for the global electricity infrastructure – generation, transmission and storage. Resour. Conserv. Recycl. 164, 105200. https://doi.org/10.1016/j.resconrec.2020.105200.

Deetman, S., Pauliuk, S., van Vuuren, D.P., van der Voet, E., Tukker, A., 2018. Scenarios for demand growth of metals in electricity generation technologies, cars, and electronic appliances. Environ. Sci. Technol. 52, 4950–4959. https://doi.org/10.1021/acs.est.7b05549.

Desing, H., Braun, G., Hischier, R., 2020. Ecological resource availability: a method to estimate resource budgets for a sustainable economy. Glob. Sustain. 3, e31. https://doi.org/10.1017/sus.2020.26.

Dewulf, J., Benini, L., Mancini, L., Sala, S., Blengini, G.A., Ardente, F., Recchioni, M., Maes, J., Pant, R., Pennington, D., 2015. Rethinking the area of protection "Natural resources". Life Cycle Assessment. Environ. Sci. Technol. 49, 5310–5317. https://doi.org/10.1021/acs.est.5b00734.

Dittrich, M., Giljum, S., Lutter, S., Polzin, C., 2012. Green Economies Around the World?: Implications of Resource Use for Development and the Environment. Sustainable Europe Research Inst. (SERI), Vienna.

Dittrich, M., Liebich, A., Ewers, B., Kathan, A., Limberger, S., Schoer, K., Müller, J., 2024. Limits to Consumption (No. Texte 165/2024). German Environment Agency, Dessau-Roßlau.

Dittrich, M., Limberger, S., Vogt, R., 2021. Preliminary study on approaches and concepts for linking the "Planetary Boundaries" concept with the use of abiotic raw materials (No. Texte 51/2021). Umweltbundesamt, Dessau-Roßlau.

Dudka, K.M., Hauschild, M.Z., Owsianiak, M., 2025. Evaluating mineral resource boundaries for application in absolute environmental sustainability assessment. Resour. Conserv. Recycl. 219, 108247. https://doi.org/10.1016/j.resconrec.2025.108247.

EC, 2020. A new circular economy action plan for a cleaner and more competitive Europe, COM(2020) 98 final.

EEA, 2025a. European Environment Information and Observation Network (EIONET) [WWW Document]. URL. https://www.eionet.europa.eu/. Accessed 5.4.25.

EEA, 2025b. France Waste prevention Factsheet. European Environment Agency (EEA), Copenhagen.

EEA, 2025c. Greece Profile on Municipal and Packaging Waste Management - 2025. European Environment Agency (EEA), Copenhagen.

EEA, 2024. Europe's circular economy in facts and figures [WWW Document]. URL. https://www.eea.europa.eu/en/analysis/publications/europes-circular-economy-in-facts. accessed 11.13.25.

ETC CE, 2025. Circular economy country profile 2024 – Finland. European Topic Centre Circular Economy and Resource Use (ETC CE).

ETC CE, 2024a. Country Profiles on Circular Economy in Europe (2024) (No. ETC/CE Reports 2024/9). European Topic Centre Circular Economy and Resource Use (ETC CE).

ETC CE, 2024b. Circular Economy Country Profile 2024 – Portugal (No. ETC-CE Report 2024/Portugal). European Topic Centre Circular Economy and Resource Use (ETC CE).

ETC CE, 2022a. Circular economy country profile – the Netherlands. European Topic Centre Circular Economy and Resource Use (ETC CE).

ETC CE, 2022b. Country Profiles on Circular Economy in Europe (2022) (No. ETC/CE Reports 2022/5). European Topic Centre Circular Economy and Resource Use (ETC CE).

ETC CE, 2022c. Circular economy country profile – France (No. ETC CE Report 2022/5). European Topic Centre On Circular economy and Resource Use.

EU, 2025. Modelling tools for EU analysis [WWW Document]. URL. https://climate.ec.europa.eu/eu-action/climate-strategies-targets/economic-analysis/modelling-tools-eu-analysis_en. accessed 11.19.25.

EU, 2022. Decision (EU) 2022/591 of the European Parliament and of the Council of 6 April 2022 on a General Union Environment Action Programme to 2030. Official Journal of the European Union.

