

# FutuRaM

Future availability  
of secondary  
raw materials

## Work Package 2

### Future Availability of Secondary Raw Materials

Scenario Storylines & Scenario Quantification  
Draft Report – Version 3



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# DRAFT REPORT – VERSION 3

## REVIEW NOTICE

Latest Revision: Thursday 30<sup>th</sup> November, 2023 at 20:41

*This is a draft report for internal review*

The chapters beyond the Scenario Storylines chapter are in the first draft stage and are undergoing continual development.

## CHANGE LOG

New in version 3:

- Revised the scenario storylines and methodology chapters based on internal review.
- Added the quantification chapter, which is not in the first draft stage.
- This chapter includes detailed descriptions of the scenario parameters and, in the case of the external elements, their quantification.
- Internal elements will be quantified using a bottom-up approach whereby waste streams interpret the scenario parameters through correlations with their product groups. This will be discussed at the next workshop.

## CONTRIBUTING

Please contribute to the work on the scenario work in the following ways:

- In a CSV file with the format: 'name, line start, line end, comment, reference' (if reference is applicable, please provide the DOI or BibTeX).
- Please use consistent formatting for the page numbers and any referencing.
- FutuRaM members add their comments to the shared document found at this link [🔗](#).
- The same template can be downloaded from here [🔗](#) and sent to SCM [✉️](#) for inclusion in the shared document.
- You can also contribute directly to the [LATEX](#) source files on the WP2 GitHub repository [🔗](#).

## WASTE STREAM NOTICE

Waste Streams, please check your sections

- Review the waste stream impact sections for each scenario
- Add more references, especially for the targets, regulations, and projections.
- Contribute to the main points raised by the reviewers of the first drafts (see below).
- Read the quantification chapter and develop your plan to interpret the scenarios in your waste stream.
- Consider how the scenario parameters and your waste stream model codebase will interface.
- Consider how your waste stream model will interface with the integrated model.

## QUANTIFICATION

- Read the quantification chapter and develop your plan to interpret the scenarios in your waste stream.
- Consider how the scenario parameters and your waste stream model codebase will interface.
- Consider how your waste stream model will interface with the integrated model.
- Contribute to the data collection in the future technology and product list here [🔗](#).

## DISCUSSION POINTS

- How to transfer general targets into product-specific values?  
*general CRM/SRM → waste streams → product groups*  
*We would need a set of constraints for each of the recovery flows and processes, as well as the individual waste flows (by code) in each WS, to backcast this.*
- Consideration of possible future resource constraints in the scenarios.  
*We suggest covering this in sensitivity analysis and multi-objective-optimisation.*
- Economic considerations (prices, subsidies, PPP vs. GPD etc.).
- Geopolitical Considerations (supply risk, trade, etc.).
- Scenarios relationship with the United Nations Framework Classification (UNFC).
- Choice of background energy scenario (i.e. STEP from the IEA)

## SOME LINKS

- Quantification: chapter 4
- Appendices: chapter 13
- WP2 folder on the FutuRaM Sharepoint See [🔗](#) for more details.

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# Front Matter

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## I. REPORT DETAILS

|                             |  |
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*Table 1.1: Version history*

| VER. NO. | DATE       | REASONS FOR RELEASE                 | RESPONSIBLE              |
|----------|------------|-------------------------------------|--------------------------|
| 1.0      | 2023-09-11 | First draft for review              | Stewart Charles McDowall |
| 2.0      | 2023-11-11 | Second draft for review             | Stewart Charles McDowall |
| 3.0      | 2023-11-22 | Addition of scenario quantification | Stewart Charles McDowall |

## II. NOTICE

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### III. PREFACE

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The FutuRaM project aims to quantify the current and future availability of secondary raw materials (SRM), focusing on critical raw materials (CRMs) [80]. This study is concerned with six waste streams in the EU member states, as well as Iceland, Norway, Switzerland, and the United Kingdom (EU27+4). In this report, the EU27+4 will henceforth be referred to as the EU, unless specified otherwise.

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#### THE WASTE STREAMS COVERED IN FUTURAM ARE:

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Waste batteries (BAT)

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Construction and demolition waste (CDW)

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End-of-life vehicles (ELV)

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Mining waste (MIN)

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Slags and ashes (SLASH)

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Waste electrical and electronic equipment (WEEE)

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Work package two (WP2) is conducting foresight studies for materials that are either classified as critical to the EU economy or are significant due to factors such as their large volumes, commercial importance, and environmental impacts [80, 1, 22, 141]. WP2 is tasked with developing a set of coherent scenarios for material use and waste/recovery over time across various sectors in the EU. This report describes the three distinct scenarios and the process by which they were developed.

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#### THE THREE SCENARIOS THAT HAVE BEEN DEVELOPED IN FUTURAM ARE:

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I. Business-as-usual (BAU)

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II. Recovery (REC)

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III. Circularity (CIR)

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## VII. EXECUTIVE SUMMARY

This report presents the first phase of the scenario development process — the storyline narrative phase. Three distinct future scenarios have been drafted up to the year 2050: Business as Usual, Recovery, and Circularity. These scenarios are designed to be internally consistent and provide an overview of the potential future landscape of waste management and SRM recovery within the EU.

The scenario development process employs a methodology that integrates both forecasting and back-casting techniques to build a comprehensive, future-facing knowledge base that can aid fact-based decision-making [81, 23, 82, 83, 76, 84, 85].

In the next phases of scenario development, future product composition and recovery technology will be assessed, scenario elements will be quantified, and all data will be integrated with the quantitative models for waste generation and SRM recovery.

The FutuRaM project aims to offer a nuanced understanding of the potential future waste management and resource recovery landscape within the EU. This approach provides insights into key drivers, uncertainties, and the possible impacts of policy and technological advancements. Additionally, by aligning SRM recovery efforts with the United Nations Framework Classification for Resources (UNFC) [150], the project aims to facilitate the commercial exploitation of SRMs and CRMs by manufacturers, recyclers, and investors. With the comprehensive knowledge base that we are developing, FutuRaM aims to support informed decision-making by policymakers and government, as well as industry and community stakeholders.

### FUTURAM'S THREE FUTURE SCENARIOS



#### Scenario I: Business-as-usual (BAU)

The BAU scenario extrapolates current trends into the future with limited change. Using forecasting techniques, it projects a potential future where there are minor advancements in resource efficiency, recovery technology, and the energy transition, but primary extraction of raw materials remains the dominant practice.



#### Scenario II: Recovery (REC)

The Recovery scenario imagines a future leveraging advanced technology to significantly enhance SRM

269 recovery from waste streams. It outlines a future where the EU successfully meets its recycling and recovery  
270 targets through an effective waste management system and circular design principles [24, 86]. This  
271 scenario sees an increased recovery rate of SRMs, extensive use of digitalisation and automation in recycling  
272 processes, and new or strengthened waste regulations in line with EU targets.

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### Scenario III: Circularity (CIR)

275 The Circularity scenario captures the ideal of a fully realised circular economy, going beyond end-of-life  
276 recovery to minimise waste at every production and consumption stage. It predicts a future where the EU's  
277 targets for recycling, recovery, and circularity are met through extensive stakeholder collaboration, new  
278 business models, and increased use of renewable energy and circular economy technologies [2, 87, 88].

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## VIII. OVERVIEW OF THE SCENARIO STORYLINES

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This scenario envisions the future based on the current situation, extending to 2050 with very little deviation from present consumption patterns and without substantial development of the secondary raw material (SRM) recovery system. While there may be advances in some areas such as resource efficiency, recovery technology, and the energy transition, substantial modifications remain hindered by economic, social, and political constraints. The extraction of primary raw materials continues to be the predominant source utilised to satisfy the EU's growing SRM demand.

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In the Business as usual (linear economy) scenario, the following are key characteristics:

- A forecasting model is used to predict the future based on the current situation and the development of existing trends.
- EU targets including those for eco-design, recycling and recovery are not met, and the current linear model largely persists.
- Material demand remains coupled with economic growth, perpetuating a trend of increasing consumption.
- Primary mining and extraction persist as the leading sources of raw materials, underlining the dependency on traditional extraction methods.
- Recycling and recovery rates continue to lag, leading to increased production of SRM-containing waste that signals missed opportunities for resource reuse.
- The EU's dependency on imports of SRMs escalates, heightening the risk of supply disruptions [25].
- Investment in new SRM recovery technologies remains minimal, stifling innovation and advancements in this field.
- The industrial focus remains on cost-effective material production and use, disregarding the long-term sustainability aspect.
- Material scarcity and price fluctuations pose potential risks to the EU industry, highlighting the vulnerability of this business model [26].
- Without any significant updates to environmental regulations, the negative impacts on ecosystems and biodiversity intensify.
- Mining activity in the EU remains limited and concentrated in only a few member states. Current exploration projects (e.g., for Lithium in PT, FR, UK and rare earths in SE) are not realised.
- The transitions to renewable energy and e-mobility continue at their current pace.



See section 3.1 for the full scenario description and waste-stream-specific scenario impact narratives.

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## Scenario II: Recovery (BAU)

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See section 3.2 for the full scenario description and the waste-stream-specific scenario impact narratives.319  
320  
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322  
323  
In the recovery scenario, the central emphasis is on harnessing sophisticated technologies to salvage SRMs from waste streams at the end of their lifecycle. While there are noticeable strides towards the incorporation of 'circular design' principles and re-X strategies (which focus on reducing, reusing, recycling, repairing, and refurbishing), material demand increases similarly to the BAU scenario. This is, however, mitigated to some extent by the implementation of a comprehensive material recovery system.324  
**Key features of this technology-promoted recovery scenario include:**

- 325 • This scenario uses a combination of forecasting and backcasting methods to envision the  
326 future.
- 327 • The backcasting method is used for scenario factors that are covered by governmental targets,  
328 starting with the desired outcome and working backwards to the present.
- 329 • The forecasting method is used for scenario factors that are not covered by governmental  
330 targets, starting with the current situation and extending to the future.
- 331 • EU targets for recycling and recovery are met, due to the EU's waste management system  
332 becoming more expansive, efficient and effective.
- 333 • Technological innovation drives increased recovery rates of SRMs, enabling the more efficient  
334 use of waste.
- 335 • Digitalisation and automation are more extensively used in recycling processes, leading to  
336 enhanced productivity and efficiency.
- 337 • Business models like leasing and take-back schemes emerge, altering traditional consumption  
338 patterns (here, the focus is on take-back for recycling).
- 339 • Ecodesign mandates are implemented, again, here, with a focus on end-of-life recovery.
- 340 • There is greater exploration and exploitation of alternative sources such as urban mining,  
341 waste streams, and tailings, presenting novel opportunities for resource acquisition.
- 342 • New waste regulations and guidelines for SRM recovery are implemented, enforcing better  
343 management and extraction of SRMs.
- 344 • Investment in research and development for SRM recovery technologies experiences an  
345 upswing, promoting continuous innovation in this field.
- 346 • Closer collaboration and information sharing between industry and government institutions  
347 (e.g., waste tracking and digital product passports) streamline processes and expedite decision-  
348 making.
- 349 • New jobs are created in the recycling and recovery sector, offering economic benefits and  
350 improving overall employment rates.
- 351 • SRM production and use become more efficient and cost-effective, fostering economic sus-  
352 tainability.

354

## Scenario III: Circularity

355



356 See section 3.3 for the full scenario description and the waste-stream-specific scenario impact narratives.

357 In this scenario, we move in the direction of the maximum achievable state of material efficiency as  
358 government policy, private innovation and social changes are rapidly driving the transition toward a circular  
359 economy. The emphasis here rests heavily on re-X strategies that are implemented in the design phase  
360 of products (e.g., repairability and re-manufacturability) and that are actualised by changes in consumer  
361 behaviour (e.g reduction, refusal, engagement in the 'sharing economy' and curtailment of the 'throw-away'  
362 mindset).363 Further, being enabled by the widespread adoption of 'circular design' principles and improvements in  
364 information transparency (e.g., waste tracking and digital product passports) the system for the treatment  
365 of post-consumer waste can divert a significant amount of their inflows (to, for example, re-use and re-  
366 manufacture) with the residual fraction being readily segregated into purer, more efficiently recoverable,  
367 material streams.368 This scenario envisions a future where government policies are in synergy with private sector innovation  
369 and societal changes, driving a wholesale transition towards a circular economy. Unlike the recovery scenario,  
370 where the focus is on the end-of-life recovery of materials, this scenario emphasises minimising waste at  
371 all stages, starting from the design phase itself.372 **The circular economy scenario is characterised by the following:**

- 373 • This scenario uses a combination of forecasting and backcasting methods to envision the  
374 future.
- 375 • The backcasting method is used for scenario factors that are covered by governmental targets,  
376 starting with the desired outcome and working backwards to the present.
- 377 • The forecasting method is used for scenario factors that are not covered by governmental  
378 targets, starting with the current situation and extending to the future.
- 379 • EU targets for recycling and recovery are met, as are those for circularity, due to advances in  
380 waste management, ecodesign and re-X strategies.
- 381 • A circular economy is implemented, prioritising waste reduction, resource efficiency, and a  
382 shift from the 'take-make-dispose' model.
- 383 • A notable increase in SRM recycling and recovery rates, indicating an efficient use of resources.
- 384 • A larger emphasis on designing products for reuse and recycling, making waste a valuable  
385 resource rather than a problem.
- 386 • More extensive use of renewable energy and clean technologies in SRM production and use,  
387 supporting a low-carbon economy.
- 388 • Collaboration between stakeholders — including industry, government, and consumers —  
389 improves, enhancing the implementation of circular practices.
- 390 • New business models like leasing and take-back schemes emerge, altering traditional con-  
391 sumption patterns [89].
- 392 • Digitalisation and data use are heightened to improve efficiency and traceability, aiding in  
393 effective resource management.

- 394
- Investment in research and development for circular economy technologies increases, driving innovation and adoption.
- 395
- Awareness and education around sustainable consumption and production practices are amplified, leading to behavioural changes in society.
- 396
- Reliance on imports decreases, suggesting greater self-sufficiency and sustainability.
- 397
- The creation of new jobs within the recycling, recovery and re-X sectors boosts the economy and alleviates social inequality.
- 398
- Stricter waste regulations and product design guidelines are introduced, accelerating the transition towards circularity.
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## IX. ABBREVIATIONS

*Table 1.2: List of abbreviations*

| ACRONYM  | DEFINITION  |
|----------|---|
| AI       | Artificial Intelligence   |
| BAU      | Business as Usual   |
| BATT     | Waste Batteries   |
| BRGM     | French Geological Survey (Bureau de Recherches Géologiques et Minières) |
| CDW      | Construction and Demolition Waste                                       |
| CE       | Circular Economy  |
| CRM      | Critical Raw Material   |
| CU       | Chalmers University   |
| EEE      | Electrical and Electronic Equipment                                     |
| ELV      | End-of-Life Vehicles  |
| Empa     | Swiss Federal Laboratories for Materials Science and Technology         |
| EoL      | End-of-Life   |
| EoU      | End-of-Use  |
| EoW      | End-of-Waste  |
| EU       | European Union  |
| EU27+4   | EU + Iceland, Norway, Switzerland and the United Kingdom                |
| EPR      | Extended Producer Responsibility  |
| GDP      | Gross Domestic Product  |
| GEC      | Global Energy and Climate [Model]                                       |
| GTK      | Geological Survey of Finland  |
| LCA      | Life Cycle Assessment   |
| LCC      | Life Cycle Cost Assessment  |
| LMU      | Ludwig Maximilian University of Munich                                  |
| LU       | Leiden University   |
| MIN      | Mining Waste  |
| R&D      | Research and Development  |
| REACH    | Registration, Evaluation, Authorization, and Restriction of Chemicals   |
| RECHARGE | EU rechargeable battery industry association                            |
| SGU      | Geological Survey of Sweden   |
| SLASH    | Slags and Ashes   |
| S-LCA    | Social Life Cycle Assessment  |
| SLCA     | Sustainability Life Cycle Assessment                                    |
| SRM      | Secondary Raw Material  |
| TRL      | Technology Readiness Level  |
| TUB      | Technische Universität Berlin   |
| UCL      | University College London   |
| UNITAR   | United Nations Institute for Training and Research                      |

*Continued on next page*

*Table 1.2 – Continued from previous page*

| ACRONYM    | DEFINITION  |
|------------|---|
| UNFC       | United Nations Framework Classification for Resources |
| VITO       | Flemish Institute for Technological Research          |
| WEEE       | Waste Electrical and Electronic Equipment             |
| WEEE Forum | Waste Electrical and Electronic Equipment Forum       |
| WFD        | Waste Framework Directive                             |

406

## X. TERMINOLOGY (ABBREVIATED)

407

The following table provides an abbreviated list of terminology used in this report.  
See section 13.1 for a complete list.

