TRANSIENCE

TRANSITIONING TOWARDS AN EFFICIENT, CARBON-NEUTRAL CIRCULAR EUROPEAN INDUSTRY

Date: 26/05/2025

D4.2 – Service and product database

WP4 – Developing satellite modules

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EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

The deliverable is intended for the broader stakeholder community of TRANSIENCE, as well as energy system and climate-economy modellers, providing them with open data for a wide range of key energy technologies, in support of assessments of a transition towards a carbon-neutral and circular European industry. As such, this product and service (P&S) database serves as a critical element to coupling different TRANSIENCE models—i.e., altogether establishing the Model for European Industry Circularity and Climate Change Mitigation (MIC3)—by providing (bulk) material compositions and critical raw material requirements, as well as translating services into product and material demand.

3. Short summary of results (<250 words)

This document presents the documentation and user manual of the TRANSIENCE project's online Product & Service (P&S) database, which provides (bulk) material compositions, critical raw material requirements, and translations of services into product and material demand, to be used among the models altogether constituting the Model for European Industry Circularity and Climate Change Mitigation (MIC3). The database contains P&S characteristics, specifications, material compositions, and supply chain-related information. It assesses material compositions (bulk materials) of various building types, passenger vehicles, batteries, wind turbines, solar PV systems, and electronic devices, using the data from the prospective life cycle assessment framework *premise* building on ecoinvent 3.10 (system model: 'allocation, cutoff by classification') and literature. Additional data on critical materials for a large set of low-carbon energy technologies has also been included. Moreover, important translations of socioeconomic indicators into physical demand are provided for selected products, end-uses, and energy services. Broadly, the P&S database will support the alignment of variables exchanged across the MIC3 modules to serve as a common reference for linking the diverse MIC3 modelling approaches. For example, the material flow analysis (MFA) module may use it to derive material requirements based on outputs from the socioeconomic model, while energy system modellers may use it to translate technology deployment (such as installed capacities of technologies) into demand for bulk and critical materials embedded in low-carbon technologies.

4. Evidence of accomplishment

The database (available on the project's Zenodo community: https://doi.org/10.5281/zenodo.15517592), and this accompanying report.

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Preface

The need to approach climate action, resource efficiency, and circularity performance as integrated, economy-wide, cross-cutting issues is growingly gaining attention in the policy world, stimulating the development of new industrial policies in Europe and worldwide. Currently, however, there is little progress in conceptualising the circular economy and understanding its interactions with climate action. State-of-the-art modelling capacity to capture the interplay of the two agendas and their implications for energy-intensive sectors as well as to represent the European industry's transformation in line with the region's vision for climate neutrality is not yet fully developed. TRANSIENCE will undertake a comprehensive characterisation and assessment of circularity principles and measures vis-à-vis decarbonisation, by looking at the twin transition of European industries through the lenses of global competitiveness, innovation, and holistic sustainability. It will then produce MIC3, a consistent, fully open-source model ecosystem to assess industrial circularity, decarbonisation, and sustainability. A series of interoperable modules on the socioeconomic, service and product, material, industrial, energy-system, and environmental perspectives of the transformation of European industry will be developed and integrated, building on and opening the code of leading modelling tools. MIC3 will finally be used in extensive scenario modelling to produce diverse pathways toward a material-efficient, circular, climate-neutral, sustainable European industry. Transparency, openness, and knowledge sharing will be promoted, and technical capacities will be developed in four industrial agglomerations in the EU, moving beyond stakeholder consultation, onto model co-development, continuous validation of assumptions, co-creation of scenario modelling, evaluation of the desirability and usability of the developed model and insights, and eventually co-production of science and action.

ICCS – Institute of Communication and Computer Systems	EL
CEPS – Centre for European Policy Studies	BE
E3M – E3-Modelling AE	EL
Fraunhofer – Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.	DE
HOL – HOLISTIC IKE	EL
PIK – Potsdam Institut für Klimafolgenforschung e.V.	DE
PNTEC – Park Naukowo-Technologiczny Euro-Centrum Spolka Z Ograniczona Odpowiedzialnoscia	PL
TECNALIA – Fundacion Tecnalia Research & Innovation	ES
UU – Universiteit Utrecht	NL
WI – Wuppertal Institut für Klima, Umwelt, Energie gGmbH	DE
PSI – Paul Scherrer Institut	CH
UCL – University College London	UK

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Executive Summary

This document, as part of Deliverable D4.2, provides the documentation and user manual of the product and service (P&S) database, which is available as an (online) Excel document[1]. The database provides detailed information on product- and service-demand characteristics, material compositions, and supply chain-related aspects. It serves as a comprehensive resource for analysing material compositions (including critical raw materials, or CRM) and translating service demands into product demands needed for establishing the Model for European Industry Circularity and Climate Change Mitigation (MIC3). Overall, the database and report cover the following aspects:

- Material compositions—including documentation of the material content of various products, focusing on bulk materials, and their respective material composition shares. Further, we provide critical raw material demand across various technologies, as raw material requirements are key for the transition towards a low-carbon energy system.
- Translation from service into product demand—methodologies and data for translating service-based demand into corresponding material requirements needed for material flow analysis (MFA).

As such, this deliverable supports the broader objectives of TRANSIENCE by enhancing transparency in material flows and supply chain dependencies, which will be used (and expanded) in the subsequent project phases.

[1] Online Excel database available at: https://doi.org/10.5281/zenodo.15517592

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1 Introduction

This report provides a documentation and explanation of the product and service (P&S) database—Deliverable D4.2 of the TRANSIENCE project—published as an Excel document. The database has been prepared to support a comprehensive understanding of the material composition of key technologies, service and product demand characteristics, and associated supply chain elements relevant to the European (industrial) energy transition. As such, its purpose is to enhance transparency in material and circular economy assessments.

The rationale of the P&S database is the growing need to connect socioeconomic service demand to physical material requirements—both bulk material (e.g., steel, copper, and aluminium) and critical raw materials (CRM—e.g., iridium and neodymium)—in the context of a low-carbon industrial energy transition. Embedded within the broader objectives of TRANSIENCE, the P&S database will be a key component of the Model for European Industry Circularity and Climate Change Mitigation (MIC3). The P&S database is one of the modules within work package WP4, supporting the integration and connection between the socioeconomic, energy-system, industrial, and material flow analysis (MFA) modules of MIC3. By enabling a translation of service demand into product-level and material-specific needs, the database aims to facilitate consistent modelling between industrial sectors of MIC3 modules.

Deliverable D4.2 targets a broad audience, including modellers (of MIC3, but also beyond), MFA researchers, policymakers, and industrial stakeholders. As such, it provides open-access data (in the form of an online, publicly available database) that can be used to explore the material compositions of various key technologies needed for a low-carbon energy system. Further, it facilitates interoperability and consistency between the MIC3 modules developed within TRANSIENCE. As such, the P&S database is a key element in aligning MFA, CRM assessments, and industrial decarbonisation pathways within TRANSIENCE, but also beyond.