European Parliament, 2021. MEPs call for binding 2030 targets for materials use and consumption footprint (Press Release) [WWW Document]. URL. https://www.europarl.europa.eu/news/en/press-room/20210122IPR96214/meps-call-for-binding-2030-targets-for-materials-use-and-consumption-footprint. Accessed 6.23.25.

Eurostat. EU. Circular Economy Monitoring Framework. https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework, 2025.

Eurostat, 2018. Economy-wide Material Flow accounts, Handbook, 2018 Edition. Publications Office of the European Union, Luxembourg.

Fanning, A.L., O'Neill, D.W., 2016. Tracking resource use relative to planetary boundaries in a steady-state framework: a case study of Canada and Spain. Ecol. Indic. 69, 836–849. https://doi.org/10.1016/j.ecolind.2016.04.034.

Fischer-Kowalski, M., Krausmann, F., Steinberger, J.K., Ayres, R.U., 2010. Towards a low carbon society : setting targets for a reduction of global resource use, social ecology working paper. Vienna : Inst. of Social Ecology. IFF - Fac. for Interdisciplinary Studies, Klagenfurt Univ.

Friends of the Earth Europe, WU Wien, EEB, 2020. A circular economy within ecological limits: why we need to set targets to reduce EU resource consumption and waste generation in the new Circular Economy Action Plan.

Google, 2025. Google Scholar.

Graedel, T., 2019. Can we define planetary boundaries on the Human use of materials? A Better Planet. De Gruyter.

Haddaway, N.R., Collins, A.M., Coughlin, D., Kirk, S., 2015. The role of Google Scholar in evidence reviews and its applicability to grey literature searching. PLoS One 10, e0138237. https://doi.org/10.1371/journal.pone.0138237.

Harzing, A., 2025. Publish or perish. https://harzing.com/resources/publish-or-perish.

Harzing, A.-W., Alakangas, S., 2016. Google Scholar, Scopus and the Web of Science: a longitudinal and cross-disciplinary comparison. Scientometrics 106, 787–804. https://doi.org/10.1007/s11192-015-1798-9.

Helander, H., Petit-Boix, A., Leipold, S., Bringezu, S., 2019. How to monitor environmental pressures of a circular economy: an assessment of indicators. J. Ind. Ecol. 23, 1278–1291. https://doi.org/10.1111/jiec.12924.

Henckens, M.L.C.M., Driessen, P.P.J., Worrell, E., 2014. Metal scarcity and sustainability, analyzing the necessity to reduce the extraction of scarce metals. Resour. Conserv. Recycl. 93, 1–8. https://doi.org/10.1016/j.resconrec.2014.09.012.

Hickel, J., O'Neill, D.W., Fanning, A.L., Zoomkawala, H., 2022. National responsibility for ecological breakdown: a fair-shares assessment of resource use, 1970–2017. Lancet Planet. Health 6, e342–e349. https://doi.org/10.1016/S2542-5196(22)00044-4.

Hoekstra, A.Y., Wiedmann, T.O., 2014. Humanity's unsustainable environmental footprint. Science 344, 1114–1117. https://doi.org/10.1126/science.1248365.

IEEP, 2022. Towards Resource Consumption Within Planetary boundaries: The case For Binding EU Material Footprint Reduction Targets. Institute for European Environmental Policy.

IPCC, 2018. Global warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission pathways, in the Context of Strengthening the Global Response to the Threat of Climate change, Sustainable development, and Efforts to Eradicate Poverty. Intergovernmental Panel on Climate Change (IPCC).

Lettenmeier, M., Liedtke, C., Rohn, H., 2014. Eight tons of material footprint—suggestion for a resource cap for household consumption in Finland. Resources 3, 488–515. https://doi.org/10.3390/resources3030488.

Li, M., Wiedmann, T., Hadjikakou, M., 2019. Towards meaningful consumption-based planetary boundary indicators: the phosphorus exceedance footprint. Glob. Environ. Change 54, 227–238. https://doi.org/10.1016/j.gloenvcha.2018.12.005.