408

*Table 1.3: List of terminology (abbreviated)*

| TERM                   | DEFINITION  |
|------------------------|---|
| Backcasting            | A method for predicting future trends based on a desired future state.  |
| Business-as-usual      | A scenario that assumes no significant changes in current trends and policies.  |
| Circular economy       | An economic system that prioritises waste reduction and resource efficiency.  |
| Critical Raw Material  | A raw material that is economically and strategically important to the EU, but with a high risk of supply disruption. |
| Forecasting            | A method for predicting future trends based on historical data.   |
| Recovery               | The process of recovering SRMs from waste streams.  |
| Re-X                   | A general term for circular strategies such as reuse, repair, refurbishment, remanufacturing and recycling.           |
| Scenario               | A plausible and coherent description of how the future may develop based on a set of assumptions.                     |
| Secondary Raw Material | A material that has been recovered from waste and can be used as a substitute for a primary raw material.             |
| Storyline              | A qualitative description of a scenario, including the key drivers, actors and events.                                |

## XI. DESCRIPTION OF FUTURAM WORK PACKAGE 2

A full breakdown of the tasks and subtasks in WP2, along with the responsible partners is provided in section 13.9. The following sections provide a brief description of each task.

More information can be found in the grant agreement [151], the consortium agreement [152], the project management plan [153] and the Milestone 6 report [154].

### DELIVERABLE

D2.1: Report on the environmental and socioeconomic barriers to SRM recovery – Month 47: May 2026

### XI.1. Objectives

WP2 will conduct foresight studies for materials critical to the EU economy, or materials that have significant impacts on EU sustainability because of their large volumes. WP2 will develop a set of coherent scenarios for material use and waste/recovery over time in various sectors in the EU: WEEE, ELV, BAT, CDW, MINW, SLASH.

### Context

Source: [151]

### MODELLING THE FUTURE OF WASTE GENERATION AND SRM RECOVERY

In WP2, modelling the foresight requires dealing with much unknown information and developments. A convincing mathematical model on the future thus requires a strong narrative developed from stakeholders and existing literature regarding how future circular behaviours, recycling and recovery technologies, and the overall material economy will develop. Furthermore, if the mathematical model used is too detailed, there will be many data gaps, leading to it being impractical to use and potentially leading to unrealistic results. This means a good balance needs to be found between data availability and its translation into a quantification of future narratives. The narratives applied to each scenario will follow plausible developments by taking into account stated MS policies by each regarding the material economy (with a special emphasis on the waste and recycling stages) and optimistic outlooks of both recycling technology using learning curves, and of increasing circular behaviour following global best practice. The rate of development towards each of these scenarios will be used for sensitivity and uncertainty analyses, such that a measure of the variability within each scenario is established.

### OPEN SCIENCE

Considering the multidisciplinary character of FutuRaM and its aim to provide consistent and robust data, procedures, models, and methods, a critical discussion, harmonisation and integration of the concepts, perspectives and is crucial for the success of the project.

The consortium is committed to making the data available in open formats during the project and free of charge for the EC and all stakeholders to use and publish, along with other relevant reports tailored for the use of the EC and respecting FutuRaM's open science principles.

**GENDER**

444 Within the FutuRaM, project no specific population group will be targeted. In contrast, the consortium is  
445 aware that research often has a diversity problem since many groups are underrepresented, e.g. women,  
446 ethnic minorities, people with disabilities and socially disadvantaged populations and we will consider  
447 specific measures that will help to address specifically these groups.

448 We will especially consider the involvement of a variety of stakeholders in WP7.

449 In work packages 2, 3 and 5 we will use Delphi panels, which have an equal representation of gender  
450 and an appropriate age distribution that encapsulates multiple perspectives. In the modelling of WP2 and 4  
451 (foresight and stock and flow models), consumption of household electronics may increase with increasing  
452 gender equality, and behavioural aspects of waste separation which could be an aspect of foresight of stock  
453 and flows.

## 454 XII. TASK DESCRIPTIONS

455 **Task 2.1. Develop scenario storyline (ULEI, TUB, Empa, Chalmers, WEEE Forum, BRGM, UNITAR, SGU) (M01-  
456 M18):** This task involves scanning, mapping, and assessing scenarios used in the grey, scientific, policy,  
457 and industry literature/reporting for the different waste streams, (e.g., the Shared Socioeconomic  
458 Pathways, the International Resource Panel Scenarios, the International Energy Agency Scenarios,  
459 etc) to develop cogent storylines for the three planned scenarios. These will cut across sectors and  
460 will be used for the Stock-Flow models (WP4) and will include the translation of general concepts  
461 such as stated policies, sustainable development, circular economy, to each sector. FutuRaM will  
462 develop at minimum three scenarios (1. Sustainability, 2. Recoverability, and 3. Business-as-usual).

463 **Task 2.2. Integrate future technologies into the scenarios (Chalmers, ULEI, TUB, Empa, WEEE Forum, BRGM,  
464 UNITAR, UCL, LMU, SGU, VITO) (M03-M20):** This task will review current and emerging technologies  
465 used in the various sectors for product manufacturing and end-of-life handling, with a special emphasis  
466 on material production, use, and recycling. Together with the storylines developed in Task 2.1, it will  
467 adapt the market share of these technologies for each sector to determine the future development  
468 of each sector.

469 **Task 2.3. Forecast material composition and products for each scenario (TUB, ULEI, UNITAR, Chalmers,  
470 BRGM, Empa, VITO) (M7-M20):** Following the scenarios from T2.1, the material compositions and  
471 future products for each sector will be determined based on the product and commodity demand  
472 and technology realisation (T2.2). This task will be coupled to the data collection in WP3 and WP4.

473 **Task 2.4. Quantify environmental and socioeconomic impacts of SRM recovery under each scenario (ULEI,  
474 TUB, Empa, UNITAR, WEEE Forum, BRGM, UCL, LMU) (M18-M36):** This task will use the information  
475 generated in Tasks 2.1-2.3, together with the material flow analysis from WP4, to quantify the future  
476 environmental and socioeconomic feedbacks for each waste sector and scenario according to future  
477 recovery technology.

478 **Task 2.5. Assess the environmental and socioeconomic impacts and bottlenecks of future SRM recovery  
479 (ULEI, TUB, Empa, UNITAR, Chalmers, UNITAR, WEEE Cycling) (M37-M47):** This task will develop a  
480 report based on an assessment on the pressures and bottlenecks associated with environmental and  
481 socioeconomic issues related to each waste sector, including the associated changes and impacts on  
482 imports and of primary raw materials production (D2.1).

F  
48

## XII.1. Interconnection with other work packages in FutuRaM

### REVIEW NOTICE

Does anyone have the original, editable version of this figure?

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486

Figure 1.1 shows the interconnection between WP2 and the other work packages in FutuRaM [151].

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WP2: Scenario Storylines | [www.futuram.eu](http://www.futuram.eu) | xxviii

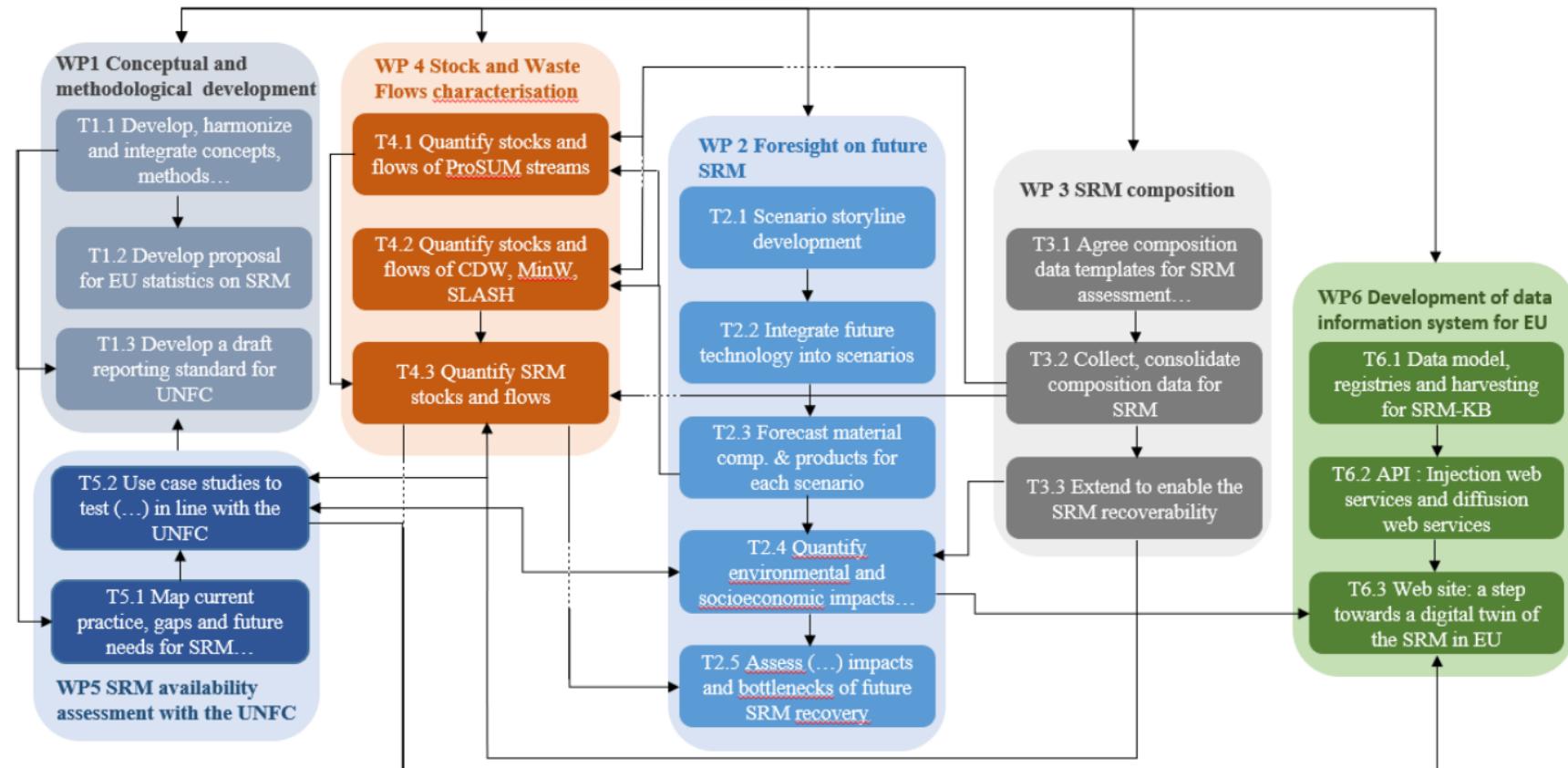


Figure 1.1: Interconnection between WP2 and the other work packages in FutuRaM

## XII.2. Work package two milestones

*Table 1.4: WP2.1 – Milestone list*

| M#   | MILESTONE NAME  | WP | DUE DATE  | RESP. PARTNER | MEANS OF VERIFICATION   |
|------|---|----|-----------|---------------|---|
| MS11 | Mapping of published scenarios and Storyline/scenario description | 2  | Dec. 2023 | ULEI          | Datasets on available scenarios are fed into D1.1 and qualitative descriptions of 3 futures for the six waste streams are circulated  |
| MS17 | Mapping of future technologies for each sector                    | 2  | Feb. 2024 | ULEI          | Dataset covering sector-specific current and emerging technologies in both the production of products and their end-of-life treatment made available to WP1 Lead and consortium members, including quantitative descriptions of future product market shares related to 6 waste streams |
| MS20 | Integration of social, environmental, and economic assessments    | 2  | May 2026  | ULEI          | Social, environmental, and economic impacts of SRM recovery have been quantified for each scenario and waste stream. Information delivered to the consortium.   |

## XII.3. Subtasks for Task 2.1 – Scenario storyline development

Table 1.5: WP2.1 – Subtask list

| WP | TASK | SUB-TASK | NAME                             | WS            | DESCRIPTION   | START | END | PARTNERS  | STATUS |
|----|------|----------|----------------------------------|---------------|---|-------|-----|---|--------|
| 2  | 2.1  | 2.1      | Scenario mapping                 | Cross-cutting | Map various studies from the academic, policy, and grey literature for future scenarios and assess the applicability within FutuRaM   | M01   | M05 | WEEE Forum, UNITAR, BRGM, CU, GTK, LMU, RECHARGE, SGU, TUB, LU, VITO, Empa, UCL | ✓      |
| 2  | 2.1  | 2.2      | Scenario methods                 | Cross-cutting | Compile various methodologies for scenario development and assess their applicability for developing scenarios on material recovery and circular economy for Europe         | M02   | M05 | WEEE Forum, UNITAR, BRGM, CU, GTK, LMU, RECHARGE, SGU, TUB, LU, VITO, Empa, UCL | ✓      |
| 2  | 2.1  | 2.3      | Scenario storylines              | Cross-cutting | Flesh out the storylines of the 3 main scenarios  | M05   | M08 | UNITAR, CU, TUB, LU   | ✓      |
| 2  | 2.1  | 2.4      | Qualitative scenario development | Cross-cutting | Use the chosen methods and qualitative methods to develop the three main scenarios to be used in FutuRaM (e.g. BAU, increased material recovery, and full circular economy) | M07   | M11 | UNITAR, CU, SGU, LU, VITO, UCL  | ✓(V3)  |

## XII.4. Consortium partner contributions to WP2

Table 1.6 lists the consortium partner contributions to WP2, in terms of person months for each sub-task. The table is based on the FutuRaM grant agreement [151].

| WP # | WP Name                              | Total PMs | Task No. | Start      | End        | ALL TASKS   | Consortium partners |        |      |          |     |     |          |     |     |            |      |      | Total |      |
|------|--------------------------------------|-----------|----------|------------|------------|---|---------------------|--------|------|----------|-----|-----|----------|-----|-----|------------|------|------|-------|------|
|      |                                      |           |          |            |            |   | WEEE Forum          | UNITAR | BRGM | Chalmers | GTK | LMU | RECHARGE | SGU | TUB | Leiden Uni | VITO | Empa | UCL   |      |
| 2    | Foresight on Secondary Raw Materials | 151.0     | 2.1      | 2022-06-01 | 2023-11-30 | Develop scenario storyline  | 1                   | 5      | 1    | 2        |     |     | .5       | 2   | 1   |            | 1    |      | 13.5  |      |
|      |                                      |           | 2.2      | 2022-08-01 | 2024-01-30 | Integrate future technologies into the scenarios  | 1                   | 4      | 2    | 6        | 1   | 1   | .5       | .5  | 6   | 1          | 2    | 1    | 3     | 29   |
|      |                                      |           | 2.3      | 2022-12-01 | 2024-01-30 | Forecast material composition and products for each scenario                              | 1                   | 4      | 2    | 2        | 1   |     | .5       |     | 8   | 4          | 2    | 2    |       | 26.5 |
|      |                                      |           | 2.4      | 2023-11-01 | 2025-05-31 | Quantify environmental and socioeconomic impacts of SRM recovery under each scenario      |                     | 2      | 2    |          |     | 11  |          |     | 2   | 11         |      | 3    | 4     | 35   |
|      |                                      |           | 2.5      | 2025-06-01 | 2026-04-30 | Assess the environmental and socioeconomic impacts and bottlenecks of future SRM recovery |                     |        | 4    | 1        |     |     |          |     | 3   | 11         |      | 1    |       | 20   |

Table 1.6: Consortium partner contributions to WP2 (person months per sub-task)

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# Methodology

498

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## 2.1. THE CONCEPTUAL FRAMEWORK FOR SCENARIO DEVELOPMENT

The conceptual framework for scenario development is based on the following principles.

**The scenarios should:**

- Be based on the best available scientific knowledge and data.
- Provide a coherent and consistent picture of possible futures.
- Provide decision makers with knowledge related to the possible consequences of their decisions.
- Consider a range of plausible future outcomes, accounting for uncertainties and alternative trajectories.
- Be developed in a participatory and collaborative manner, involving relevant stakeholders and experts.
- Be transparent and well-documented, allowing for replication and further analysis (e.g., publication in peer-reviewed journals and open-access repositories).
- Be flexible and adaptable, allowing for updates and adjustments as new information becomes available.
- Consider the interconnections and interactions between different sectors, waste streams, and policy domains.
- Take into account the broader societal, economic, and environmental context in which the waste streams operate.
- Incorporate a long-term perspective, considering the potential impacts and implications over several decades.
- Capture both quantitative and qualitative aspects, integrating data-driven modelling with qualitative narratives and storylines.
- Be regularly reviewed and updated to reflect evolving knowledge, technological advancements, and policy developments.
- Be used as a tool for learning and exploration, encouraging dialogue and collaboration among stakeholders.
- Inform policy and decision-making processes, providing insights into the potential consequences of different choices and interventions.
- Be communicated effectively to a wide range of audiences, ensuring accessibility and clarity of information.
- Contribute to the advancement of knowledge and understanding in the field of waste management, resource recovery, and circular economy.