2 Product & Service Database

The TRANSIENCE P&S database comprises two main elements: first, bulk material compositions and critical raw materials for various products and technologies (Section 2.1) and, second, translations of services into product demand (Section 2.2). An overview of the Excel sheets of the database, as well as the explanation of the different Excel Tabs, is provided in the database itself and in the Annex of this document. Here, we briefly describe the two main elements and purposes of the database.

2.1 Material compositions

One of the main goals of the P&S database is the provision of material compositions for a wide range of key products and technologies for transitioning the European energy system towards net-zero goals:

- Battery electricity storage technologies (lithium-ion, lead-acid, and molten salt)
- Solar PV systems (multi-Si, considering different sizes)
- Onshore wind turbines (different sizes)
- Various electronic devices, including laptops, computers, smartphones, televisions, refrigerators, washing machines, and printers
- Passenger cars (such as internal combustion engines, plug-in hybrids, and electric vehicles)
- Buildings (including those related to single-family houses, multi-family houses, retail, offices, hotels, educational, and healthcare)

The material compositions are derived using (i) the premise prospective life cycle assessment (LCA) framework, building on the ecoinvent 3.10 database (Wernet et al., 2016) and (ii) external literature sources (mainly for the material composition of buildings and vehicles). The procedure for the former is briefly described below. The sheets providing these material compositions are listed in **Table 1**.

Table 1. Sheets that correspond to material compositions in the P&S database.

Sheet	Explanation
MInventory_batteries	Material composition (bulk materials) for different battery technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology follows the approach described in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
MInventory_solar_pv	Material composition (bulk materials) for different solar photovoltaic (PV) technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072. Finally, it is worth noting that solar PV panels have been updated by premise considering future efficiency improvements (see 'Photovoltaics panels' in: https://premise.readthedocs.io/en/latest/transform.html).
MInventory_wind_turbines	Material composition (bulk materials) for different wind turbine technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding

	assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
MInventory_devices	Material composition (bulk materials) for different electronic devices (e.g., laptop, phone, and washing machine) generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
MInventory_concrete_buildings	Material composition (concrete) for buildings in kg/m² based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153.
MInventory_steel_buildings	Material composition (steel) for buildings in kg/m² based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153.
MInventory_insulation_buildings	Material composition (insulation) for buildings in kg/m² based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153. And: Nemry, F., Uihlein, A., Colodel, C. M., Wittstock, B., Braune, A., Wetzel, C., ... & Gallon, N. (2008). Environmental improvement potentials of residential buildings (IMPRO-building). European Commission, Joint Research Centre. https://op.europa.eu/en/publication-detail/-/publication/85dcd023-6800-400a-bb6f-cbbdb3826f9b.
MInventory_glass_buildings	Material composition (glass) for buildings in kg/m² based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153. And: Nemry, F., Uihlein, A., Colodel, C. M., Wittstock, B., Braune, A., Wetzel, C., ... & Gallon, N. (2008). Environmental improvement potentials of residential buildings (IMPRO-building). European Commission, Joint Research Centre. https://op.europa.eu/en/publication-detail/-/publication/85dcd023-6800-400a-bb6f-cbbdb3826f9b.
MInventory_steel_vehicles	Material composition (steel) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.
MInventory_plastics_vehicles	Material composition (plastics) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.
MInventory_glass_vehicles	Material composition (glass) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.

We mainly source life cycle inventories from Python package *premise* (Sacchi et al., 2022), building on the ecoinvent 3.10 database (Wernet et al., 2016), to generate material compositions of battery electricity storage technologies, solar PV systems, onshore wind turbines, and various electronic devices. When considering the supply array of a product or technology, life cycle assessment (LCA) accounts for all materials and energy inputs throughout the entire supply chain. However, for the material composition in our P&S database, we are only interested in the materials that end up in the product or technology (i.e., direct requirements), implying the need to apply some modifications to provide material compositions of direct materials ending up in a product or technology.

To achieve this, we apply the methodology proposed by Amatuni et al. (Amatuni et al., 2024), which is specifically designed to work with life cycle inventory (LCI) data from (prospective) LCA databases such as those based on ecoinvent. Estimating material compositions from LCIs can be challenging because, as indicated, LCI data include not only the physical materials that make up a product, but also inputs like electricity, fuels, and auxiliary services that are consumed during (or before) manufacturing or use. These indirect flows, while essential for production, do not end up in the final product itself.

The method of Amatuni et al. (Amatuni et al., 2024) addresses this concern by introducing a material incorporation parameter for each technosphere flow. As such, it suggests distinguishing between (technosphere) flows that end up in a product or technology (or not) by assigning a material incorporation parameter (0 to 1) in the supply array. For example, electricity consumption flows (and other interventions) should not be included and are assigned a value of 0, as they relate to indirect materials in the power supply chain and do not end up in the product or technology. In contrast, materials like steel or copper are assigned a value of 1. Using this method, we quantify the following bulk materials: aluminium, copper, steel, rubber, glass, zinc, magnesium, and plastics.

Special attention is paid to plastics. We distinguish between twenty-nine different polymers and resins: polyamide (PA), polycarbonate (PC), polyester (PES), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyurethane (PUR), polyol (PU:polyol), phenyl isocyanate (PU:phenyl isocyanate), polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), acrylonitrile-butadiene-styrene (ABS), epoxy (EPOXY), polymethyl methacrylate (PMMA), phenolic resin (PF), polyvinyl fluoride (PVF), melamine formaldehyde (MF), urea formaldehyde (UF), polylactide (PLA), polysulfone (PSU), styrene-acrylonitrile (SAN), acrylic (ACRYLIC), bisphenol A epoxy-based vinyl ester resin (VER), ethylene-vinyl acetate (EVA), ethylvinylacetate (EVA), polymer foaming (FOAM), and polyphenylene sulfide (PPS). An overview of the included activities associated with those plastics and other bulk materials is provided in the *'Docs_ecoinvent_database'* tab of the P&S database.

However, it is worth noting that (a) the selected technologies and products may have different system boundaries—as explained in the 'Information' column of sheets starting with 'MIventory_...'—meaning it might be difficult to compare between different alternatives within a technology category and (b) solar PV panels and other key technologies have been updated by premise, considering future efficiency improvements (see 'Photovoltaics panels' in: https://premise.readthedocs.io/en/latest/transform.html).