Müller, F., Kosmol, J., Keßler, H., Angrick, M., Rechenberg, B., 2017. Dematerialization—a disputable strategy for resource conservation put under scrutiny. Resources 6, 68. https://doi.org/10.3390/resources6040068.

Nuss, P., Günther, J., Kosmol, J., Golde, M., Müller, F., Frerk, M., 2021. Monitoring framework for the use of natural resources in Germany. Resour. Conserv. Recycl. 175, 105858. https://doi.org/10.1016/j.resconrec.2021.105858.

OECD, 2022. Global Plastics Outlook: Policy Scenarios to 2060. OECD Publishing, Paris. https://doi.org/10.1787/aa1edf33-en.

OECD, 2019. Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences. OECD Publishing, Paris.

O'Neill, D.W., Fanning, A.L., Lamb, W.F., Steinberger, J.K., 2018. A good life for all within planetary boundaries. Nat. Sustain. 1 (1), 88–95. https://doi.org/10.1038/s41893-018-0021-4.

Pauliuk, S., Arvesen, A., Stadler, K., Hertwich, E.G., 2017. Industrial ecology in integrated assessment models. Nat. Clim. Change 7, 13–20. https://doi.org/10.1038/nclimate3148.

Pfister, C., 1995. Das 1950er Syndrom. Der weg in die Konsumgesellschaft, Pfister, Christian (Hg.) (1995). Das 1950er Syndrom. Der Weg in Die Konsumgesellschaft. Haupt Verlag. Haupt Verlag, Bern, Bern.

Potočnik, J., 2025. Setting the net-zero by 2050 for material use [WWW Document]. URL. https://www.systemstransformationhub.org/news/setting-the-net-zero-by-2050-for-material-use. Accessed 5.11.26.

Sala, S., Crenna, E., Secchi, M., Sanyé-Mengual, E., 2020. Environmental sustainability of European production and consumption assessed against planetary boundaries. J. Environ. Manage. 269, 110686. https://doi.org/10.1016/j.jenvman.2020.110686.

Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M., Owen, A., 2016. Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. J. Clean. Prod. 132, 45–56. https://doi.org/10.1016/j.jclepro.2015.06.100.

Schmidt-Bleek, F., 1994. Wieviel Umwelt braucht der mensch? Faktor 10-das Maß Für ökologisches Wirtschaften. Birkhäuser Verlag, Berlin.

Schmidt-Bleek, F., 1992. Will Germany remain a good place for industry? The ecological side of the coin. Fresenius Environ. Bull. 1, 417–422.

Schweizerische Eidgenossenschaft, 2022. BBl 2022 2403 - Bundesgesetz über Die Ziele im Klimaschut… Fedlex. Die Publikationsplattform des Bundesrechts.

Sonderegger, T., Berger, M., Alvarenga, R., Bach, V., Cimprich, A., Dewulf, J., Frischknecht, R., Guinée, J., Helbig, C., Huppertz, T., Jolliet, O., Motoshita, M., Northey, S., Rugani, B., Schrijvers, D., Schulze, R., Sonnemann, G., Valero, A., Weidema, B.P., Young, S.B., 2020. Mineral resources in life cycle impact assessment—Part I: a critical review of existing methods. Int. J. Life Cycle Assess. 25, 784–797. https://doi.org/10.1007/s11367-020-01736-6.

Streeck, J., Veléz-Henao, J.A., Kikstra, J.S., Pachauri, S., Min, J., Krausmann, F., Haberl, H., Pauliuk, S., Zaini, T., Wiedenhofer, D., 2025. Small increases in material stocks to achieve decent living standards globally. Nat. Sustain. 8, 1567–1581. https://doi.org/10.1038/s41893-025-01670-1.

Potočnik, J., Teixeira, I., 2025. Setting targets for sustainable material consumption: How science can support government action for setting material demand targets and defining material transition pathways (An IRP Co-Chairs Think Piece) [Report in preparation]. UNEP International Resource Panel (IRP) and SYSTEMIQ.

Swiss Confederation, 2022. 2030 Sustainable Development strategy.

Swiss Federal Council, 2018. Environment Switzerland 2018. Swiss Federal Council, Bern, Switzerland.