By adhering to these principles, the FutuRaM project aims to develop robust, informative, and policy-relevant scenarios that support sustainable decision-making and contribute to the transition towards a more circular and resource-efficient economy.

## 2.2. SCENARIO STORYLINE DEVELOPMENT PROCESS

Building scenarios involves several steps and various methodologies, these will differ depending on the specific context and objectives of the exercise [81, 23, 82, 83, 76, 90, 91, 92, 93].

The following section provides an overview of the scenario development process used in FutuRaM. Figure 2.1 provides a visual representation of the process.

### 2.2.1. Step 1: Define the scope and objectives

#### Scope and objectives of the scenario development process

The scope and objectives of the scenario development process are defined in the context of the overall aim, scope, and objectives of the FutuRaM project.

##### Aim of FutuRaM:

FutuRaM will develop the Secondary Raw Materials knowledge base on the availability and recoverability of secondary raw materials (SRMs) within the European Union (EU), with a special focus on critical raw materials (CRMs). The project research will enable fact-based decision-making for the recovery and use of SRMs within and outside the EU, and disseminate the data generated via an accessible knowledge base developed in the project [152, 153].

##### Scope of FutuRaM:

FutuRaM will establish a methodology, reporting structure, and guidance to improve the raw materials knowledge base up to 2050. FutuRaM will focus on six waste streams: batteries; electrical and electronic equipment; vehicles; mining; slags and ashes; and construction and demolition.

It will integrate SRM and CRM data to model their current stocks and flows and consider economic, technological, geopolitical, regulatory, social and environmental factors to further develop, demonstrate, and align SRM recovery projects with the United Nations Framework Classification for Resources (UNFC) [150].

This will enable the commercial exploitation of SRMs and CRMs by manufacturers, recyclers, and investors, and the knowledge base developed in the project will support policymakers and governmental authorities.

Selected objectives of the FutuRaM project are presented in Table 2.1 [152, 153].

#### Scope of Work Package 2 (WP2):

Given this context, the scope of the scenario development process is to develop a set of plausible scenarios that explore the future of waste management, resource recovery, and circular economy in the EU.

The scenarios will be used to identify key drivers and uncertainties that will influence the future of waste management and resource recovery. The scenarios will also be used to evaluate the potential impacts of different policy interventions and technological advancements.

##### Thematic scope

The scenarios will be centred on the six waste streams of FutuRaM: WEEE, ELV, BAT, CDW, MIN, and SLASH. Additionally, consideration will be given to sectors and policy domains that are relevant to these waste streams and the general context of the system. These include manufacturing, energy, and transportation, as well as policies related to the environment, the economy, society, technology, and geopolitics.

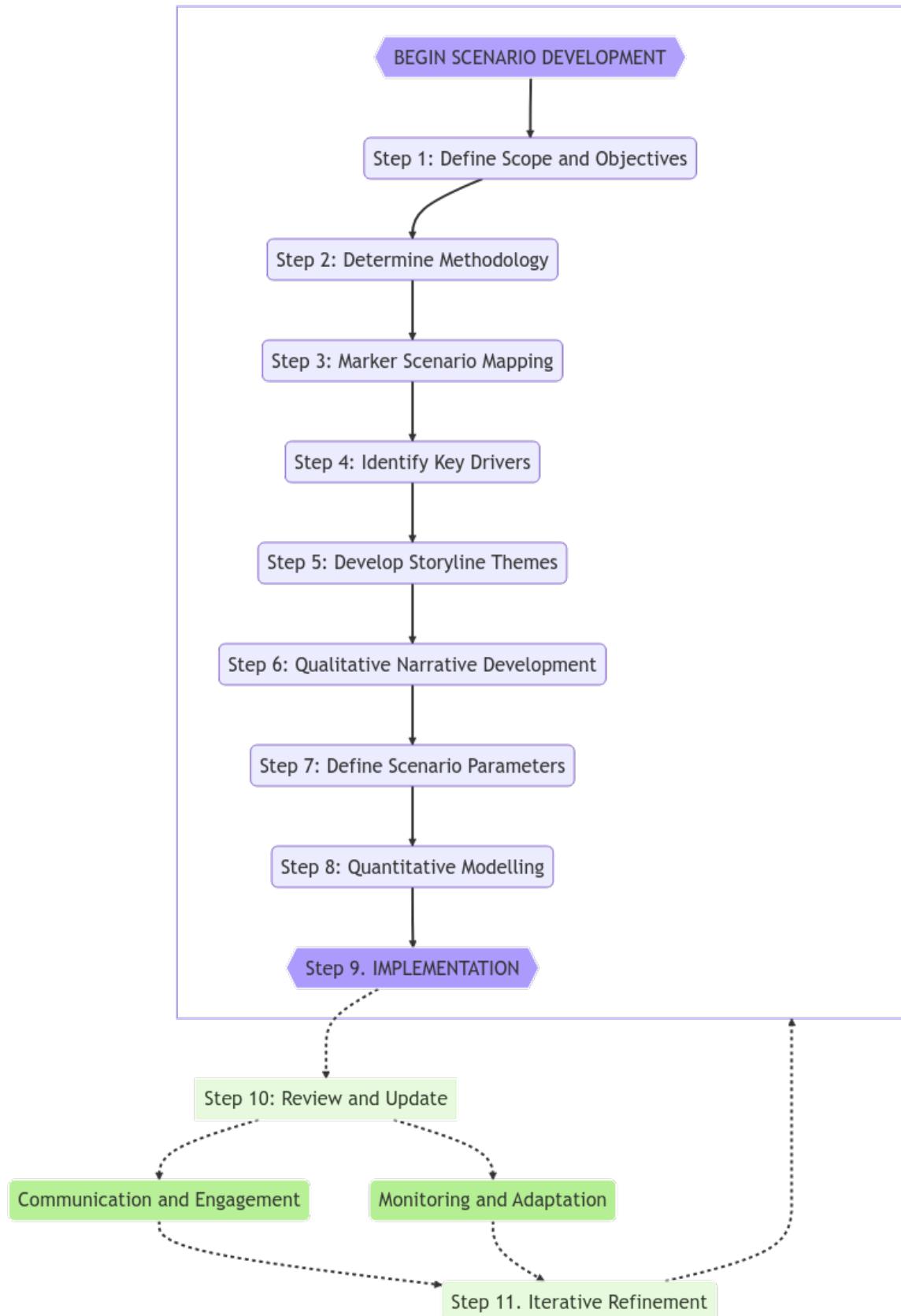


Figure 2.1: Scenario storyline development process

*Table 2.1: Selected objectives of the FutuRaM project*

| NEED   | ACTION   |
|--|--|
| A successful transition to a climate-neutral, circular and digitised EU economy relies heavily on a secure supply of raw materials.  | FutuRaM will quantify the future availability of SRMs for three future scenarios for the EU material economy. Forecast material demand, SRM supply for each scenario, and raw material imports to evaluate EU material autonomy.   |
| Presently, several socioeconomic scenarios have been developed at national, EU, and/or global scales to assess the energy and mobility transition. Still lacking are specific scenarios for the SRM and CRM recovery systems | FutuRaM will develop stock-flow models for six waste streams based on holistic scenarios to map current and future material use in the economy of the EU-27 plus Iceland, Norway, Switzerland and the United Kingdom. FutuRaM will extend existing model approaches by a set of distinct scenarios that cover circular economy, high SRMs recoverability, and business as usual. |

### 585 **Geographic scope**

586 The scenarios will be developed for the EU-27 plus Iceland, Norway, Switzerland and the United  
 587 Kingdom (EU27+4). The scenarios will consider the current and future waste management practices and  
 588 resource recovery technologies in these countries. Additionally, the scenarios will consider the current and

589 future policies and targets related to waste management and resource efficiency in these countries. To  
 590 some extent, the scenarios will also consider the current and future trade relationships between these  
 591 countries and other countries around the world.

### 592 **Temporal scope**

593 The scenarios will be developed for the time horizon of 2025–2050. This time horizon is aligned with  
 594 the long-term targets of the EU, including the EU Green Deal, the EU Circular Economy Action Plan, and  
 595 the EU Industrial Strategy.

596 The discrete stages in the forecasts are planned to be: 2025, 2030, 2035, 2040, 2045 and 2050.

597 The temporal resolution of the scenarios will be determined during the quantification phase of the  
 598 scenario development process.

599 While it is possible to develop scenarios with a high (or even continuous) temporal resolution, that  
 600 of these scenarios will be determined based on the availability and quality of data. It is important to  
 601 acknowledge that providing too high a temporal resolution may lead to a false sense of accuracy and  
 602 precision.

603 Furthermore, the scenarios will be developed with the understanding that the further into the future we  
 604 look, the more uncertain the predictions become [83, 94, 95].

### 605 **Consideration of EU legislation and policy targets**

606 The scenarios developed in FutuRaM consider targets that the EU is setting for specific elements, materials,  
 607 and waste streams. The targets incorporated into FutuRaM's scenarios are aligned with the ambitions of the  
 608 EU's Green Deal [3] and its Critical Raw Materials (CRM) act [1].

609 Additionally, the consumer-product-centric waste streams BATT, ELV, and WEEE have specific EU  
 610 legislation that is directly applicable to them and will be considered in detail in the scenarios [4, 5, 6, 142, 7,

## WP2 — Aims and objectives definition

*Table 2.2: FutuRaM WP2 aims and objectives*

| AIM   | OBJECTIVE  |
|---|--|
| Quantifying the current and future availability of secondary raw materials (SRM), particularly critical raw materials (CRM), for the identified waste streams from 2025 until 2050.       | Developing a set of plausible scenarios that encompass these waste streams and provide quantitative estimates of the current and future availability of SRM and CRMs.  |
| Informing private and public sector decision-making processes by assessing the impacts of different legislative and policy strategies related to waste management and resource efficiency | The scenarios will cover a range of such strategies, grouped in coherent sets in each of the three storylines including recycling, reuse, remanufacturing, and landfilling.<br>Integration of the scenario with the system model will allow assessment of the impacts of these strategies not only on the availability of SRM and CRMs, but also on the environment, the economy, and society. |

611 8].

### GENERAL POLICIES AND LEGISLATION

612 613 **The EU Green Deal** [3] is a set of policy initiatives by the European Commission with the overarching  
614 aim of making the EU climate-neutral in 2050.

615 This policy portfolio is a response to the Paris Agreement and the United Nations Sustainable Develop-  
616 ment Goals. It covers a wide range of economic sectors with an emphasis on investments towards building  
617 local, 'sustainable' industries.

618 The scope of FutuRaM is aligned with the EU Green Deal's goal of ensuring the sustainable sourcing and  
619 use of raw materials, reducing dependency on imports, and promoting resource security. These goals can  
620 conflict with each other; however, the modelling in FutuRaM will explore the trade-offs between them (e.g.,  
621 optimising local sourcing may result in higher negative externalities).

622 **The EU Circular Economy Action Plan** [2] is a policy framework developed by the European Commission  
623 to promote the circular economy in the European Union.

624 It sets out a comprehensive set of measures and targets to improve resource efficiency, reduce waste,  
625 and foster sustainable production and consumption. The Action Plan includes initiatives related to product  
626 design, waste management, recycling, and resource efficiency, among others. The Action Plan is a key  
627 element of the European Green Deal and is closely linked to the EU Industrial Strategy.

#### 628 **The Circular Economy Action Plan:**

- 629 • Aims to promote the transition to a more circular economy in the EU.
- 630 • Sets out a range of measures to promote the sustainable use of resources, reduce waste, and  
631 increase recycling.
- 632 • Includes proposals for new legislation, such as an EU-wide framework for the circular econ-  
633 omy, and revisions to existing legislation, such as the WEEE Directive.
- 634 • Emphasises the importance of product design for the circular economy and proposes mea-  
635 sures to promote eco-design and repairability.
- 636 • Includes initiatives to promote the use of secondary raw materials, such as the establish-  
637 ment of a European Raw Materials Alliance.
- 638 • Aims to reduce greenhouse gas emissions and improve resource efficiency in the EU.
- 639 • Calls for increased cooperation and dialogue among stakeholders in the circular economy.

640  
641     **The Critical Raw Materials Act (CRM Act) [1]** is an EU regulation that aims to ensure a secure and  
sustainable supply of raw materials to the EU.

642     The Act identifies a list of strategic raw materials, which are crucial to technologies important to Europe's  
643     green and digital ambitions and for defence and space applications, that are subject to potential supply risks.  
644     The regulation will cover the entire raw materials value chain, from primary extraction to manufacturing to  
645     potential recovery as a secondary raw material.

646     For example: According to the CRM act, by 2030, a single 'third country' (ex-EU, ex-Schengen) should  
647     produce no more than 65% of the EU's annual consumption of each strategic raw material.

648     Clear benchmarks have been set for the domestic capacities of the EU in 2030:

- 649         • Extract at least 10% of the EU's annual consumption  
650         • Process at least 40% of the EU's annual consumption  
651         • Recycle at least 15% of the EU's annual consumption

652     These benchmarks have been included in the scenarios developed in FutuRaM. Specifically, in the  
653     Recovery scenario (REC), where the emphasis is on the recovery of materials from waste streams, and the  
654     Circularity scenario (CIR) where the emphasis is on the implementation of 're-X' strategies, such as recycling,  
655     remanufacturing, and reuse.

656     Many of these targets, benchmarks and mandates — despite being included in legislation — are consid-  
657     ered too optimistic to be included in the Business-as-usual scenario (BAU) as they often make expectations  
658     whose attainment is likely highly unrealistic without radical reform of the waste management system. For  
659     example, the targets in the Battery Act suggest near-complete recovery for several elements [8].

## 660     *Extent of policy and legislation inclusion in the scenarios*

661     The targets that result from the planned and ongoing review processes are non-negotiable and legally  
662     binding and thus should be incorporated into our scenarios. These targets, however, are only applicable  
663     to post-consumer products, namely WEEE, BAT and ELV. This envisioned future in which legally binding  
664     targets for collection, reuse and/or material recycling are achieved can be implemented as the Recovery  
665     scenario.

666     If there are no targets set for a specific consumer product category, then approach targets similar to  
667     the WEEE directive and in line with the EU Green Deal. For the Recovery, and especially for the Circularity  
668     scenario, FutuRaM will also consider the effects of proposed ecodesign requirements for sustainable  
669     products (e.g., longer lifetimes, increased reusability, repairability, recyclability).

670     However, for waste that does not consist of discarded consumer products, but instead results from  
671     industrial production activities, in particular for MIN and SLASH, we must still produce specific scenarios  
672     related to mining, metallurgy, and waste and fuel combustion. The production of new mining wastes will  
673     depend on new local mining activity.

674     Predicted production in the EU until 2050 will be forecast (equally across the three scenarios) and the  
675     flows into the MIN waste stream can be calculated with the respective transfer coefficients. The recovery  
676     of historical MIN stock, which is a target of the CRM Act, should be modelled differently. It requires a  
677     hypothesis about the percentage of historical tailings recoverable by commodity and country.

678     The scenarios will account for increasing resource use effectiveness and production process efficiency  
679     thus indicating lower volumes and quality of generated production residues (both by-products and waste  
680     such as red mud, waste rock, slags, etc.) per unit of product (expressed either as product mass or product  
681     value), whether that product is a metal (e.g., a copper cathode), metal alloy (e.g., aluminium alloy n° 5183)  
682     or metal product (e.g., cold rolled stainless steel sheet).

683 Excepting the BAU storyline, WEEE, ELV, and BATT waste material recovery will follow the targets in the  
684 EU.

685 For SLASH and MIN, we will evaluate recent trends in waste generation and extract plausible ranges of  
686 generation toward 2050.

687 For CDW, embedded WEEE will follow EU targets, and bulk waste will incorporate storylines and  
688 scenarios that are congruent with predicted demolition rates (where renovation is the alternative emphasised  
689 in the CIR storyline).

690 Various drivers will be assigned to move between these ranges and will be key to the specific, harmonized  
691 storyline for the scenario. Finally, the targets and storylines will be aligned with assumptions on technology  
692 development.

### 693 ***Consideration of geopolitical developments***

694 The storylines also attempt to consider geopolitical considerations and thus supply chain resiliency for  
695 satisfying the product demand in the scenarios. We must omit, however, possible changes in waste flow  
696 volumes and composition that could arise from any material supply constraints.

697 The reasoning for this is that it would needlessly confusate the interpretation of the modelling results as  
698 the incertitude of these potentialities is very high and this realm is outside the scope of FutuRaM's mandate  
699 and expertise.

700 The most volatile aspect of the 'criticality calculation' is the risk profile of the producing country. For  
701 many material-exporting nations, this is not something that can be reliably forecast, especially not over the  
702 next 30 years. Thus, it will be assumed that the growth in material demand for (among other needs) the  
703 energy and mobility transitions can be satisfied either by an increase in mining and metallurgy activities  
704 within the EU or by growing imports from raw material-producing countries outside the EU.