The initial code of Ref. (Amatuni et al., 2024) has been used and modified to consider such additional life cycle inventories and to further automate the generation of material compositions for the technologies and products that we are interested in. Material compositions are generated for the year 2025, up to 2050 (using 5 year time intervals), and provided in absolute mass per product or technology (column 'Mass (kg) [*year*]'), relative percentage ('Percentage corrected (%) [*year*]'), and rescaled to the actual mass ('Mass (kg), rescaled on corrected (%) [*year*]'), which may be relevant if the provided total mass of a product or technology is different from the sum of materials based on the separate bulk material contributions. A full explanation is given in **Table 2**.

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Table 2. Explanation of columns in sheets (starting with 'MInventory_...') that provide material compositions based on the ecoinvent database.

Column names	Description
Mass (kg) [2025] – Mass (kg) [2050]	The absolute mass of the material in kilograms for each respective year. Represents the unadjusted material composition based on modelling assumptions.
Mass (kg), rescaled on corrected (%) [2025] – Mass (kg), rescaled on corrected (%) [2050]	Material mass rescaled to match the total product or technology mass (e.g., the mass indicated in the ecoinvent or premise database). This adjusts for products/technologies where the sum of modelled material components differs from the actual known total mass.
Percentage corrected (%) [2025] – Percentage corrected (%) [2050]	Share of each material as a percentage of the total product or technology mass for the given year, corrected to ensure the total adds up to 100%.

As indicated, material compositions are provided until the year 2050, considering a 5-year interval using the *premise* Python package to generate prospective LCA databases (Sacchi et al., 2022). To achieve this, the background LCA database is modified to be consistent with the 2◦C scenario of the integrated assessment model REMIND (Baumstark et al., 2021; Luderer et al., 2015). The considered REMIND scenario provides an example of a 2°C-compatible energy system transformation but represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. Possibly, more future scenarios (e.g., less ambitious climate scenarios) could be integrated, including database background changes to be performed in the next TRANSIENCE project phase. As such, it would be possible to consider circular economy measures in the generation of prospective LCA databases (including the output of MIC3 modules) that subsequently may have significant influence on material compositions generated from those (prospective) LCA databases.

An example of material compositions for electronic devices is plotted in the stacked bar chart in **Figure 1**. The products (or technologies) are provided on the x-axis, and the relative contribution of the (bulk) materials is given on the y-axis. It is worth noting that no distinction is made between different plastics within this figure (for clarity reasons); more detailed contributions regarding plastics can be found in the online P&S database.

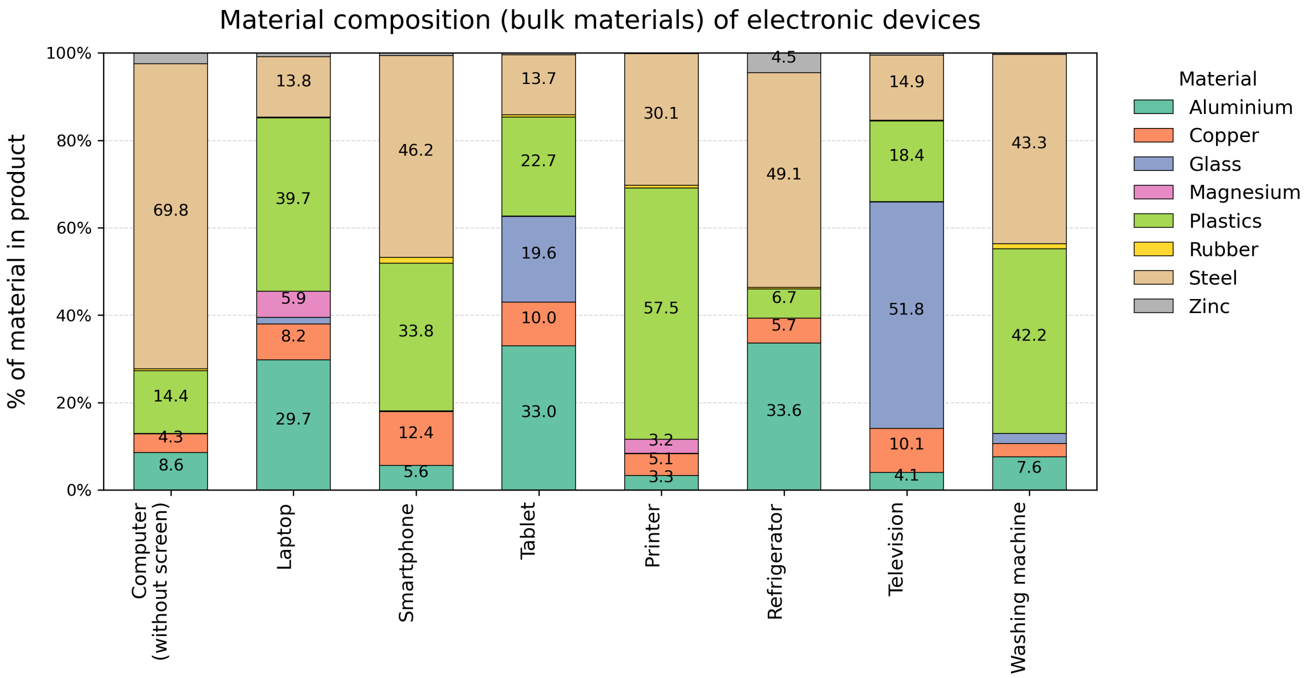

Figure 1. Stacked bar chart showing the material composition of electronic devices, with relative contributions of bulk materials in percentages. It is worth noting that both the absolute and relative figures are provided in the online P&S database[1].

Life cycle inventories for buildings and vehicles remain underrepresented in the ecoinvent database, as it only includes a few generic data points. Thus, we acquire detailed material composition data for buildings and vehicles from various scientific literature sources (Andreas Wurzer, 2016; Lotz et al., 2024; Lotz & Herbst, 2020; Nemry et al., 2008; Pauliuk et al., 2021a, 2021b) to complete the material inventory file of the P&S database.

Critical raw material (CRM) requirements

Data on CRM for a large set of low-carbon energy technologies has also been included in the P&S database, which has been partially generated in the context of the PRISMA project (PSI (Technology Assessment group), 2025). Given the increased attention and importance of CRM (European Union, 2020; Junne et al., 2020), we include various key technologies and associated critical raw material demand:

- Internal combustion engine vehicles (ICEV)
- Battery-electric vehicles (EV)
- Wind turbines (both direct-drive permanent magnet and gearbox-based systems)
- Various photovoltaic technologies (crystalline silicon, CdTe, CIGS, amorphous silicon, and perovskite)
- Concentrated solar power systems (parabolic trough and tower with power block)
- Nuclear power
- Hydrogen production (PEM electrolysers, alkaline electrolysers, and high-temperature electrolysers using yttrium) and fuel cell technologies

The sheets that correspond to critical raw material demands are provided in **Table 3**.