Thomassen, G., Eswaran, A., Van Passel, S., Dewulf, J., 2024. A planetary boundary for mineral, metal, and fossil resource extraction rates: how much primary materials can a circular economy extract? Environ. Sci. Technol. 58, 20345–20351. https://doi.org/10.1021/acs.est.4c08688.

UBA, 2015. Gesamtwirtschaftliche Ziele und Indikatoren zur Rohstoffinanspruchnahme.

UNEP, 2025. Global Environment Outlook 7 [WWW Document]. URL. https://www.unep.org/geo/global-environment-outlook-7. Accessed 11.11.25.

UNEP IRP, 2024. Global Resources Outlook 2024: Bend the Trend — Pathways to a Liveable Planet As Resource Use Spikes. International Resource Panel.

UNEP IRP, 2014. Managing and conserving the natural resource base for sustained economic and social development. United Nations Environment Program (UNEP). International Resource Panel.

UNEP IRP, 2011. Decoupling natural resource use and environmental impacts from economic growth. United Nations Environment Program (UNEP). International Resource Panel.

Van der Voet, E., Van Oers, L., Verboon, M., Kuipers, K., 2019. Environmental implications of future demand scenarios for metals: methodology and application to the case of seven major metals. J. Ind. Ecol. 23, 141–155. https://doi.org/10.1111/jiec.12722.

Vélez-Henao, J.A., Pauliuk, S., 2024. Correction to "material requirements of Decent living standards. Environ. Sci. Technol. 58, 1783–1785. https://doi.org/10.1021/acs.est.3c09400.

Vélez-Henao, J.A., Pauliuk, S., 2023. Material requirements of decent living standards. Environ. Sci. Technol. 57, 14206–14217. https://doi.org/10.1021/acs.est.3c03957.

Wang, P., Chen, W.-Q., Cui, X., Li, J., Li, W., Wang, C., Cai, W., Geng, X., 2022. Critical mineral constraints in global renewable scenarios under 1.5 °C target. Environ. Res. Lett. 17, 125004. https://doi.org/10.1088/1748-9326/aca4ea.

Watari, T., Nansai, K., Giurco, D., Nakajima, K., McLellan, B., Helbig, C., 2020. Global metal use targets in line with climate goals. Environ. Sci. Technol. 54, 12476–12483. https://doi.org/10.1021/acs.est.0c02471.

Watari, T., Nansai, K., Nakajima, K., 2021a. Major metals demand, supply, and environmental impacts to 2100: a critical review. Resour. Conserv. Recycl. 164, 105107. https://doi.org/10.1016/j.resconrec.2020.105107.

Watari, T., Nansai, K., Nakajima, K., 2021b. Contraction and convergence of in-use metal stocks to meet climate goals. Glob. Environ. Change 69, 102284. https://doi.org/10.1016/j.gloenvcha.2021.102284.

WEF, 2019. The Next Frontier: Natural Resource Targets Shaping a Competitive Circular Economy within Planetary Boundaries. World Economic Forum, Cologny/Geneva.

Wiedenhofer, W., Rovenskaya, W., Haas, H., Krausmann, F., Pallua, I., Fischer-Kowalski, M., 2013. Is there a 1970s syndrome? Analyzing structural breaks in the metabolism of industrial economies. Energy Procedia 40, 182–191. https://doi.org/10.1016/j.egypro.2013.08.022. European Geosciences Union General Assembly 2013, EGUDivision Energy, Resources & the Environment, ERE.

Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2015. The material footprint of nations. Proc. Natl. Acad. Sci. 112, 6271–6276. https://doi.org/10.1073/pnas.1220362110.

Yossapoll, C., Caudill, R., Axe, L., Dickinson, D., Watts, D., Mosovsky, J., 2002. Carrying capacity estimates for assessing environmental performance and sustainability. In: Conference Record 2002 IEEE International Symposium on Electronics and the Environment (Cat. No.02CH37273). Presented at the Conference Record 2002 IEEE International Symposium on Electronics and the Environment (Cat. No.02CH37273), pp. 32–37. https://doi.org/10.1109/ISEE.2002.1003234.

UNEP IRP, 2025. Approaches to develop science based targets of natural resource use: A Rapid Study and Assessment [Report in preparation]. UNEP International Resource Panel (IRP).