705 That is, if we go for increased domestic EU production to minimize geopolitical supply risk, it may  
706 indicate more EU production residue generation even under increased production efficiency and resource  
707 effectiveness. The increase of domestic industrial activity, as a response to an envisioned increased internal  
708 demand, supposes an equivalent rise of societal approval for mining and refining activities on EU territory.

709 If the increased demand is, however, satisfied by imports from non-EU countries, which we know have  
710 domestic resource consumption also growing significantly due to the energy and mobility transition, our  
711 assumption would be to shift the mining and refining activities from EU countries towards resource-rich  
712 non-EU countries.

713 This shift would also imply an increased risk for geopolitical instability and/or security of supply of critical  
714 raw materials to the EU.

715 This situation is front of mind for many in policy and business and the EU is 'applying a policy mix  
716 that aims to increase domestic capacity, diversify suppliers, and support the multilateral rules-based trade  
717 environment.'

718 However, '...most experts predict that reshoring or nearshoring will be of limited importance. With  
719 time, though, resilience may improve through international cooperation, diversification and the accelerated  
720 uptake of digital technologies.' [27]

721 Note: supply constrictions will be considered in the model's sensitivity analysis and the codebase will  
722 be designed to allow for the optimisation of the SRM recovery system based on any value statements  
723 (such as profit, environmental impacts, supply and demand).

## 2.2.2. Step 2: Determine methodology

### ***Methodology types and selection criteria***

The second step in the scenario development process is to determine the methodology to be used. This involves identifying the most appropriate methods and tools for the specific context and objectives of the scenario development process. The methodology should be selected based on the following criteria:

#### **Relevance:**

The methodology should be relevant to the specific context and objectives of the scenario development process.

#### **Applicability:**

The methodology should be applicable to the specific context and objectives of the scenario development process.

#### **Feasibility:**

The methodology should be feasible given the available resources (e.g., time, budget, expertise, data, etc.).

#### **Transparency:**

The methodology should be transparent and well-documented, allowing for replication and further analysis.

#### **Flexibility:**

The methodology should be flexible and adaptable, allowing for updates and adjustments as new information becomes available.

#### **Accessibility:**

The methodology should be accessible to a wide range of stakeholders, ensuring that it can be understood and used by non-experts.

#### **Effectiveness:**

The methodology should be effective in achieving the objectives of the scenario development process.

#### **Efficiency:**

The methodology should be efficient in terms of time, cost, and resources required to implement it.

#### **Acceptability:**

The methodology should be acceptable to stakeholders, ensuring that it is perceived as fair and legitimate.

Further details are given in this section, and the table in section 13.3 provides an overview of the methods and tools considered, along with a brief description of each and its relevance to the specific context and objectives of the FutuRaM scenario development process.

### ***Choice of methodology***

The grant proposal for the FutuRaM project outlined that there should be at least three scenarios developed, namely business as usual, recovery, and circularity. This remains the case; however, during the scenario development process, additional scenarios or scenario dimensions were considered, including supply chain security and the energy transition.

#### **Considered dimension — Supply chain security:**

Due to various political developments in 2022, the question of the security of the EU's supply chains for CRMs was brought into focus. This led to the proposal from stakeholders to consider a scenario dimension that would explore the security of the EU's supply chains for CRMs.

## **Considered dimension – Energy transition:**

The energy transition is a key topic in the EU's policy agenda, and the *FutuRaM* project is concerned with the role of CRMs in the energy transition. Therefore, the proposal was made to consider a scenario dimension that would explore the energy transition in the EU.

### **Method – Multi-criteria analysis and cross-impact analysis**

In order to assess the potential inclusion of these additional scenario dimensions, a multi-criteria analysis and a cross-impact analysis were conducted [96]. The addition of extra dimensions increases the possible number of scenarios significantly. By assessing the consistency and plausibility of these combinations with a matrix-based method, it was possible to reduce the number of scenarios.

For example, low progress in the energy transition is unlikely to concur with high progress in recycling/circularity indicators and can be excluded. In contrast, different levels for the supply chain security dimension would result in an additional scenario, as this dimension is considered independent of the others.

Ultimately, supply chain security was eliminated as a scenario dimension. This is due to the consortium's inability to speculate on geopolitical developments and the added incertitude it would introduce to the scenarios.

The potential of supply constraints will, however, be considered in the future sensitivity analysis of the model, as well as potentially through an array of explorative multi-object optimisation procedures. This can produce projects to answer the question, 'What would happen to the SRM system if element x is constrained, and what would be the optimal response to this constraint?'

## Method – Delphi

The Delphi method [97] was used in the initial stages of the scenario-building process to gather and aggregate the opinions of experts or stakeholders. Internal consultation with consortium members who were experts in their respective waste streams or other aspects of the recovery system was conducted.

The method involves steps such as the selection of experts, generation of initial questionnaires, iterative rounds of responses, and convergence and consensus building. For the later stages of the process, further rounds of consultation will be conducted with external stakeholders, including representatives from industry, academia, and government.

## *Choice of Scenario Type*

The general types of scenarios are summarized in Table 2.3. In the context of futures studies, various approaches and methodologies are employed to understand the potential trajectories of future developments [23, 82, 83, 90, 91, 92].

We can classify scenario studies into three primary categories, each addressing distinct questions about the future. These categories are tailored to better align with the specific objectives of scenario usage:

### **Predictive Scenarios (Answering ‘What Will Happen?’):**

### **Pros:**

These scenarios offer insights into potential future outcomes, aiding in long-term planning.

**803 Cons:**

804 They are contingent on assumptions and may not account for unexpected events.

**805 Applicability:**

806 Predictive scenarios are valuable when the aim is to forecast future developments under  
807 certain conditions.

**808 Explorative Scenarios (Answering 'What Can Happen?'):****809 Pros:**

810 Explorative scenarios explore a wide range of potential future scenarios, fostering prepared-  
811 ness for various outcomes.

**812 Cons:**

813 They do not prioritize the likelihood or desirability of scenarios.

**814 Applicability:**

815 These scenarios are beneficial when considering multiple potential futures and the need to  
816 adapt to diverse outcomes.

**817 Normative Scenarios (Answering 'How Can a Specific Target Be Reached?'):****818 Pros:**

819 Normative scenarios focus on achieving predefined objectives and offer guidance on strategies  
820 to attain them.

**821 Cons:**

822 They are inherently normative, starting with specific goals in mind.

**823 Applicability:**

824 Normative scenarios are suitable when the objective is to work towards predefined targets  
825 and develop actionable plans to reach them.

826 The choice of scenario category is influenced not only by the characteristics of the system under study  
827 but also by the user's worldview, perceptions, and study objectives. Additionally, the user's perspective plays  
828 a crucial role in determining the most suitable approach. For instance, the decision to employ predictive,  
829 explorative, or normative scenarios hinges on the user's goals and the nature of the questions they seek to  
830 answer.

831 Furthermore, considerations regarding the predictability of the future and the potential for influencing it  
832 can impact the selection of scenario types. For example, some users may argue that uncertainty in certain  
833 parameters makes long-term predictions less meaningful, while others may see value in using forecasting  
834 and optimisation models to stimulate discussions and inform decision-making processes.

835 In practice, a combination of qualitative and quantitative techniques can be employed to create sce-  
836 narios tailored to specific needs. For instance, a blend of techniques may be used to generate forecasts,  
837 especially when external factors are uncertain. Likewise, strategic scenarios often begin with external  
838 scenario generation and proceed to identify available policy options.

Table 2.3: Types of scenario (adapted from [23, 82])

| SCENARIO CATEGORY                             | SCENARIO TYPE | OUTCOME  | TIMEFRAME       | SYSTEM STRUCTURE         | FOCUS ON FACTORS                         |
|---|---------------|--|-----------------|--------------------------|--|
| <b>Predictive</b><br><i>what will happen?</i> | Forecasts     | Typically quantitative, sometimes qualitative    | Often short     | Typically one            | Typically external                       |
|   | What-if       | Typically quantitative, sometimes qualitative    | Often short     | One to several           | External and, possibly, internal         |
| <b>Explorative</b><br><i>what can happen?</i> | External      | Typically qualitative, quantitatively possible   | Often long      | Often several            | External                                 |
|   | Strategic     | Qualitative and quantitative                     | Often long      | Often several            | Internal under influence of the external |
| <b>Normative</b>                              | Preserving    | Typically quantitative                           | Often long      | One                      | Both external and internal               |
|   | Transforming  | Typically qualitative with quantitative elements | Often very long | Changing, can be several | Not applicable                           |

F

Back to ToC

839      The scenarios developed in the FutuRaM project are a combination of predictive and normative:

840      **BAU:**

841      *What will happen if current trends continue?* This scenario is predictive in nature, based on the assumption that the current trends and developments in waste management and resource recovery systems will continue into the future.



844      **Recovery:**

845      *What will it take to achieve the EU's targets for material use and recovery?*  
846      *Focus on technology* This scenario is normative, focusing on manipulating the technology and infrastructure of the recovery system to achieve the EU's targets and mandates.



848      **Circularity:**

849      *What will it take to achieve the EU's targets for material use and recovery?*  
850      *Focus on re-X strategies* This scenario is a combination of normative and explorative, considering the targets and mandates of the EU's circular economy action plan and exploring re-X strategies in the recovery system.

853      The methodology and scenario types were selected based on their relevance, applicability, feasibility, transparency, flexibility, accessibility, effectiveness, efficiency, and acceptability to the scenario development process.

## 856      2.2.3. Step 3: Marker-scenario mapping

### 857      *Justification and methodology*

858      This preliminary step in the scenario development process involves conducting a literature study to identify  
859      existing scenarios that are relevant to the FutuRaM project. This step is crucial as it serves several important  
860      purposes and provides valuable insights for the overall scenario development process. It helps the scenario  
861      development team to build on existing knowledge, identify relevant scenarios, gain insights and inspiration,  
862      fill knowledge gaps, and enhance credibility and comparability.

#### 863      **Building on existing knowledge**

864      Conducting a literature study allows the FutuRaM project team to tap into existing knowledge and expertise  
865      in the fields of waste management, resource recovery, and circular economy. It provides a foundation of  
866      existing scenarios that have been developed by other researchers, organizations, or institutions. By building  
867      on this existing knowledge, the FutuRaM project can leverage the insights, methodologies, and findings  
868      from previous scenario studies, saving time and resources.

#### 869      **Identifying relevant scenarios**

870      Marker scenario mapping helps identify scenarios that are relevant to the specific objectives and scope of  
871      the FutuRaM project. By reviewing the literature, the project team can assess the applicability of existing  
872      scenarios to their research questions and determine which scenarios align with the waste streams, sectors,  
873      and policy domains being considered. This step ensures that the scenarios selected for further analysis are  
874      well-suited to address the project's goals.

#### 875      **Gaining insights and inspiration**

876      Reviewing existing scenarios provides the FutuRaM project team with valuable insights and inspiration for the  
877      development of their own scenarios. It allows them to understand the different approaches, assumptions,

878  
879 and methodologies used in previous scenario studies. This knowledge can inform the design and structure  
of the FutuRaM scenarios, helping to ensure a rigorous and well-founded approach.

880 **Filling knowledge gaps**

881 Marker scenario mapping helps identify any gaps or areas of limited knowledge in the existing scenario  
882 landscape. It allows the FutuRaM project team to identify topics or aspects that have not been adequately  
883 addressed in previous scenarios. This awareness of knowledge gaps can guide the project team in focusing  
884 their efforts on areas where new insights and contributions can be made, leading to a more comprehensive  
885 and innovative scenario development process.

886 **Enhancing credibility and comparability**

887 By conducting a literature study and referencing existing scenarios, the FutuRaM project can enhance the  
888 credibility and comparability of their own scenarios. The project team can reference and compare their  
889 findings, assumptions, and results with those from previous studies, contributing to the overall body of  
890 knowledge in the field. This promotes transparency, robustness, and consistency in the scenario develop-  
891 ment process and allows for better benchmarking and evaluation of the FutuRaM scenario set.

892 ***Content of the marker scenario mapping for application to FutuRaM's***  
893 ***scenarios***

894 Table 13.4 in section 13.4 presents an overview of the marker scenarios considered in the FutuRaM project.  
895 The table is not intended to be exhaustive but rather to provide an overview of the different scenarios that  
896 have been developed in the fields of waste management, resource recovery, and circular economy.

897 **2.2.4. Step 4: Identification of key drivers of change**

898 In this step, the key drivers of change that will shape the future of the scenarios are identified. Key drivers are  
899 the factors or forces that have a significant influence on the waste management system and its development  
900 over time. These drivers can be social, economic, technological, environmental, or policy-related.

901 The purpose of identifying key drivers of change is to understand the factors that will have the greatest  
902 impact on waste management and to ensure that the scenarios capture the range of possible outcomes  
903 influenced by these drivers.

904 The process of identifying key drivers involves a combination of literature review, expert consultations,  
905 and stakeholder engagement. It requires a comprehensive analysis of relevant trends, uncertainties, and  
906 emerging issues that may affect the waste management system.

907 The key drivers identified in this step will be used to develop the storyline themes and scenario parame-  
908 ters in the next step.

909 Figure 2.2 illustrates the process of identifying key drivers of change.

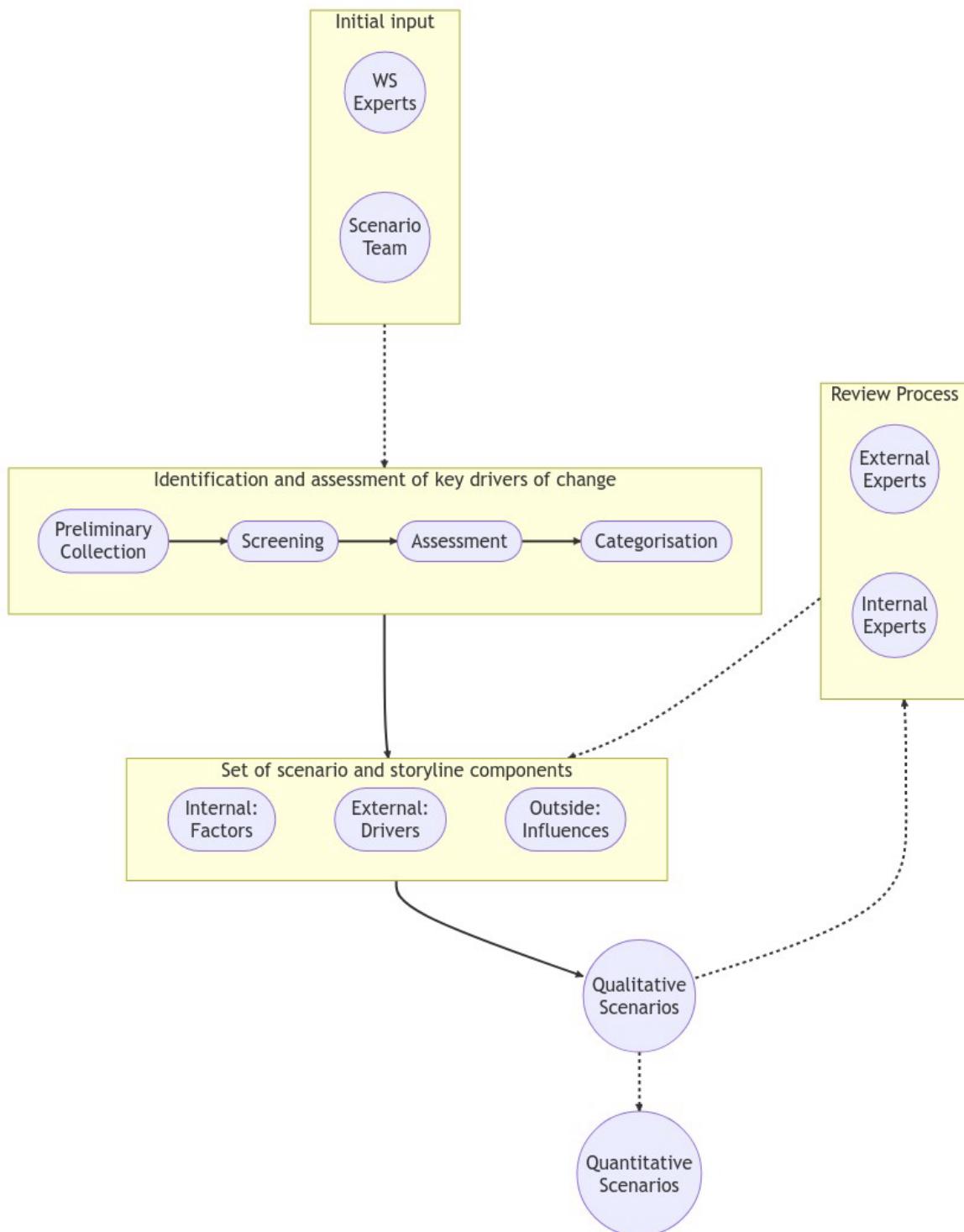


Figure 2.2: An illustration of the process used for identifying key drivers of change

910  
911

## **Methodology and results of this stage in *FutuRaM's scenario development:***

912  
913

The overall goal of this process is to identify and include elements in the storylines and scenarios that are relevant, plausible, and influential in shaping the future.