Table 3. Sheets that correspond to critical raw material compositions in the P&S database.

Sheet	Explanation
ICEV	Critical material demand for conventional gasoline and diesel-powered vehicles.
EV	Critical material demand for battery-electric vehicles, including lithium, cobalt, and nickel requirements.
Wind-DDPM	Critical material demand for direct-drive wind turbines using permanent magnets.
Wind-Gearbox	Critical material demand for wind turbines using a gearbox system.
c-Si	Critical material demand for crystalline silicon-based photovoltaic panels.
CdTe	Critical material demand for CdTe thin-film solar panels.
CIGS	Critical material demand for Copper Indium Gallium Selenide thin-film solar panels.
a-Si	Critical material demand for amorphous silicon-based solar panels, often used in flexible and thin-film applications.
perovskite	Critical material demand for perovskite-based solar technologies.
Parabolic Trough - PB	Critical material demand for parabolic trough concentrated solar power systems (parabolic trough concentrated solar power with power block).
CSP Tower - PB	Critical material demand for concentrated solar power tower with power block.
Nuclear	Critical material demand for nuclear power generation.
PEMFC	Critical material demand for polymer electrolyte membrane fuel cells (PEMFC).
SOFC-Y	Critical material demand for solid oxide fuel cells.
PAFC	Critical material demand for phosphoric acid fuel cells.
PEMEL	Critical material demand for proton exchange membrane (PEM) electrolyzers used for hydrogen production.
AEL	Critical material demand for alkaline electrolyzers.
HTEL - Yttrium	Critical material demand for high-temperature electrolyzers.

An overview of those technologies can be found in the 'Technologies_CMs' tab. Critical material requirements are reported in kilograms per unit product or technology, typically also per kilogram or MW for energy generation or conversion technologies. The full overview of potentially critical materials can be found in the Excel Tab 'Materials'. Finally, a full set of references used to determine those critical material requirements is provided in the 'References_CMs' tab.

2.2 Translation from service into product demand

The second main goal of the P&S database is the consistent translation from service into product demand, or more precisely, the translation of (socio-) economic indicators into physical units. For this purpose, we distinguish between a bottom-up approach for detailed application sectors and a top-down approach for broad application sectors. The bottom-up approach is applied for buildings and vehicles, while the top-down approach covers packaging, steel, plastics, and cement. First, for the bottom-up approach, we translate the service demand into product demand differentiated based on the required granularity, using predefined allocation rules. The level of detail (granularity) depends on the sector and application; for example, residential heating demand may be translated into product demand for heat pumps, boilers, or district heating systems. Using the material compositions detailed in the previous section, this product demand is then converted into a corresponding material demand.

Second, for the top-down approach, service demand is directly translated into material demand through regression analysis of historical trends. Those translations are required to align the various modules within the MIC3 framework effectively.

It is worth noting that this mapping should be considered work in progress due to the unavailability of the full MIC3 model outputs required to establish and validate these relationships comprehensively at this stage. Thus, we show the exemplary approach for cement, packaging, and steel as representative of other sectors (e.g., plastics). We will continue refining the methods and data as more detailed outputs become available. The sheets that provide data and preliminary translations from service into product demand are shown in **Table 4**.

Table 4. Sheets in the P&S database that provide preliminary data and methods to translate service demand into product demand.

Sheet	Explanation
Floor_space	Floor space per capita in m^2 for 28 countries from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Residential_share	Share of SFH and MFH in the residential building stock from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Commercial_change	Change in commercial building stock between years from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Vehicle_share	Share of different vehicle types in new vehicles based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo.
Packaging	Change in packaging demand.
Steel	Change in steel demand by sector and region.
Cement	Change in cement demand by sector and region.
Plastics	Change in plastic demand by sector and region.

2.2.1 Buildings

As noted, we apply a bottom-up approach for translating the demand for building-related services into the building stock. Due to their fundamentally different characteristics, we distinguish between residential and non-residential buildings. The following data is acquired to translate population and sectoral changes into the building stock:

- Changes in population can be translated into changes in physical demand for residential buildings by assuming a linear relationship between them. Our bottom-up approach uses floor space use per capita as a conversion factor (Excel Tab 'Floor_space'), which varies between countries and is a key factor to determine building material demand (Lotz et al., 2024). On the other hand, the building stock is determined by the share of single- and multi-family houses (Excel Tab 'Residential_share'), which influences the requirements of different construction materials (Lotz et al., 2024).
- For commercial buildings, the translation is driven by yearly changes in the commercial building stock (Excel Tab 'Commercial_change'), which impacts the demand for specific building types and ultimately different construction materials (Lotz et al., 2024).

2.2.2 Vehicles

Similar to buildings, we apply a bottom-up approach for translating transport service into passenger vehicle demand. In this case, another MIC3 module (OPEN-PROM) provides detailed information on new registrations of passenger vehicles. Thus, the P&S database provides further data for the country-specific differentiation of vehicle sizes, such as microcars, (personal) passenger vehicles, minivans, and light trucks (Excel Tab 'Vehicle_share'), which are a crucial factor to determine vehicle material demand (Pauliuk et al., 2021a).

2.2.3 Packaging

The MIC3 socio-economic module (OPEN-GEM) is expected to deliver (relatively) detailed indicators for the packaging sector, such as the production of single sectors, intermediate consumption of those sectors, and final household demand, as well as aggregated indicators such as the gross domestic product (GDP). The MFA module can be driven by production or final demand. It follows that both modules could potentially be linked in various ways. Which option is applied in practice depends on the research question at hand, but also on the data available for calibrating such a link, which is currently still uncertain.

Regarding the broadly defined "plastic packaging" sector, we have explored the possibilities to link the socio-economic module to the MFA module. Plastic packaging demand consists of both demand for household and commercial/industrial packaging, permeating all types of products, applications, and economic sectors. Consequently, economic indicators such as final household demand or industrial production are likely not broad enough to adequately capture the correlation between economic development and physical demand for plastic packaging. An aggregate economic indicator, such as the GDP, seems more appropriate.

In this first phase of the project, we have implemented a linear regression analysis with the following scope:

- Socio-economic indicator: logarithm of GDP in chain-linked volumes (2015), in million euros.
- MFA variables:
    - Production (the "converter demand" from packaging manufacturers).
    - Imports and exports of new empty packaging.
- Geography: EU27 + all individual Member States.
- Time horizon: 1995-2023 (data availability varies by country).

We obtained the production, exports, and imports by summing up Eurostat PRODOM statistics covering 12 plastic packaging products (see details in **Table 5** below) (Eurostat, 2025).

The resulting regression analyses vary greatly in quality; please refer to Sheet 'Packaging' in the P&S database. The correlation generally reveals a good fit for imports and exports. On the other hand, the correlation for production is not usable for all countries initially considered; however, this was anticipated since some (especially smaller) countries may have a very limited plastic manufacturing industry.