914  
915  
916

The selection, screening, and categorisation steps ensure that the elements chosen for the development of storylines and scenarios are consistent, coherent, and aligned with the objectives and scope of the scenario exercise.

917

### **1. Preliminary collection:**

918  
919

This step involved gathering a pool of potential elements that could be included in the storylines and scenarios.

920  
921  
922

These elements were derived from expert input from waste streams and the scenario development team, including taking knowledge from the literature review and existing scenarios identified in Step 2 – Marker scenario mapping.

923  
924

This step was conducted using the PESTLE analysis framework. The PESTEL (or PESTLE) framework is a strategic tool used to understand the macro-environmental factors that can affect a system.

925  
926

A PESTEL analysis can help identify opportunities and threats linked to each of these factors, understand the broader context, and shape scenarios accordingly [98, 77].

927

**The acronym PESTEL stands for:**

928

#### **Political:**

929  
930  
931

These factors refer to the impact of government policies, regulations, and political stability. This includes issues like tax policy, labour laws, environmental regulations, trade restrictions and reforms, tariffs, and political stability.

932

#### **Economic:**

933  
934  
935

These factors relate to the broader economic environment, including factors like economic growth, exchange rates, inflation rates, interest rates, disposable income of consumers and businesses, and the general health of the economy.

936

#### **Sociocultural:**

937  
938  
939

These factors include societal trends and characteristics that could affect your business. They include demographic trends (like age, gender, and ethnicity), cultural trends, lifestyle preferences, consumer attitudes, and broader societal expectations.

940

#### **Technological:**

941  
942  
943

These factors refer to the impact of emerging technologies, research and development activities, automation, the rate of technological change, and the adoption of technology within your market.

944

#### **Environmental:**

945  
946  
947

These factors refer to ecological aspects that can affect a system. This includes environmental regulations, consumer attitudes towards sustainability, climate change, and other natural events.

948

#### **Legal:**

949  
950  
951

These factors include laws and regulations with which your business must comply. These can include labour law, consumer law, health and safety law, and restrictions on the import or export of goods.

952

**The 68 elements identified in the initial screening stage are listed in section 13.5.**

953  
954 **2. Screening:**

955 In the screening step, the collected elements are evaluated and assessed based on specific criteria.  
956 This was conducted through a literature study and internal consultation of scientists in the project.  
957 This evaluation helps determine the relevance, reliability, and significance of each element for the  
958 development of storylines and scenarios. Many elements were aggregated, especially if they were  
959 deemed to follow similar trends to others (e.g., recyclability mandates and improved recyclability in  
960 project design). Elements that did not meet the predefined criteria or were deemed irrelevant, 'un-  
961 modellable' or unreliable were excluded from further consideration (e.g., corruption, data protection,  
and supply chain conflict).

962 The 28 elements that were identified in this stage are listed in section 13.6.

963 In Figure 2.3, an excerpt of a spreadsheet illustrates part of the screening process for the FutuRaM  
964 scenarios, which was informed by the waste streams. In this exercise, the elements were evaluated  
965 based on their relevance to the waste streams and their potential impact on the waste management  
966 system.

967 The elements were also assessed based on their plausibility and likelihood of occurrence in the future.  
968 The elements that were deemed relevant, plausible, and influential were included in the storylines  
969 and scenarios.

| THIS TABLE IS FOR THE ASSESSMENT OF THE RELEVENCE OF EACH SCENARIO ELEMENT TO INDIVIDUAL WASTE STREAM FLOWS | ELV         |                        |         | BAT                |                      |                            |              |         | WEEE                         |                |               |                          |            |                      |
|---|-------------|------------------------|---------|--------------------|----------------------|----------------------------|--------------|---------|------------------------------|----------------|---------------|--------------------------|------------|----------------------|
|   | Bulk metals | Critical raw materials | Average | Portable Batteries | Industrial Batteries | Automotive (SLI) Batteries | EV Batteries | Average | CAT-I - Temperature exchange | CAT-II Screens | CAT-III Lamps | CAT-IVa Large equipments | CAT-IVb PV | CAT-Small equipments |
| DRIVER/FACTOR   |             |                        |         |                    |                      |                            |              |         |                              |                |               |                          |            |                      |
| Population  |             |                        |         | 5.00               | 5.00                 | 4.00                       | 5.00         | 4.75    | 5.00                         | 5.00           | 5.00          | 5.00                     | 5.00       | 5.                   |
| Resource shortage   | 3.00        | 5.00                   | 4.00    | 5.00               | 5.00                 | 2.00                       | 5.00         | 4.25    | 4.00                         | 5.00           | 4.00          | 4.00                     | 5.00       | 4.                   |
| Treatment cost  |             |                        |         | 4.00               | 4.00                 | 4.00                       | 4.00         | 4.00    | 4.00                         | 4.00           | 4.00          | 4.00                     | 4.00       | 4.                   |
| Digital product passports   | 3.00        | 3.00                   | 3.00    | 4.00               | 4.00                 | 4.00                       | 4.00         | 4.00    | 3.00                         | 3.00           | 3.00          | 3.00                     | 3.00       | 3.                   |
| Obsolescence  | 1.00        | 5.00                   | 3.00    | 4.00               | 4.00                 | 3.00                       | 4.00         | 3.75    |                              |                |               |                          |            |                      |
| Digitalization  | 1.00        | 5.00                   | 3.00    | 4.00               | 4.00                 | 3.00                       | 4.00         | 3.75    |                              |                |               |                          |            |                      |
| SRM prices  |             |                        |         | 4.00               | 4.00                 | 2.00                       | 4.00         | 3.50    | 4.00                         | 4.00           | 4.00          | 4.00                     | 4.00       | 4.                   |
| Product prices  |             |                        |         | 3.00               | 4.00                 | 1.00                       | 4.00         | 3.00    | 3.00                         | 5.00           | 3.00          | 3.00                     | 3.00       | 3.                   |
| Recyclability mandates  | 4.00        | 5.00                   | 4.50    | 3.00               | 3.00                 | 3.00                       | 3.00         | 3.00    | 2.00                         | 3.00           | 2.00          | 2.00                     | 2.00       | 3.                   |
| Conflict in supply chain  | 4.00        | 5.00                   | 4.50    | 4.00               | 4.00                 | 0.00                       | 4.00         | 3.00    | 2.00                         | 3.00           | 2.00          | 2.00                     | 3.00       | 2.                   |
| Obligatory recycling standards for treatment facilities   |             |                        |         | 3.00               | 3.00                 | 3.00                       | 3.00         | 3.00    | 2.00                         | 2.00           | 2.00          | 1.00                     | 1.00       | 2.                   |
| Improved durability   | 4.00        | 5.00                   | 4.50    | 3.00               | 3.00                 | 1.00                       | 3.00         | 2.50    |                              |                |               |                          |            |                      |
| Composition change  |             |                        |         | 3.00               | 3.00                 | 0.00                       | 4.00         | 2.50    |                              |                |               |                          |            |                      |
| Subsidies   |             |                        |         | 2.00               | 3.00                 | 1.00                       | 3.00         | 2.25    | 3.00                         | 2.00           | 3.00          | 4.00                     | 4.00       | 2.                   |
| Availability of recovery technologies   |             |                        |         | 3.00               | 3.00                 | 0.00                       | 3.00         | 2.25    | 1.00                         | 4.00           | 1.00          | 1.00                     | 4.00       | 4.                   |
| Taxation (raw materials, landfill)  | 4.00        | 4.00                   | 4.00    | 2.00               | 2.00                 | 3.00                       | 2.00         | 2.25    | 2.00                         | 2.00           | 2.00          | 2.00                     | 4.00       | 2.                   |
| Obligatory removal of CRMs from waste   |             |                        |         | 3.00               | 3.00                 | 0.00                       | 3.00         | 2.25    | 1.00                         | 2.00           | 2.00          | 1.00                     | 2.00       | 2.                   |
| Corruption  | 2.00        | 2.00                   | 2.00    | 3.00               | 3.00                 | 0.00                       | 3.00         | 2.25    | 1.00                         | 1.00           | 1.00          | 1.00                     | 1.00       | 1.                   |
| Supply chain due diligence laws   | 4.00        | 4.00                   | 4.00    | 0.00               | 4.00                 | 0.00                       | 4.00         | 2.00    | 0.00                         | 1.00           | 0.00          | 0.00                     | 1.00       | 1.                   |
| Improved recyclability  | 4.00        | 5.00                   | 4.50    | 2.00               | 2.00                 | 0.00                       | 2.00         | 1.50    |                              |                |               |                          |            |                      |
| Ecodesign   |             |                        |         | 2.00               | 2.00                 | 0.00                       | 2.00         | 1.50    |                              |                |               |                          |            |                      |
| Trade barriers  | 3.00        | 5.00                   | 4.00    | 2.00               | 2.00                 | 0.00                       | 2.00         | 1.50    | 2.00                         | 3.00           | 2.00          | 2.00                     | 3.00       | 2.                   |
| Industrialisation of Europe   | 4.00        | 5.00                   | 4.50    | 0.00               | 2.00                 | 0.00                       | 3.00         | 1.25    | 3.00                         | 3.00           | 1.00          | 3.00                     | 3.00       | 1.                   |
| Reduced consumerism   | 5.00        | 3.00                   | 4.00    | 0.00               | 1.00                 | 4.00                       | 0.00         | 1.25    | 1.00                         | 3.00           | 2.00          | 1.00                     | 0.00       | 2.                   |
| Accessibility/Infrastructure  |             |                        | #DIV/0! | 3.00               | 0.00                 | 0.00                       | 0.00         | 0.75    | 3.00                         | 4.00           | 4.00          | 3.00                     | 3.00       | 4.                   |
| New mines in rich EU countries?   | 3.00        | 5.00                   | 4.00    | 1.00               | 1.00                 | 0.00                       | 1.00         | 0.75    | 3.00                         | 2.00           | 3.00          | 4.00                     | 4.00       | 2.                   |
| Miniturisation  | 3.00        | 5.00                   | 4.00    | 1.00               | 0.00                 | 0.00                       | 0.00         | 0.25    |                              |                |               |                          |            |                      |
| Sharing economy   | 4.00        | 4.00                   | 4.00    | 1.00               | 0.00                 | 0.00                       | 0.00         | 0.25    | 1.00                         | 1.00           | 1.00          | 3.00                     | 1.00       | 1.                   |
| Repairability mandates  | 5.00        | 5.00                   | 5.00    | 0.00               | 0.00                 | 0.00                       | 0.00         | 0.00    | 2.00                         | 3.00           | 3.00          | 3.00                     | 2.00       | 3.                   |
| Renewable energy targets  |             |                        |         | 0.00               | 0.00                 | 0.00                       | 0.00         | 0.00    | 0.00                         | 0.00           | 0.00          | 0.00                     | 5.00       | 0.                   |

Figure 2.3: An excerpt of a spreadsheet used as part of the screening process

970  
971     **3. Assessment:**  
972  
973

Once the screening process was complete, the remaining elements were aggregated and categorized based on their thematic relevance or characteristics. This categorisation helps organize the elements into meaningful groups or themes that align with the objectives and scope of the scenarios. The

974     21 elements that were identified in this stage are listed in Table 2.4. Note that CIR and REC are  
975     very similar for many scenario elements, the main difference being the way in which the targets are  
976     achieved. That is, for CIR, re-X strategies are promoted, whereas, for REC, the focus is on technological  
977     advancements in the recovery system. This distinction will have a significant impact on how the  
978     scenarios are quantitatively modelled and on the subsequent outcomes of these models.

Table 2.4: List of drivers and factors identified in the screening phase

| DOMAIN | DRIVER/FACTOR   | DEFINITION   | INTERNAL | BAU | REC | CIR |
|--------|---|--|----------|-----|-----|-----|
| TECH   | Recovery technology   | Implementation and advancements in waste recovery technologies                   | TRUE     | I   | III | III |
| TECH   | Product technology  | Changes in product function or composition                                       | TRUE     | I   | III | III |
| TECH   | Integration of SRM system across EU                             | Integration of a secondary raw material recovery system across EU countries      | TRUE     | I   | III | III |
| ENV    | Increased drive for environmental protection                    | Growing concern and motivation for environmental conservation                    | TRUE     | I   | III | III |
| ECO    | Progress toward renewable energy targets                        | Advancements and achievements in renewable energy generation                     | TRUE     | III | III | III |
| ECO    | Subsidies and taxation to promote circularity                   | Financial incentives or taxes to encourage circular economy                      | TRUE     | I   | II  | III |
| SOC    | Participation in re-X activities                                | Engagement in refuse-reduce-repair-reuse activities                              | TRUE     | I   | I   | III |
| POL    | Stricter environmental regulations                              | Tightening of environmental laws and regulations                                 | TRUE     | II  | III | III |
| POL    | Stricter waste management regulations                           | Strengthening of waste management laws and regulations                           | TRUE     | II  | III | III |
| POL    | Supply chain due diligence laws: implementation and enforcement | Obligations for identifying and mitigating negative impacts in supply chains     | TRUE     | I   | III | III |
| POL    | Compliance with waste targets                                   | Meeting specific waste management and recycling targets                          | TRUE     | I   | III | III |
| ENV    | Resource shortages  | Limited availability of natural resources  | FALSE    | n/a | n/a | n/a |
| ECO    | Raw material vs SRM prices                                      | Price dynamics and competition between raw materials and secondary raw materials | FALSE    | n/a | n/a | n/a |
| ENV    | Climate change impactsmitigation                                | Effects and actions related to climate change                                    | FALSE    | n/a | n/a | n/a |
| ECO    | International trade and co-operation (vs. autarky)              | Collaborative trade agreements and global cooperation                            | FALSE    | n/a | n/a | n/a |
| ECO    | Energy prices   | Costs and fluctuations in energy prices  | FALSE    | n/a | n/a | n/a |
| ECO    | Economic growth   | Overall economic expansion and development                                       | FALSE    | n/a | n/a | n/a |
| ECO    | Re-industrialisation of EU                                      | Shift towards increased industrial activities in the EU                          | FALSE    | n/a | n/a | n/a |
| SOC    | NIMBY to projects   | Opposition to local projects and developments                                    | FALSE    | n/a | n/a | n/a |
| SOC    | Population and urbanisation                                     | Growth and urban development of population                                       | FALSE    | n/a | n/a | n/a |
| ECO    | CO2 market price  | Price and market dynamics of carbon emissions                                    | FALSE    | n/a | n/a | n/a |

#### 979 4. Categorisation

980 The scenario elements were then assessed based on their potential impact on the waste management  
981 system. For each element, an assessment was made as to whether it was within the scope of FutuRaM  
982 to include them as variables in the models, and therefore also the scenarios and their storylines.

983 Those deemed to be within the scope are 'internal' and will be intensively researched and modelled  
984 (e.g., composition and design changes).

985 Those deemed to be outside the scope are 'external' and will be included in the storylines, will vary  
986 over time, but will not vary across the three scenarios (e.g., population and GPD).

987 Those deemed to be outside the scope and also outside the influence of the waste management  
988 system are 'outside' and will not be included in the storylines or scenarios, though, in some cases,  
989 may be considered in the sensitivity analysis (e.g., supply constraints).

#### 990 ***Justification for keeping certain elements outside of the scenario models:***

992 The purpose of the FutuRaM project is not to provide all-encompassing scenarios that attempt to  
993 capture every possible future development. Such scenarios are inherently inaccurate and can give  
994 a false sense of certainty to the model's outcomes. Instead, the focus of FutuRaM is specifically on  
995 the Sustainable Resource Management (SRM) system and its implications for the future. Therefore,  
996 the scenarios developed within FutuRaM should selectively incorporate elements that have a direct  
997 impact on the SRM system.

998 Furthermore, the scenarios should prioritize elements that can be considered as 'policy knobs', meaning  
999 variables or factors that can be adjusted or controlled to test different settings. By including these, the  
1000 scenarios can explore the effects of different policy decisions or interventions on the SRM system's  
1001 outcomes. This targeted approach ensures that the scenarios generated are relevant to the project's  
1002 objectives and facilitate meaningful analysis.

1003 It is crucial to avoid excessive complexity and convolution in scenario modelling. When there are  
1004 too many convoluted elements included, the results of the modelling exercise can become, at best,  
1005 difficult to understand and interpret. At worst, the outcomes may become practically useless due to  
1006 the overwhelming interactions and uncertainties introduced by the complex elements. Therefore,  
1007 careful consideration is necessary to strike a balance between incorporating essential factors and  
1008 maintaining the clarity and usefulness of the scenario modelling results.

#### 1009 ***Examples:***

##### 1010 **Resource shortages:**

1011 Resource shortages can be highly unpredictable and subject to various external factors such  
1012 as geopolitical events, natural disasters, or technological advancements. The precise timing  
1013 and extent of resource shortages are challenging to forecast accurately, making it difficult to  
1014 include them within the model without introducing significant uncertainty.

1015 This is especially true for the long-term time horizon of the FutuRaM scenario set. This factor  
1016 will, however, be considered in the sensitivity analysis of the model and additionally, the  
1017 codebase will be designed to allow for the optimization of the SRM recovery system based  
1018 on any supply-demand value statements.

##### 1019 **Raw material vs SRM prices:**

1020 The dynamics and competition between raw materials and secondary raw materials can  
1021 be complex and influenced by various market factors, technological advancements and  
1022 policy interventions. As with resource shortages, these dynamics are challenging to forecast

1023  
1024  
1025  
1026  
1027  
accurately, making it difficult to include them within the model without introducing significant uncertainty.

It will, however, be possible to couple the model with a market model to explore the effects of different price dynamics on the SRM system's outcomes. This could be considered in a multi-objective optimization procedure performed as an extension to the model.

## 1028 **2.2.5. Step 5: Develop storyline themes**

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1031  
Given that the scenario themes and directions were broadly dictated by the FutuRaM project charter, the rough shapes of the storyline narratives were already defined. That is: the effects on the availability of SRMs from the development of the SRM recovery system and the development of re-X strategies.

## 1032 **2.2.6. Step 6: Qualitative narrative development**

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1036  
The scenario storylines will be described in detail in the next section. This step involved taking the themes defined by the charter and the elements identified in the previous steps and working with the internal waste stream groups to develop qualitative estimates about how each of these elements (at their different levels) may have an impact on the amounts and composition of the SRM flows in their purview.

## 1037 **2.2.7. Step 7: Definition of scenario parameters**

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1039  
The scenario parameters are the set of quantitative values or functions that will be used to define the scenario inputs for the model. Details of these parameters can be found in chapter 4.

## 1040 **2.2.8. Step 8: Quantitative modelling**

1041 Full details of the scenario quantification process can be found in chapter 4.

## 1042 **2.2.9. Step 9: Implementation**

1043 The scenario implementation will be performed in the next stages of the project.

## 1044 **2.2.10. Step 10: Review process**

1045  
1046 The review process is intended to ensure that the elements included in the storylines and scenarios are relevant, plausible, and consistent with the scenario objectives and scope.

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1048  
1049  
1050  
1051 The first stage of the review process is to open the scenario development process to the wider FutuRaM consortium. This will be done by sharing the scenario development process and the results of the assessment and categorisation step with the consortium and inviting feedback and suggestions. The feedback will be used to refine the elements and their categorisation and to identify any elements that may have been missed in the initial assessment.

1052      The second stage will involve opening the scenario development process to external stakeholders and  
1053      subject matter experts.

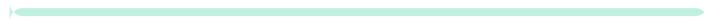
1054      The scenario review process will be performed repeatedly over all stages of the project. This document  
1055      is a living document and will be updated as the project progresses.

## 1056      **Conclusion of methodology section**

1057      The methodology used for the FutuRaM scenario development ensured that the selected elements were  
1058      relevant, plausible, and influential. The use of the PESTEL analysis framework and Delphi method during  
1059      the preliminary collection phase provided a comprehensive overview of the macro-environmental factors.

1060      Furthermore, the screening process and the assessment by internal experts ensured that the selected  
1061      elements were coherent, consistent, and aligned with the objectives and scope of the scenario exercise.

1062      The final list of scenario elements is suited to the goal of the FutuRaM project — to quantify the future  
1063      availability of SRMs and to evaluate EU material autonomy — and will be used to develop the three FutuRaM  
1064      scenarios into a quantitative model.





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1069

# Scenario storylines

1070

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## 3.1. SCENARIO I: BUSINESS-AS-USUAL

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1086

### 3.1.1. Context

“

#### Can the Supply of Natural Resources Really Be Infinite? Yes!

Hold your hat — our supplies of natural resources are not finite in any economic sense. Nor does past experience give reason to expect natural resources to become more scarce. Rather, if history is any guide, **natural resources will progressively become less costly, hence less scarce**, and will constitute a smaller proportion of our expenses in future years. Population growth is likely to have a long-run beneficial impact on the natural-resource situation.

— Julian Lincoln Simon in *The Ultimate Resource* [70, 71]

”

1087

1088

“

Population growth, along with over-consumption per capita, is driving civilisation over the edge: billions of people are now hungry or micronutrient malnourished, and climate disruption is killing people. [Societal collapse] is a near certainty in the next few decades, and the risk is increasing continually as long as perpetual growth of the human enterprise remains the goal of economic and political systems. As I've said many times, '**perpetual growth is the creed of the cancer cell**'

— Paul Ehrlich [155], see also [72, 73, 99]

”

1089

1090

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### 3.1.2. Storyline narrative

This scenario envisions the future based on the current situation, extending to 2050 with very little deviation from present consumption patterns and the secondary raw material (SRM) system [28]. While there may be advances in some areas such as resource efficiency, recovery technology, and the energy transition, substantial modifications remain hindered by economic, social, and political constraints. The primary extraction of raw materials continues to be the primary source to meet the EU's demand.

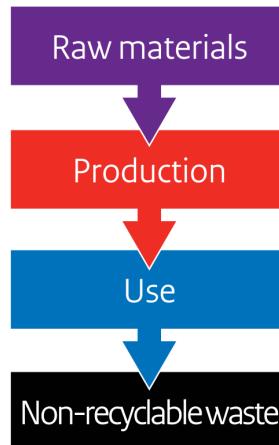
In the Business As Usual (BAU) scenario, we are projecting the trajectory of the present into the future, extending up to the mid-century mark, 2050, with minimal disruption to existing consumption habits and the secondary raw material (SRM) system. This scenario unfolds on the assumption that the current pace and direction of technological, economic, and social development continue unhindered, and is characterised by a strong persistence of today's patterns.

In this scenario, we see moderate improvements in resource efficiency, advancements in recovery technology, and a slow transition towards greener energy sources. However, these developments are only minor tweaks to the existing system, failing to disrupt or fundamentally alter the established structure. The potential for transformational change remains largely untapped due to various hurdles. Economic constraints, social resistance to change, political inertia, and entrenched interests act as barriers to change, stifling efforts toward a more sustainable SRM system.

Primary extraction of raw materials remains the dominant source for raw materials consumed in the EU,

1109 continuing the linear 'take-make-dispose' model of resource consumption (see Figure 3.1). Base metals are  
 1110 well recycled, given their developed markets and economies of scale but rare/special metals are wasted  
 1111 because recycling technologies and economics do not allow for their recovery. Recycling and recovery rates  
 1112 remain stubbornly low, resulting in significant CRM waste. Meanwhile, material demand continues to rise in  
 1113 tandem with GDP growth, further exacerbating the resource pressure.

Linear economy



*Figure 3.1: The linear economy model in the business-as-usual scenario [9]*

1114 Moreover, the environmental impacts of mining and extraction persist as a significant concern. These  
 1115 operations continue to degrade ecosystems, leading to loss of biodiversity and contributing to climate  
 1116 change [29]. Simultaneously, the EU becomes increasingly dependent on imports of SRMs, raising concerns  
 1117 about supply chain security and geopolitical risks [29].

1118 Innovation in SRM recovery technologies is hampered by a lack of investment and regulatory support.  
 1119 The focus remains predominantly on cost-effective material production and use, with little regard for  
 1120 environmental implications or long-term sustainability. Material scarcity and price fluctuations, therefore,  
 1121 may become a considerable risk to the EU industry, limiting stable penetration of new recovery technology  
 1122 and threatening economic stability.

1123 Moreover, the tightening of environmental regulations is restricted, inadequately addressing emerging  
 1124 challenges or incentivising sustainable practices. The lack of regulatory progress may further exacerbate  
 1125 environmental damage and biodiversity loss.

1126 In essence, the BAU scenario is characterised by a continuation of current trends and practices, a  
 1127 future where the potential for a sustainable SRM system is unrealised due to the stranglehold of prevailing  
 1128 economic, social, and political constraints.

1129 In the Business-as-usual (linear economy) scenario, the following are key characteristics:

- 1130 • A forecasting model is used to predict the future based on the current situation and the development of existing trends.
- 1131 • Many EU targets for recycling and recovery are not met, and the current linear model largely persists.
- 1132 • Material demand keeps pace with GDP growth, perpetuating a trend of increasing consumption. Primary mining and extraction persist as the leading sources of raw materials, underlining the dependency on traditional extraction methods.
- 1133 • Recycling and recovery rates continue to lag, leading to an accumulation of SRM waste that signals missed opportunities for resource reuse.

- 1139
- The environmental repercussions of mining and extraction, such as land degradation and water pollution, continue to be a pressing concern, reflecting the ecological toll of this linear model.
- 1140
- The EU's dependency on imports of SRMs escalates, heightening the risk of supply disruptions. While supply disruption can serve to stimulate investment in new SRM recovery, volatility stifles innovation and advancements in this field.
- 1141
- The industrial focus remains on cost-effective material production and use, disregarding the long-term sustainability aspect.
- 1142
- 
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### 3.1.3. Waste stream specific scenario impacts

#### **BATT (Battery waste)**

Sources: [24, 86, 7, 8]

In the business-as-usual (BAU) scenario, the management of end-of-life batteries remains largely unchanged. The lack of technological innovation and regulatory incentives leads to a continued low recovery rate of valuable materials from battery waste.

- A growing volume of battery waste due to the increased use of electronic transport and renewable energy storage systems.
- Lack of technological innovation and regulatory incentives lead to low recovery rates for certain battery types and certain elements.
- Collection systems for battery waste remain sporadic and unstandardised.
- Primary extraction remains the dominant source of battery materials.
- Share of LIB will increase (EV, LMT, Industrial LIB uptake)
- LIB Battery Chemistries will change and new LIB technologies will enter the market. Though, not with a focus on recycling and recovery.
- Larger portable batteries: shift towards Li-ion batteries
- Small format batteries in EEE: no significant change in battery chemistry.
- Use of critical resources continues but is already decreasing (BATT chemistry already changing towards less CRM content)
- Large-scale reuse of batteries is minimal
- Collection rates do not fulfil the EU targets
- Recycling efficiencies do not fulfil the EU targets
- Recovery rates do not fulfil the EU targets

#### **ELV (End-of-Life Vehicles)**

Sources: [86, 142, 30, 31, 32, 33]

The BAU scenario maintains the current approach to end-of-life vehicles, with minimal improvements in the recovery and recycling process. The absence of effective technologies and regulatory incentives results in low recovery rates of valuable materials from ELVs.

- Legislation banning new ICEVs from 2035
- Current recovery technologies are unable to significantly improve the extraction of valuable materials from ELVs.
- Consumer demand continues to drive high production of new vehicles.
- ELV collection systems remain at their current efficiency.
- A significant proportion of vehicle components continue to end up as waste.
- Gradual and slow improvement of recycling chain technology efficiency
- No new legislation to improve recovery and support circular strategies in comparison to 2023



## WEEE (*Waste Electrical and Electronic Equipment*)

Sources: [5, 6, 34, 35, 36, 78]

In the BAU scenario, the treatment of WEEE does not significantly change. The lack of technological progress and effective regulation results in low recovery rates of valuable materials from WEEE.

- Limited improvements in the recovery of valuable materials from WEEE.
- High consumer demand for new electronics continues to drive high WEEE generation.
- Ineffective collection systems and lack of public interest result in significant amounts of WEEE ending up in landfills.
- No significant growth in collaboration between government and industry for WEEE recovery.
- The majority of WEEE continues to be treated with common domestic waste, with low recycling rates.
- No groundbreaking technologies and practices to improve recovery and circularity.
- Reuse of products and components is not widely utilised
- Changes in legislation (e.g., circular economy and product design targets, targets for collection and recycling) are not strictly implemented.
- The BAU and the REC scenarios are similar from the put-on-market perspective (e.g., production and consumption remain the same), but it's the recovery stage that makes the difference.



## MIN (*Mining Waste*)

Sources:

The BAU scenario sees the continuation of current practices in mining waste management. The absence of advanced recovery technologies and regulatory incentives leads to low recovery rates of valuable materials from mining waste.

- Limited technological advancements lead to static recovery rates of valuable materials from mining waste.
- Continued reliance on primary extraction as the dominant source of raw materials.
- Minimal advances in collaboration between government and industry for mining waste recovery.
- Low levels of traceability and management of mining waste.
- Mining waste remains a significant environmental challenge.
- Mining waste recovery projects remain too expensive.
- Little incentive for the private sector and public sector, except for monitoring environmental risks of existing deposits.



## CDW (*Construction and Demolition Waste*)

Sources: [10]



1218 In the BAU scenario, the management of Construction and Demolition Waste (CDW) remains largely  
 1219 unchanged.

- 1220 • Focus on new construction to meet demand, no changes in CDW generation rate.
- 1221 • No increase or refurbishment or renovation activities relative to new construction rates.
- 1222 • Continue meeting the 2020 EU target from the Waste Directive [10] of 70% CDW recovery  
   (including preparation for re-use, recycling, and other material recovery, including backfilling)
- 1223 • Recovery of metals remains on already high levels ( 90%) [100].
- 1224 • Recovery of minerals remains on already high levels ( 70%) by using them as aggregates in  
   road construction and backfilling [100].
- 1225 • Recycling of wind turbines stays around 85% (mainly metals), permanent magnets continue  
   to be recycled as part of the metal fractions.[CITATION]
- 1226 • Base metals are recovered as they have been, though there are limited improvements in recov-  
   ery technologies and regulatory incentives.
- 1227 • Repowering trends for wind turbines persist.
- 1228 • Excluding wind turbines, there is no particular focus on the recovery of CRMs from CDW,  
   where they constitute only a small fraction of the total mass (e.g., embedded in scrap steel).



## **SLASH (Slags and Ashes)**

1235 **Sources:** [143, 144, 101, 145, 102]

1236 In the BAU scenario, SLASH continues to be treated generally as low or negative-value waste. The ab-  
 1237 sence of economically profitable recovery technologies or regulatory mandates leads to low improvements  
 1238 in the recovery rates of CRMs from SLASH.

### **SLAGS**

1240 Slags are waste products from the metallurgical industry and contain mainly minerals with some metals  
 1241 that could not be recovered during the metallurgical process. The reasons the metals are not recovered are:

- 1242 1. Current technology does not allow further recovery
- 1243 2. The metals are not of economic interest.

1244 More than 90% of the slags are minerals, therefore the slags that are in line with the environmental  
 1245 criteria (end of waste criteria) are valorised as aggregates for the construction industry or as SCM (cement  
 1246 replacement materials).

1247 Slags containing high concentrations of heavy metals are landfilled.

- 1248 • The volume of slags will stay stable. From 2013-2023, there was a stable production of metals,  
   which results in a stable production of slags.
- 1249 • Due to the energy transition, it is expected the volume of slags from "classic" furnaces (eg  
   BOF) will reduce and the number of slags from electric arc furnace will go up.
- 1250 • There are limited facilities to recover CRMs/SRMs, but the metallurgical companies do their  
   best to recover as much of the metals as per their economic interests.

## ASHES

Ashes are the waste products from the incineration of fossil fuels, biomass, or waste. We distinguish two main types: fly ashes and bottom ashes. Coal fly ashes are used as SCM to replace cement up to 30%. Biomass (bottom and fly) ashes are used (based on the composition) as fertilizer or landfilled. Fly ashes from waste incineration are landfilled, while the bottom ashes are — depending on the location in the EU — further treated.

The fractions that are rich in ferrous metals, aluminium, copper, and zinc are separated and used as input materials for the Fe, Cu, Zn, Al industries. By processing the Cu-rich fractions, PGMs, Ag, and Au are also recovered. The main part of the bottom ashes consists of mineral aggregates, which are used in the construction industry (when they are in line with the environmental criteria). In case the ashes are not treated (or only partly treated), they will be landfilled.