In a first approach, we suggest using the correlation at the level of single countries for which the R^2 exceeds a reasonable threshold. It is worth noting that the R^2 is a statistical measure that indicates the proportion of the variance in the dependent variable, that is explained by the independent variable in a regression model. For the remaining countries, the correlation at the EU27 level may be used.

Table 5. Overview of data sources used for the regression of packaging demand.

Dataset	Resolution
Eurostat PRODCOM statistics "Sold production, exports and imports" Data code: estat_ds-056120	Products: • [22221200] Plastic sacks and bags (including cones) (excluding polymers of ethylene) • [22221300] Plastic boxes, cases, crates and similar articles for the conveyance or packing of goods • [22221450] Plastic carboys, bottles, flasks and similar articles for the conveyance or packing of goods, of a capacity <= 2 litres

	• [22221470] Plastic carboys, bottles, flasks and similar articles for the conveyance or packing of goods, of a capacity > 2 litres • [22221910] Spools, cops, bobbins and similar supports, of plastics • [22221920] Plastic caps and capsules for bottles • [22221925] Plastic stoppers, lids, caps, capsules and other closures • [22221930] Plastic stoppers, lids, caps and other closures (excluding bottles) • [22221940] Plastic netting extruded in tubular form • [22221950] Articles for the conveyance or packaging of goods, of plastics (excluding boxes, cases, crates and similar articles; sacks and bags, including cones; carboys, bottles, flasks and similar articles; spools, spindles, bobbins and similar supports; stoppers, lids, caps and other closures) • [22221990] Other articles for the conveyance or packing of goods of plastics • [24102222] Other ingots, primary forms and long semi-finished products (of stainless steel) Indicators: • [EXPQNT] Export quantity • [IMPQNT] Import quantity • [PRODQNT] Production quantity
Eurostat annual national accounts "Gross domestic product (GDP) and main components (output, expenditure and income)" Data code: nama_10_gdp	National accounts indicators (ESA 2010): • [B1GQ] Gross domestic product at market prices Unit of measure: • [CLV15_MEUR] Chain linked volumes (2015), million euro

2.2.4 Steel

Each steel-consuming sector (construction, automotive, other transport, mechanical engineering, metalware, and domestic appliances) is coupled to a macroeconomic or production-based driver. For most steel-consuming sectors, we rely on sector-specific production data.

However, detailed production data may not be available through the OPEN-GEM framework for some steel-consuming sectors (e.g., metalware and miscellaneous). Thus, we use an alternative approach to translate service into demand. In these cases, we may estimate steel demand by translating economic activity into material use, for example, using gross value added (GVA) as a proxy for service demand, as provided by OPEN-GEM. This top-down approach links service demand—represented by sectoral economic output—to steel use through regression analysis of historical data. In this section, we first examine (i) the correlation between the overall iron and steel industry and its corresponding GVA and (ii) the steel used in the machinery industry and its corresponding GVA in the machinery sector.

For this first exercise, data on GVA is sourced from Eurostat using the Eurostat Python package (Eurostat, 2025). It is worth noting that Eurostat provides many different GVA-related indicators, which may be country-specific. Here, we focus on aggregated EU27 countries since we do not have (yet) detailed information on country-specific steel demand (Eurostat table: '*sbs_na_ind_r2*' using '*C2410*' for the iron and steel industry in combination with ‘V12150’ for representing production values in million euros). Steel (real) consumption data is sourced from Eurofer (EUROFER, 2019, 2024). Using this data, we perform a regression analysis to determine the trend between GVA (independent variable) and steel demand (dependent variable) in Europe.

Figure 2 illustrates the input data on annual log-transformed GVA (in million EUR) and steel consumption (in tonnes) for EU27 countries between 2008 and 2020. The trajectories of both variables exhibit a similar trend, with noticeable drops during economic recessions (e.g., 2009 and 2020). Despite those fluctuations, it suggests that, while economic output has rebounded in many periods, steel consumption has not always followed proportionally.

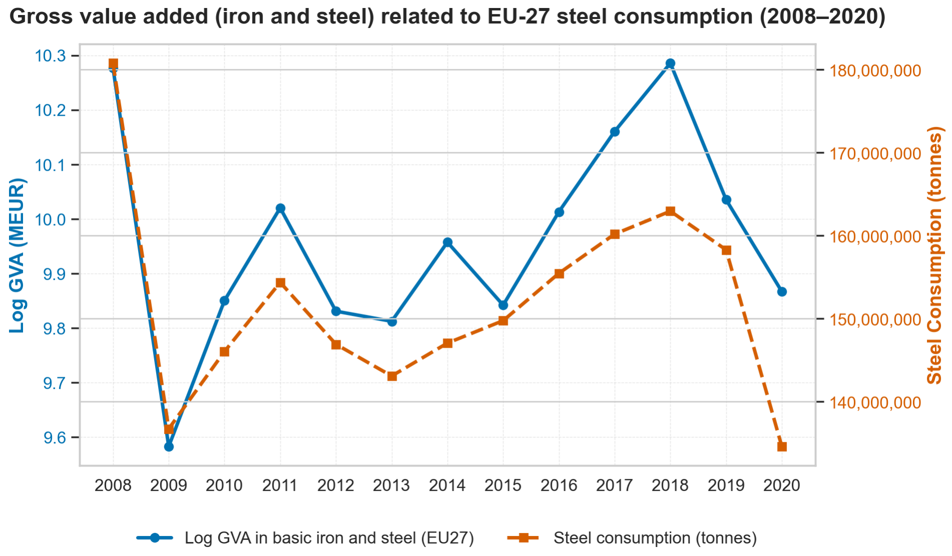

Figure 2. Gross value added (GVA, log scale) in the basic iron and steel sector as well as steel consumption in the EU27 countries from 2008 to 2020. The primary y-axis illustrates the logarithmic GVA in million euros, indicating economic output trends, while the secondary y-axis shows steel consumption in tonnes per year. GVA = gross value added.

However, overall, **Figure 3** proves that there is a clear relationship (R^2=0.77) between economic activity and steel consumption in EU27 countries. This suggests that steel consumption remains tied to the GVA generated in the basic iron and steel sector.