- In the last 10–20 years in some EU countries, we have seen a shift from landfilling towards incineration. This will lead to an increase in the volume of ashes from waste incineration.
- There was a drop in the use of coal as a fuel source, so the volume of coal ashes dropped over the last 10 years and is expected to drop further.
- At the same time the volume of biomass incineration went up. It is uncertain if this volume will increase in the future further (due to the high pressure on land that is needed to produce this biomass).
- Almost all coal fly ashes are used as SCM (high-value stream up to 80 EUR/ton). For Biomass fly ashes there are no sorting facilities, while for waste incineration bottom ashes, there are sorting installations in place, but for the moment, they are not present in all EU countries, and therefore, there is still room for improvement.
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## 3.2. SCENARIO II: RECOVERY

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### 3.2.1. Context

We are in a period of economic transition. The 'cowboy economy' of the past is obsolescent, if not obsolete. Environmental services are no longer free goods, and this fact is driving major changes. Recycling is the wave of the (immediate) future. **The potential savings in terms of energy and capital have long been obvious. The savings in terms of reduced environmental impact are less obvious but increasingly important.** The obstacle to greater use recycling has been the fact that economies of scale still favor large primary mining and smelting complexes over (necessarily) smaller and less centralized recyclers. But this advantage is declining over time as the inventory of potentially recyclable metals in industrialized society grows to the point that efficient collection and logistic systems, and efficient markets, justify significant investments in recycling. **Increasing energy and other resource costs, together with increasing costs of waste treatment and disposal, will favor this shift in any case.** But government policies, driven by unemployment and environmental concerns, taken together, may accelerate the shift by gradually reducing taxes on labor and increasing taxes on extractive resource use.

— Robert U. Ayres [103]

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One does not require much of an imagination to picture how complex it is to physically and chemically separate these components again to ultimately retrieve the metals. **It's just about as difficult as recycling your morning cup of coffee into its ingredients...** There are no simple answers here — at some point, the amount of effort also outweighs the value of the metal content. This knowledge should prompt a consciousness shift in our utilization of our limited resources...

**The inconvenient truth is that closing the loop is impossible!** Therefore, an honest discussion involves speaking transparently about losses in the process: in the form of energy, metals, and dust, for example. There are technological and economic limits to closing the loop.

— Prof. Dr. Dr. h.c. mult. Markus Reuter [156]

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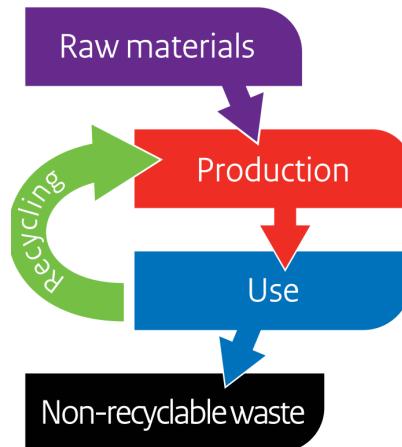
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### 3.2.2. Storyline narrative

In the recovery scenario, the central emphasis is on harnessing sophisticated technologies to salvage SRMs from waste streams at the end of their lifecycle. While there are noticeable strides towards the incorporation of 'circular design' principles and re-X strategies, they are mostly seen at the end-of-life and material demand is akin to that observed in the BAU scenario. This is, however, mitigated by the implementation of a comprehensive material recovery system. Figure 3.2 presents a simplified visual depiction of the dominant material flow paths in the recovery scenario.

In this scenario, the central actor is the waste treatment sector, with the spotlight falling on the enhancement of recovery technology. The implementation and optimisation of cutting-edge technologies, such

## Reuse economy



*Figure 3.2: The reuse economy model in the recovery scenario [9]*

1295 as Artificial Intelligence (AI), automation, and advanced robotics, play a significant role in revolutionising  
 1296 waste treatment processes. These technologies streamline waste sorting, improve the quality of recovered  
 1297 materials, and increase the overall efficiency of the recovery process.

1298 This scenario calls for an emphasis on policy development and standardisation to foster EU-wide  
 1299 development, integration, and compliance. Here, the role of governments and policy-makers becomes  
 1300 crucial in setting more ambitious recovery targets, developing conducive regulatory frameworks, and  
 1301 enforcing compliance. This multi-pronged approach also involves strengthening cross-border cooperation,  
 1302 harmonising waste management standards, and promoting knowledge and technology transfer among EU  
 1303 member states.

1304 To realise more ambitious environmental impact reduction targets, significant progress needs to be  
 1305 made in both technological and policy aspects. Enhancing technological capabilities will improve recovery  
 1306 rates, while robust policy measures will ensure these advancements are integrated into the wider economy  
 1307 in a regulated manner. The future of this scenario depends on the successful fusion of advanced technology,  
 1308 regulatory harmonisation, and a commitment to continuous improvement in waste management and SRM  
 1309 recovery.

1310 Key characteristics of this technology-promoted recovery scenario include:

- 1311 • This scenario uses a combination of forecasting and backcasting methods to envision the  
 1312 future.
- 1313 • The backcasting method is used for scenario factors that are covered by governmental targets,  
 1314 starting with the desired outcome and working backwards to the present.
- 1315 • The forecasting method is used for scenario factors that are not covered by governmental  
 1316 targets, starting with the current situation and extending to the future.
- 1317 • EU targets for recycling and recovery are met, due to the EU's waste management system  
 1318 becoming more expansive, efficient and effective.
- 1319 • Technological innovation drives increased recovery rates of SRMs, enabling the more efficient  
 1320 use of waste.
- 1321 • Digitalisation and automation are more extensively used in recycling processes, leading to  
 1322 enhanced productivity and accuracy.
- 1323 • There is greater exploration and exploitation of alternative sources such as urban mining,  
 1324 waste streams, and tailings, presenting novel opportunities for resource acquisition.

- 1325 • New waste regulations and guidelines for SRM recovery are implemented, enforcing better  
1326 management and extraction of SRMs.
  - 1327 • Investment in research and development for SRM recovery technologies experiences an  
1328 upswing, promoting continuous innovation in this field.
  - 1329 • Closer collaboration and information sharing between industry and government institutions  
1330 streamline processes and expedite decision-making.
  - 1331 • New jobs are created in the recycling and recovery sector, offering economic benefits and  
1332 improving overall employment rates.
  - 1333 • SRM production and use become more efficient and cost-effective, fostering economic sus-  
1334 tainability.
  - 1335 • Environmental impact from mining and extraction is reduced, signalling a more sustainable  
1336 approach to resource acquisition.
  - 1337 • The EU's dependence on primary extraction is reduced, with SRM recovery becoming a more  
1338 significant source of raw materials.
-

### 3.2.3. Waste stream specific scenario impacts



#### BATT (Battery waste)

Sources: [24, 86, 7, 8]

Under the recovery scenario, end-of-life batteries become a crucial source of secondary raw materials, primarily due to the increased adoption of electric vehicles and renewable energy storage systems. Technological innovation drives the recovery and recycling process, ensuring valuable materials are extracted from waste batteries for reuse.

- Increase in end-of-life batteries due to the growth of electric vehicles and renewable energy storage.
- Advanced recovery technologies facilitate the efficient extraction of valuable materials from battery waste.
- Standardised collection systems enhance the quantity and quality of battery waste available for recovery.
- Industry and government collaboration lead to investments in research and development of battery recovery technologies.
- Battery passports have a strong impact on collection, material recovery rates and recycling rates.
- Collection
  - Portable battery collection increases according to the trend seen in the WEEE waste stream.
  - Improved collection of light means of transport (LMT) batteries.
  - Improved regulation and collection of Industrial batteries.
- Material recovery
  - Improved recycling technologies
  - Battery Pass will improve material recovery
  - Higher recovery rate for lithium
  - Increase in recycling by average weight
  - Recycling of plastics
- Ambitious goals of recycling/recovery rates compete with reuse, so reuse remains low.
- Improved public awareness means that fewer batteries end up in the municipal waste stream and there is less hoarding.
- Against this: there is competition for the batteries from the reuse vs. recycling market.
- Design for recycling (DFR):
  - Material and composition selection for recycling [86].
  - Higher requirements on disassemblability.
  - Information available to promote efficient recovery.



#### ELV (End-of-Life Vehicles)

Sources: [86, 142, 30, 31, 32, 33]



The recovery scenario envisions a more effective and technology-driven end-of-life vehicle treatment process. Advancements in recovery technologies allow for improved extraction of valuable materials from vehicles at their end of life, although consumerism still drives high demand for new vehicles.

- Innovations in recovery technologies allow for a higher recovery rate of CRM-containing materials from ELVs.
- The total number of vehicles produced remains high due to consumer demand.
- Improved systems for ELV collection are established, ensuring efficient management of ELV waste.
- Increased collaboration between the government and industry leads to investments in ELV recovery technologies.
- Focus on managing end-of-life of vehicles
- EU recovery targets are reached (currently implemented/proposed targets, but also increased and new targets)
- Common/bulk materials (Fe, Non-Fe, plastics etc.,) and precious metals (Au, Ag, Pd, Pt) reach high mass recycling rates and high element recycling rates. Other CRMs currently not recovered reach a moderate level of recovery.
- For instance,
  - More advanced dismantling and processing steps (e.g., components and materials)
  - More specialised recovery of certain components and materials (e.g., electric motors including permanent magnets and embedded REE) as suggested in the proposal for a revised ELV directive.
  - More public and private interest in developing recycling chains
  - Increase in collection rate due to increase in participation from the public and businesses, i.e., target-based incentives with strong regulations and monitoring
- Design for recycling (DFR):
  - Higher requirements on 'disassemblability'.
  - Information available to enable recovery.



## **WEEE (Waste Electrical and Electronic Equipment)**

**Sources:** [5, 6, 34, 35, 36, 78]

Under the recovery scenario, WEEE becomes a significant resource for secondary raw materials. Technological advancements in the sector improve the efficiency of WEEE treatment, although the consumerism-driven demand for new electronics remains high.

- Advanced technologies enable higher recovery rates of valuable materials from WEEE
- Despite advancements in design for recyclability, WEEE generation remains high due to the consumer demand for new electronics
- Standardised and segregated collection systems for WEEE are implemented, improving the supply of materials for recovery
- Increased industry-government collaboration leads to further development in WEEE recovery technologies
- Consumer behaviour remains a significant hurdle for more efficient WEEE management



- Higher recycling rate — make full use of the disposed parts. For instance:
  - more automation of the dismantling and processing steps (e.g., AI)
  - recycling technologies improvements (e.g., small components recovery is also happening)
  - more effective collection infrastructure
  - financial support provided to recyclers/operators
  - bans on WEEE exports push for increased domestic recycling [37]
- 'Design for recovery' principle — Ecodesign mandates changes in weight and composition of EEE so complexity and the type of materials used
- Higher public awareness and participation on WEEE issue and management
- Higher compliance from the public, the producers and the businesses
- Strong regulations and monitoring are in place with higher collection and recycling targets which are set and implemented and fines are set for those who fail to achieve the targets
- Focus is given more to the EoL management of WEEE



## **MIN (Mining Waste)**

### **Sources:**

Under the recovery scenario, technological advancements enable the extraction of residual valuable materials from mining waste, transforming it into a more valuable resource.

- Technological advancements facilitate the extraction of valuable materials from mining waste.
- Despite progress in recovery technologies, primary extraction remains the dominant source of raw materials due to high consumer demand.
- Government and industry collaboration support the development of technologies for the recovery of materials from mining waste.
- Increased traceability and management of mining waste through digitalisation.
- Mining waste remains a significant environmental challenge.



## **CDW (Construction and Demolition Waste)**

### **Sources: [10]**

Under the recovery scenario, Construction and Demolition Waste (CDW) becomes an important resource for secondary raw materials, though mostly base metals and aggregates. Despite some progress in eco-design and material efficiency, the construction industry continues to generate significant amounts of waste or 'downcycled' materials. Some progress in eco-design and material efficiency, but the construction industry continues to generate significant amounts of waste or 'downcycled' materials.

- Focus on new construction to meet demand, no changes in CDW generation rate.
- No increase or refurbishment or renovation activities.
- Enhancement of the quality of recycling to recover materials at higher value.
- Increased investment and enhanced regulatory system in waste management, contributing to increased recovery.



- 1455 • Creation of new waste recovery infrastructure that improves recovery.
- 1456 • Widespread application of selective demolition and strict on-site waste sorting leading to an increase in recovery of waste.
- 1458 • Recovery of minerals is intensified with a stronger focus on closed-loop recycling (e.g., cement and aggregate are separated, aggregate is used, but cement is not treated).
- 1459 • Recovery of other materials like glass, plastics, and wood is also intensified.
- 1460 • Better separation of waste at source leads to a higher quality of secondary raw materials.
- 1461 • Repowering trends for wind turbines stay the same.
- 1462 • Improved recycling of wind turbine blades is notable, especially regarding plastics; permanent magnets are recycled at a functional level.



## SLASH (*Slags and Ashes*)

1466 Sources: [143, 144, 101, 145, 102]

1467 In the recovery scenario, SLASH are recognized as a potential resource for secondary raw materials.  
1468 Advances in recovery technologies enable the extraction of valuable metals from SLASH, however, the  
1469 total volume of CRMs recovered from this material remains low, except in cases of supply constraint.

- 1470 • Digital solutions enhance the traceability and management of SLASH.
- 1471 • More functional collection infrastructure.
- 1472 • Financial support provided to recyclers/operators.
- 1473 • Introduction of SRM/CRM recovery targets. For example, recovery of P from biomass ash for  
1474 fertilizer.
- 1475 • Higher awareness and participation of relevant sectors on SLASH issues and management.
- 1476 • Strong regulations and monitoring are in place with higher collection and recycling targets.

## SLAGS

- 1478 • Advanced recovery technologies allow for the extraction of valuable metals and minerals from  
1479 slags.
- 1480 • New recovery technologies are installed in the metallurgical industry.
- 1481 • All metals are recovered from the slags, and the slag itself only contains minerals or metals as  
1482 trace elements.
- 1483 • Due to the low metal content, the slags are ideal resources for the construction industry.

## ASHES

- 1485 • New recovery technologies are installed in the incineration industry.
- 1486 • We expect a shift in the volume and quality of the ashes.
- 1487 • Coal fly ashes are the same as in BAU reducing over time to almost zero.
- 1488 • Biomass ashes have the same volume and quality.



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1490  
1491  
1492  
1493
- Waste incineration ashes: due to the recovery scenario there will be a shift from landfill and incineration towards recycling, reuse, and repair. In countries with a high landfill rate, this will lead to higher volumes of ashes. In countries with a low landfill rate, and a high volume of incineration: this will lead to lower volumes of ashes, and a shift in the composition (with less CRM content in the ashes, due to better pre-sorting)

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### 3.3. SCENARIO III: CIRCULARITY

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#### 3.3.1. Context

A circular economy is one that is regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption.

— *Ellen MacArthur Foundation [38]*

##### A Circular Economy in the Netherlands by 2050!

Imagine we are in the year 2050. In the Netherlands we are living within the planetary boundaries of the Earth rather than permanently crossing them. This is because our relationship with nature, which used to be highly disturbed and led to climate change, has changed for the better ...

... The Netherlands now has a circular economy.

... The Dutch Government intends to achieve a fully circular economy by 2050 and to halve the use of primary abiotic raw materials by 2030.

— *National Circular Economy Programme, Government of the Netherlands [11]*

##### Circularity of the Dutch economy has barely increased

Of all natural resources that were deployed in the Dutch economy in 2020, 13 percent consisted of recycled materials. This percentage is virtually the same as in 2014. In terms of recycling, the circularity of the Dutch economy has barely increased.

— *CBS (Statistics Netherlands) [146]*

“

The circular economy promises radical technological transformations in a couple of decades, “nothing less than to open up new and immense horizons for industry”, “provide multiple value creation mechanisms”, produce “better welfare, GDP, and employment outcomes” [38]. Looking at these claims, one wonders whether policymakers really believe that in 30 years EU citizens will live in an inclusive economy with zero waste, zero emissions, with a perpetual economic growth, continuously absorbing massive flows of immigrants while protecting and enhancing the ecological processes and environmental biodiversity.

...for a young scientist it is not advisable and even shocking to say in policy circles that:

- (i) Reaching zero emissions for metabolic systems is impossible (open/living systems must breathe),
- (ii) The economic process is entropic and therefore a circular economy enabling perpetual economic growth is impossible (it is the biosphere and not the technosphere that recycles matter, while energy cannot be recycled), and
- (iii) The existing technosphere has been built on and relied on fossil fuels for over 200 years, and it cannot be completely replaced in 30 years reaching zero emissions while fulfilling all the sustainable development goals (including rapid economic growth in the developing world).