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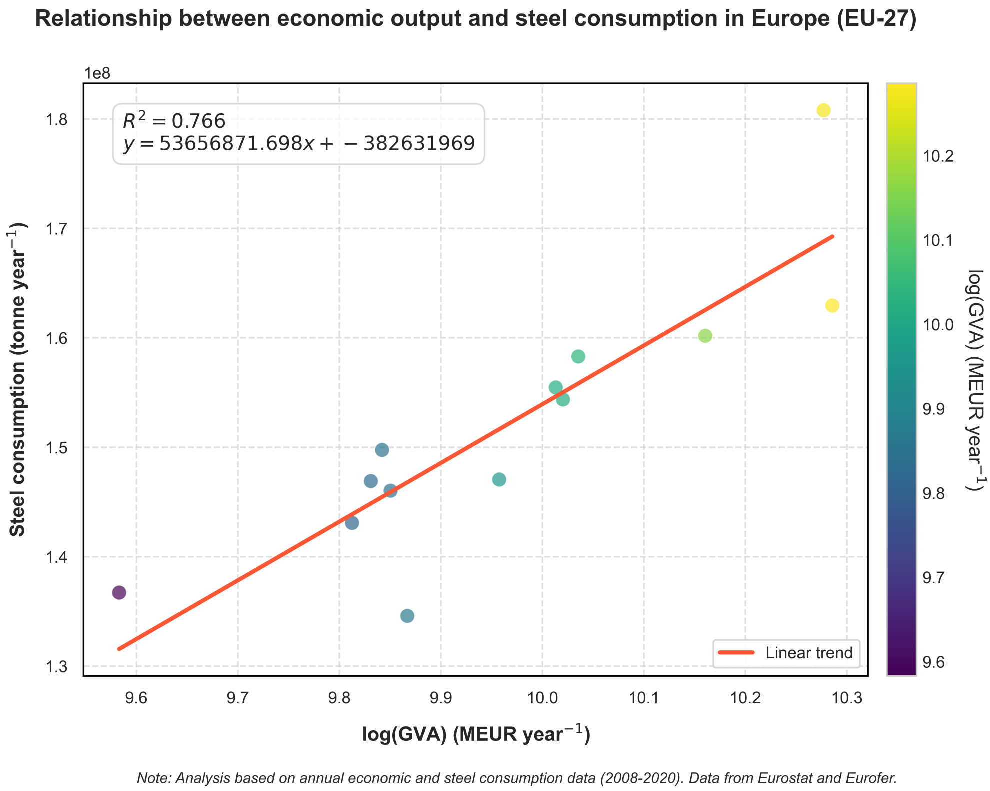

Figure 3. Correlation between annual log GVA (in million euros, MEUR year^{-1}) and total steel demand (tonnes year^{-1}), with a trend line based on linear regression. Each point represents a single year coloured by its specific GVA. GVA = gross value added.

Such relationships can serve as a basis for estimating steel demand in sectors where direct production data is unavailable. In future work, this method can be refined with country-specific regressions, allowing estimation of steel demand at finer geographic and sectoral resolution—critical for effective decarbonization planning and circular economy assessments. It is worth noting that this trend may be very different between (European) countries.

Steel for machinery

In the following paragraphs, we refer to mechanical engineering steel as the steel products used in the machinery and equipment manufacturing sector. To link the socio-economic module with the MFA module, we establish a correlation between mechanical engineering steel consumption in physical units and the economic development of the machinery manufacturing sector. Obtaining mechanical engineering steel consumption data involved two steps.

First, historical consumption of all finished steel products in the EU-27+UK is calculated from EUROFER (EUROFER, 2024) and CAEF (The European Foundry Association, 2025) data through this formula:

	Domestic production of finished steel products (excl. castings)
+	Domestic production of castings
+	Imports of finished steel products (excl. tubes + castings)
+	Imports of tubes
+	Imports of castings
-	Exports of finished steel products (excl. tubes + castings)
-	Exports of tubes

- Exports of castings

= Domestic consumption of steel products incl. tubes and castings

We obtain a timeseries for the period 2004-2019, which we can then break down using shares of total finished steel demand by sector taken from EUROFER.

In parallel, we obtain sectoral GVA data from Eurostat for the NACE sector "Manufacture of machinery and equipment n.e.c. (C28)" (Eurostat, 2025). Finally, we built a simple linear regression between GVA and steel consumption, as well as a multiple regression between time, GVA, and steel consumption. For this specific case, it turns out that the multiple regression is more appropriate. The R^2 is twice as large (at 0.65) in the case of the multiple regression. **Figure 4** provides an illustration of the actual steel demand and the projected steel demand based on this multiple regression (see the Tab 'Steel' in the P&S database).

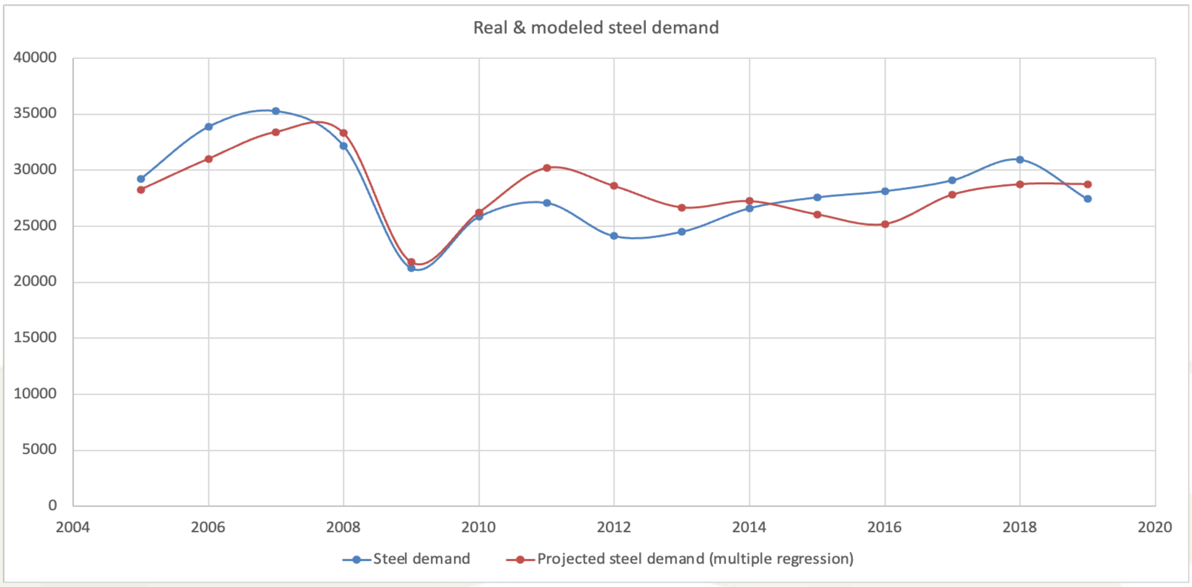

Figure 4. Steel demand over the years in terms of actual 'Steel demand' and the 'Project steel demand' (multiple regression).

This approach can be used as an approximation to link economic development in the machinery and equipment manufacturing sector with demand for mechanical engineering steel in the EU27+UK.

For missing steel-demanding sectors, future work aims to perform additional sector- and country-specific regression analysis based on historical data, which allows for estimating the potential steel demand for the country and sector under study.

2.2.5 Cement

The cement-consuming sectors are driven by domestic production in the construction industry (buildings and infrastructure), data provided by the OPEN-GEM MIC3 module. Specifically, the domestic production of construction activities is the primary input variable representing service demand.

Using regression analysis, we can estimate the corresponding material requirements for the cement industry based on historical production data (see **Figure 5**). Due to the current missing data on construction from OPEN-GEM, we source GVA data from the Eurostat Python package (Eurostat, 2025) for the construction industry (buildings). Cement data is sourced from CEM bureau (CEMBUREAU, 2024). As such, the regression analysis accounts for potential structural changes and (decoupling) trends between construction activity and cement intensity over time.

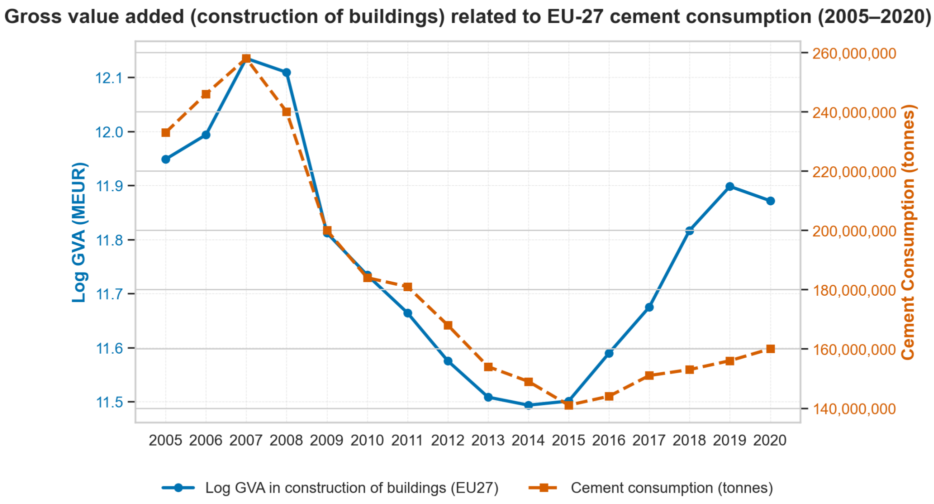

Figure 5. Gross value added (GVA, log scale) in the construction sector (buildings) and cement consumption in the EU27 from 2005 to 2020. The primary y-axis illustrates the logarithmic GVA in million euros, indicating economic output trends, while the secondary y-axis shows cement consumption in tonnes per year.

Figure 6 illustrates the relationship ($R^2 = 0.67$) between economic output (GVA in building construction) and cement demand in EU27 countries. The strength of this relationship implies that changes in building construction output have a significant and direct impact on cement demand in EU27 countries. This finding supports the continued use of sectoral GVA as a key driver in material demand models.

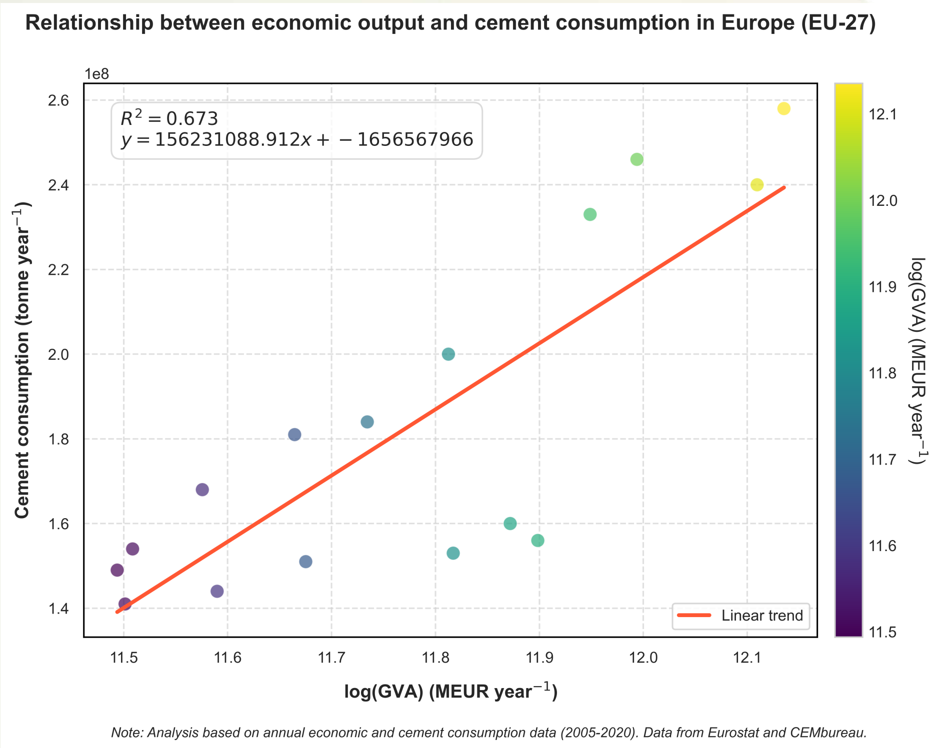

Figure 6. Correlation between annual GVA of construction of buildings (in million euros, MEUR year^{-1}) and total cement demand (tonnes year^{-1}), with a trend line based on linear regression. Each point represents a single year, coloured by its specific GVA. GVA = gross value added.

Future efforts aim to increase the granularity and details of such analyses, for example, by exploring variations between EU-27 member states and/or specific steel-consuming sectors.

Depending on the model outputs of OPEN-GEM and future development pathways, we may test additional indicators beyond GVA to better capture steel demand (and other materials) in a circular economy. Given the limitations of the linear relationships, applied in previous paragraphs, we may explore non-linear trends to account for the complex dynamics of economic and technological factors.

3 Conclusions

TRANSIENCE aims to support the transition towards a circular and climate-neutral industry in Europe by developing a dynamic modelling framework (MIC3) to assess sectoral (and circular) transformation pathways. A key component of TRANSIENCE is the product and service (P&S) database, which links service demand with product demand across key sectors for the European industry, including construction, mobility, packaging, steel, cement, and plastic industries. This document provides an overview of the role and structure of the P&S database within TRANSIENCE and, as such, a comprehensive description of the Excel component of the P&S database[2].

Overall, the P&S database and this report cover several key elements for the MIC3 framework. First, we provide material compositions of various products, focusing on bulk materials and their respective material composition shares, using literature sources as well as a new approach to generate compositions based on available life cycle inventories. As such, those material compositions provide detailed information on the types and quantities of materials embedded in different products and technologies, which may be used by the material flow analysis (MFA) modules. Additionally, the P&S database provides the demand for critical raw materials across various technologies needed to transition towards a low-carbon European Industry. Finally, the report provides preliminary methodologies and data sources to translate service-based demand from MIC3 models—such as socioeconomic data on packaging, plastics, mobility, buildings, cement, and steel—into corresponding product and material demand.

Future updates will expand the P&S database by refining the methods and providing additional translations from service demand into product demand. As such, the P&S database is intended to remain a living document with ongoing improvements throughout the project timeline. Overall, the P&S database is (and will be) a critical element for systematically analysing material flows and coupling TRANSIENCE modules within the MIC3 framework.

[2] Online Excel database available at: https://zenodo.org/communities/transience/

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Annex

Table 6. Description of the Excel tabs included in the P&S database.

Material compositions	
MInventory_batteries	Material composition (bulk materials) for different battery technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology follows the approach described in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
MInventory_solar_pv	Material composition (bulk materials) for different solar photovoltaic (PV) technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072. Finally, it is worth noting that solar PV panels have been updated by premise considering future efficiency improvements (see 'Photovoltaics panels' in: https://premise.readthedocs.io/en/latest/transform.html).
MInventory_wind_turbines	Material composition (bulk materials) for different wind turbine technologies generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
MInventory_devices	Material composition (bulk materials) for different electronic devices (e.g., laptop, phone, and washing machine) generated using ecoinvent background database 'cutoff by classification' 3.10. The REMIND scenario used for future material compositions provides an example of a 2°C-compatible energy system transformation, but it represents only one possible future pathway among many others. As such, the results should be interpreted with caution, considering the uncertainty embedded in such a specific IAM scenario and corresponding assumptions. The methodology is consistent with the approach outlined in: Amatuni, L., Steubing, B., Heijungs, R., Yamamoto, T., & Mogollón, J. M. (2024). Deriving material composition of products using life cycle inventory databases. Journal of Industrial Ecology, 28(5), 1060-1072.
Docs_ecoinvent_database	Documentation of the ecoinvent activities considered to calculate the material demand and compositions.
MInventory_concrete_buildings	Material composition (concrete) for buildings in kg/m^2 based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153.
MInventory_steel_buildings	Material composition (steel) for buildings in kg/m^2 based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153.
MInventory_insulation_buildings	Material composition (insulation) for buildings in kg/m^2 based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153. and Nemry, F., Uihlein, A., Colodel, C. M., Wittstock, B., Braune, A., Wetzel, C., ... & Gallon, N. (2008). Environmental improvement potentials of residential buildings (IMPRO-building). European Commission, Joint Research Centre. https://op.europa.eu/en/publication-detail/-/publication/85dcd023-6800-400a-bb6f-cbbdb3826f9b.

MInventory_glass_buildings	Material composition (glass) for buildings in kg/m² based on: Lotz, M. T., Herbst, A., Müller, A., Kranzl, L., Carreon, J. R., & Worrell, E. (2024). A material flow model of steel and concrete in EU buildings: National differences of the service-stock-flow nexus. Cleaner Waste Systems, 8, 100153. https://doi.org/10.1016/j.clwas.2024.100153. and Nemry, F., Uihlein, A., Colodel, C. M., Wittstock, B., Braune, A., Wetzel, C., ... & Gallon, N. (2008). Environmental improvement potentials of residential buildings (IMPRO-building). European Commission, Joint Research Centre. https://op.europa.eu/en/publication-detail/-/publication/85dcd023-6800-400a-bb6f-cbbdb3826f9b.
MInventory_steel_vehicles	Material composition (steel) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.
MInventory_plastics_vehicles	Material composition (plastics) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.
MInventory_glass_vehicles	Material composition (glass) for vehicles in kg/vehicle based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Data is reproduced from (CC BY 4.0): Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo. and Andreas Wurzer. (2016). Bewertung möglicher gesetzlicher Lenkungseffekte auf Basis gesamtheitlicher Lebenszyklusanalysen im Verkehrssektor MASTERARBEIT zur Erlangung des akademischen Grades eines Diplom-Ingenieurs.
Translation from service into product demand	
Floor_space	Floor space per capita in m² for 28 countries from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Residential_share	Share of SFH and MFH in the residential building stock from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Commercial_change	Change in commercial building stock between years from: Lotz, M. T., & Herbst, A. (2020). newTRENDs. Deliverable 6.1 Decarbonization and circular economy in industry. https://newtrends2020.eu/.
Vehicle_share	Share of different vehicle types in new vehicles based on: Pauliuk, S., Heeren, N., Berrill, P., Fishman, T., Nistad, A., Tu, Q., ... & Hertwich, E. (2021). Database of the ODYM-RECC v2. 4 Model, Used for the GLOBAL Case Study on Material Efficiency and Climate Change Mitigation [Data Set]. Zenodo.
Packaging	Change in packaging demand.
Steel	Change in steel demand by sector and region.
Cement	Change in cement demand by sector and region.
Plastics	Change in plastic demand by sector and region.
Translation_references	Placeholder sheet that aims to indicate and collect relevant literature to translate service into product demand.
Critical material requirements	
Technologies_CMs	Overview of the technologies analyzed to assess critical materials required for different technologies, detailing the demand for elements like rare earth metals, lithium, and other critical raw materials.
Materials	List of materials considered in the datasets.
ICEV	Critical material demand for conventional gasoline and diesel-powered vehicles.
EV	Critical material demand for battery-electric vehicles, including lithium, cobalt, and aluminium requirements.

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Wind-DDPM	Critical material demand for direct-drive wind turbines using permanent magnets.
Wind-Gearbox	Critical material demand for wind turbines using a gearbox system.
c-Si	Critical material demand for for crystalline silicon-based photovoltaic panels.
CdTe	Critical material demand for CdTe thin-film solar panels.
CIGS	Critical material demand for Copper Indium Gallium Selenide thin-film solar panels.
a-Si	Critical material demand for amorphous silicon-based solar panels, often used in flexible and thin-film applications.
perovskite	Critical material demand for perovskite-based solar technologies.
Parabolic Trough - PB	Critical material demand for parabolic trough concentrated solar power systems (parabolic trough concentrated solar power with power block).
CSP Tower - PB	Critical material demand for concentrated solar power tower with power block.
Nuclear	Critical material demand for nuclear power generation.
PEMFC	Critical material demand for polymer electrolyte membrane fuel cells (PEMFC).
SOFC-Y	Critical material demand for solid oxide fuel cells.
PAFC	Critical material demand for phosphoric acid fuel cells.
PEMEL	Critical material demand for proton exchange membrane (PEM) electrolyzers used for hydrogen production.
AEL	Critical material demand for alkaline electrolyzers.
HTEL - Yttrium	Critical material demand for high-temperature electrolyzers.
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