— M. Giampietro and S.O. Funtowicz [104]

”

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1507

### 3.3.2. Storyline narrative

1508 A circular economy focuses on significantly enhancing resource efficiency. This can be achieved through  
1509 four primary strategies:

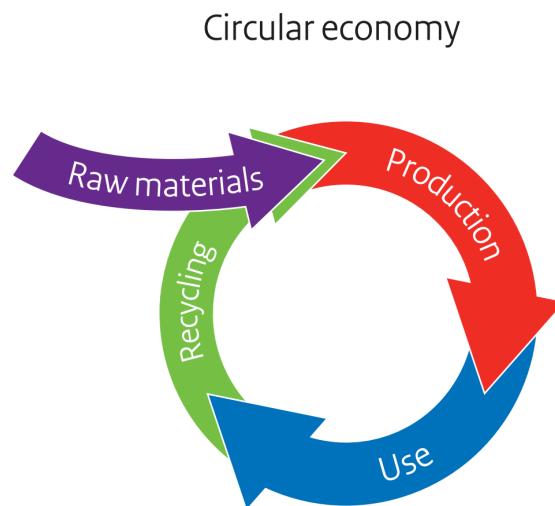
- 1510 1. Minimizing resource use (narrowing the loop) through shared utilization or opting out of certain  
1511 product use, along with improved manufacturing efficiencies;
- 1512 2. Prolonging the life and utility of products and their components (slowing the loop) via reuse and  
1513 repair, thereby reducing the need for new raw materials;
- 1514 3. Recycling materials (closing the loop) to diminish the quantity of material incinerated or sent to  
1515 landfills, consequently cutting down the demand for new raw materials;
- 1516 4. Replacing finite resources with renewable ones (like bioresources) or alternative primary resources  
1517 that have a lower environmental impact.

1518 In this scenario, we move in the direction of the maximum achievable state of material efficiency as  
1519 government policy, private innovation and social changes are rapidly driving the transition toward a circular  
1520 economy. The emphasis here rests heavily on re-X strategies that are implemented in the design phase  
1521 of products (e.g., repairability and re-manufacturability) and that are actualised by changes in consumer  
1522 behaviour (e.g reduction, refusal, engagement in the ‘sharing economy’ and curtailment of the ‘throw-away’  
1523 mindset).

1524 Figure 3.3 presents a simplified visual depiction of the dominant material flow paths in the recovery  
1525 scenario.

1526 Further, being enabled by the widespread adoption of ‘circular design’ principles and improvements in  
1527 information transparency (e.g., waste tracking and digital product passports) the system for the treatment  
1528 of post-consumer waste can divert a significant amount of their inflows (to, for example, re-use and re-  
1529 manufacture) with the residual fraction being readily segregated into purer, more efficiently recoverable,  
1530 material streams.

1531 This scenario envisions a future where government policies are in synergy with private sector innovation  
1532 and societal changes, driving a wholesale transition towards a circular economy. Unlike the recovery scenario,



*Figure 3.3: The simplified circular economy model in the circularity scenario [9]*

1533 where the focus is on the end-of-life recovery of materials, this scenario emphasises minimising waste at  
 1534 all stages, starting from the design phase itself, where both policymakers and designers are moving away  
 1535 from short-lived products towards products designed for longevity.

1536 The emphasis is on re-X strategies that are integrated throughout the entirety of a product's lifecycle.  
 1537 This includes repairability, where products are designed to be easily fixed rather than replaced; and re-  
 1538 manufurability, where products or their components are designed to be restored to their original state,  
 1539 extending their lifespan and reducing the need for new resources. This scenario calls for a drastic change in  
 1540 consumer behaviour, where reduction in consumption and waste, refusal of non-sustainable options, and  
 1541 active participation in the 'sharing economy' become the norm rather than the exception.

1542 In the circularity scenario, the widespread adoption of 'circular design' principles becomes a cornerstone  
 1543 of production. In a circular design approach, products are designed and produced in a way that considers  
 1544 their entire lifecycle, including eventual disassembly and reuse. New economic models make it costly for  
 1545 producers to generate short-lived products and material waste. Companies are now giving priority to the  
 1546 design of products that are easily repairable, can be disassembled, and reused. The rise of technology  
 1547 has paved the way for predictive maintenance tools. These allow businesses to keep a tab on material  
 1548 conditions through sensors and carry out repairs before a malfunction occurs, a method gaining traction in  
 1549 transport and manufacturing.

1550 Additionally, this scenario envisions an improvement in transparency, with measures such as waste  
 1551 tracking and digital product passports becoming standard. Waste tracking allows for efficient management of  
 1552 waste flows, aiding in effective resource planning, while digital product passports provide information about  
 1553 a product's composition and how it can be properly disassembled, reused, or recycled. Material composition,  
 1554 including raw materials, is transparent to all involved in the value chain, promoting closer collaboration.  
 1555 Producers see the advantage of being open about their product details to aid in repair, repurposing, and  
 1556 recycling activities. This transparency about product components, durability, and reparability increases  
 1557 consumer demand for products that are designed to last and can be reused or recycled.

### 3.3.3. Scenario needs and impacts

In the proposed scenario, the European Union (EU) embarks on a pivotal transition towards a circular economy. This framework emphasises the retention of product, material, and resource value within the economic matrix for extended durations, simultaneously minimising waste generation. This transition is integral to the EU's strategic goal of cultivating a sustainable, low-carbon, resource-efficient, and globally competitive economy.

The implications of this shift are multifaceted. It presents an avenue for the EU to rejuvenate its economic architecture while providing businesses with a protective shield against challenges such as resource scarcity and price volatility. This revised economic model fosters the emergence of efficient, innovative production and consumption methods, thus offering novel business opportunities. Moreover, the circular economy approach has palpable socio-economic benefits, including diverse job creation and enhanced social integration.

From an environmental perspective, the transition aids in the reduction of the cumulative energy footprint and helps mitigate irreversible ecological damages. This encompasses challenges related to climate shifts, biodiversity conservation, and comprehensive pollution control. Several studies accentuate the overarching benefits of this economic approach, highlighting potential reductions in prevalent carbon dioxide emissions.

The successful implementation of this vision necessitates a collaborative approach involving various stakeholders, encompassing businesses, consumers, and regulatory entities. A robust regulatory framework is indispensable, designed to promote optimal practices and delineate clear progression benchmarks. This comprehensive framework encompasses the entirety of the circular economy's value chain, from production to consumption, extending into realms of repair, remanufacturing, and waste management, culminating in the reintroduction of secondary raw materials into the economic cycle.

Environmental fiscal reforms are crucial for a circular economy transition. Taxes should pivot from labour to resource depletion, promoting a double dividend. The EU can leverage the VAT directive and the European semester process to endorse flexible rates on circular services like repair. It's imperative to abolish harmful subsidies, notably on fossil fuels, which are inherently linear and which Member States have pledged to eliminate. The tax framework should incentivise pioneers challenging the established linear economy. Analysing tax shifts at the national level can determine tax effectiveness and pinpoint instruments that best bolster circularity.

The contribution of member states is paramount. They play a dual role, both in the actualisation of EU directives and in the integration of complementary regional initiatives. The principles of a circular economy possess global applicability, necessitating harmonised strategies within the EU and with external international partners. Such synergised efforts are crucial for the fulfilment of broader international commitments, notably the U.N. 2030 Agenda for Sustainable Development [12]. The ultimate objective remains the establishment of a sustainable future characterised by judicious consumption and production protocols.

### 3.3.4. Waste stream specific scenario impacts

#### **BATT (Battery waste)**

Sources: [24, 86, 7, 8]

In the circularity scenario, battery waste treatment undergoes a massive transformation. The shift towards electric vehicles and renewable energy storage significantly increases the quantity of end-of-life batteries. However, thanks to new regulations, technological advancements, and business models, the majority of battery components are recycled or reused.

- Massive increase in end-of-life batteries due to the shift to electric vehicles and renewable energy storage.
- New regulations incentivise battery manufacturers to design for recycling.
- Battery recycling technologies improve, enabling higher recovery rates of valuable metals.
- Standardised collection systems for battery waste are established, improving the efficiency of the recycling process.
- Service-based business models like leasing ensure manufacturers retain ownership of the batteries, promoting circularity.
- Greater transparency through digital product passports aids in effective battery waste management.
- Battery passport and publicly accessible information from the new Battery Regulation (SoH, SoC, Predicted lifetime/warranty, etc.) given by the economic operator that places the battery on the market enables high re-use rates.
- Increased repairability/modularity.
- Reduced demand from 'sharing economy' and more 'sustainable' transport choices.
- New emerging technologies more suited for reuse/repair.
- Ambitious targets set by business and public policy.

#### **ELV (End-of-Life Vehicles)**

Sources: [86, 142, 30, 31, 32, 33]

For End-of-Life Vehicles (ELVs), the circular economy model affects the way vehicles are designed, used, and discarded. Emphasising extended vehicle life through repair and remanufacturing, this scenario also focuses on the recovery of materials from vehicles at the end of their life.

- Vehicle design shifts towards repairability, upgradability, and recyclability, increasing the lifespan of vehicles.
- Standardised systems for ELV collection are established, ensuring efficient waste management.
- Innovative technologies enable higher recovery rates of metals and other valuable materials from ELVs.
- Service-based models like vehicle leasing and sharing could reduce the total number of vehicles produced.

- 1633 • Digital product passports provide information about vehicle components, aiding in effective recycling or reuse.
- 1634
- 1635 • Focus on managing the use-phase of vehicles.
- 1636 • Circular strategies take place before material recovery so that material recovery is “delayed”.
- 1637 • Information available to enable these strategies.
- 1638 • EU vehicles policy has implications for materials in vehicles, such as ‘lightweighting’ and down-sizing
- 1639
  - 1640 – Increase in average occupancy and average vehicle-kilometres per trip.
  - 1641 – Decrease in average lifetime (in terms of years): As the utilisation factor increases.
- 1642 • Increase in circular strategies due to an increase in participation from the public and businesses, i.e., target-based incentives with strong regulations and monitoring.
- 1643



## ***WEEE (Waste Electrical and Electronic Equipment)***

Sources: [5, 6, 34, 35, 36, 78]

In the circularity scenario, WEEE becomes a valuable resource instead of a disposal challenge. Thanks to product design changes and the application of advanced recovery technologies, a significant percentage of the materials in WEEE is reclaimed and fed back into the production cycle.

- 1644 • Electronic products are designed for longevity, repairability, upgradability, and recyclability.
- 1645
- 1646 • Advanced technologies enable higher recovery rates of precious metals from WEEE.
- 1647
- 1648 • Collection systems for WEEE are improved, ensuring a steady supply of materials to feed the recovery system.
- 1649
- 1650 • Digitalisation and data use enhance traceability and efficiency in WEEE management.
- 1651
- 1652 • Service-based models for electronics promote the use of products as a service rather than ownership, reducing WEEE generation [89].
- 1653
- 1654 • Increased durability and lifespans.
- 1655
- 1656 • Increased repairability.
- 1657
- 1658 • More sharing and product-service systems, correspond to a reduction in the lifetime (for some equipment).
- 1659
- 1660 • More reuse practices (expanded second-hand market).
- 1661
- 1662 • Less hoarding.
- 1663
- 1664 • Higher formal collection and recycling rate.
- 1665
- 1666 • Focus is given more to the production and use phase rather than the EoL (End-of-Life).
- 1667
- 1668 • ‘Design for circularity’ principle: Ecodesign mandates repairability, durability, no obsolescence, modularity, and that continual software upgrades are possible [13, 147].
- 1669
- 1670 • Electronically compatible chargers and battery packs can be used by different products.
- 1671
- The above also means that chargers and batteries are not integrated into the product and that the product is designed to be easily disassembled.
- Strong regulations and monitoring are in place with higher reuse and circular targets, which are set and implemented, and fines are imposed on the member states that fail to achieve the targets.



- Support and development of circular strategies infrastructure (e.g., easy information access for repairability, repair shops, accessibility to spare components on the market, etc.).
- Greater use of connected products, smart technologies, and the IoT. Used to monitor and diagnose product performance in situ which, can extend product and component life.



## MIN (Mining Waste)

### Sources:

In this scenario, the impact on mining waste is two-fold. Firstly, the need for primary mining is reduced due to lower demand, efficient resource use and high recovery rates of materials. Secondly, mining waste itself is treated as a valuable resource, with advanced technologies being used to extract residual valuable materials.

- A Decrease in primary mining reduces the generation of mining waste.
- Advanced technologies are employed to extract valuable materials from mining waste.
- Policies and regulations incentivise the reuse of mining waste in various applications.
- Digital solutions improve tracking and management of mining waste.
- Collaboration between stakeholders promotes circular practices in the mining industry.



## CDW (Construction and Demolition Waste)

### Sources: [10]

Construction and Demolition Waste (CDW) is another sector that sees significant improvement in the circularity scenario. This scenario reduces the generation of CDW and promotes the recovery of valuable materials from the waste stream.

- Less demolition and new construction results in a reduction of CDW.
- Buildings are designed for disassembly and reuse, increasing the lifespan of materials and reducing CDW.
- Longer lifetimes for buildings (more renovation and refurbishment) and wind turbines (less repowering, i.e. changing of wind turbines before the end of theoretical lifespan).
- Wind turbine blades are refurbished or repaired and then reused.
- Recycling technologies for CDW improve, allowing higher recovery rates of materials and less 'downcycling'.
- Policies and regulations incentivise the use of recycled materials in construction.
- Standardised systems for CDW collection and separation are improved.
- Digital tools like building information modelling (BIM) improve resource management in construction and renovation.
- Focus on dismantling and selective deconstruction: constructions are taken apart in a way that individual parts can be reused.



## SLASH (*Slags and Ashes*)

Sources: [143, 144, 101, 145, 102]

In the circularity scenario, SLASH are recognised as a potential resource for secondary raw materials. Advances in recovery technologies enable the extraction of valuable metals from SLASH, however, the total volume of CRMs recovered from this material remains low, except in cases of supply constraint. In the circularity scenario, the conditions are very similar to that of the recovery scenario, except that volumes will decrease, due to a general decrease in waste generation.

- Digital solutions enhance the traceability and management of SLASH.
- More functional collection infrastructure.
- Financial support provided to recyclers/operators.
- Introduction of SRM/CRM recovery targets. For example, recovery of P from biomass ash for fertiliser.
- Higher awareness and participation of relevant sectors on SLASH issues and management.
- Strong regulations and monitoring are in place with higher collection and recycling targets.

## SLAGS

- Advanced recovery technologies allow for the extraction of valuable metals and minerals from slags.
- New recovery technologies are installed in the metallurgical industry.
- All metals are recovered from the slags, and the slag itself only contains minerals or metals as trace elements.
- Due to the low metal content, the slags are ideal resources for the construction industry.

## ASHES

- New recovery technologies are installed in the incineration industry.
- We expect a shift in the volume and quality of the ashes.
- Coal fly ashes are the same as in BAU reducing over time to almost zero.
- Biomass ashes have the same volume and quality.
- Waste incineration ashes: due to the recovery scenario there will be a shift from landfill and incineration towards recycling, reuse, and repair. In countries with a high landfill rate, this will lead to higher volumes of ashes. In countries with a low landfill rate, and a high volume of incineration: this will lead to lower volumes of ashes, and a shift in the composition (with less CRMs in the ashes, due to better pre-sorting)



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# Quantification

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## 4.1. INTRODUCTION

In the FutuRaM project, scenario elements are categorised based on their influence and relevance to the secondary raw material (SRM) system. This categorisation aids in refining the focus of the scenarios and ensuring they are relevant, manageable, and useful.

Following the process detailed in chapter 2, the resultant scenario elements were classified in preparation for quantification. These elements are listed in Table 13.8.

### Internal Elements:

(section 4.4 and section 4.5) These are directly within the scope of FutuRaM and significantly impact the waste management system. They are integral to the models and scenarios. For example, changes in waste composition and recovery methods fall under this category. These elements are thoroughly researched and modeled as they are central to understanding and projecting the SRM system's future.

### External Elements:

(section 4.3) Elements deemed external are still relevant to the scenarios but are not as directly related as the internal elements. External elements are set as the background of the three scenarios, allowing a better focus on the main variables of importance to FutuRaM. These elements do not vary across the three different scenarios but they do change over time. These elements include demographics, economic growth, and the renewable energy transition.

### Outside Elements:

(section 4.3) These are factors outside the scope and influence of the waste management system and are not included in the scenario storylines or directly in the models. They may be considered in sensitivity analysis but are not primary drivers in the scenario development. For instance, resource supply constraints are external factors that could impact the waste management system but are too unpredictable and complex to model directly within the scenarios. Their inclusion could introduce significant uncertainty and make the models less interpretable and actionable. These elements are, however, considered important, and their possible impacts on the SRM system will be explored in exercises of sensitivity analysis and optimisation.

The rationale behind this categorisation is to maintain focus and clarity in the scenario modeling. Including too many complex and indirectly related elements can convolute the scenarios, making them overly complex and less useful for practical decision-making and policy analysis. By concentrating on integral elements — or those that can be controlled or influenced by associated policy decisions — FutuRaM ensures that its scenarios are both manageable and directly relevant to its objectives of exploring different futures of the SRM system. This approach strikes a balance between realism and practicality, ensuring the scenarios are both meaningful and actionable.

### 4.1.1. Quantification and Implementation of scenario elements in the models

#### External drivers

For each external driver in the scenarios, the values are defined globally and each waste stream will interpret this into their models using a "top-down" approach. This will require the development of correlations between the scenario driver and the parameter in the waste stream model. The resolution of this will be different for each scenario driver and each waste stream.

1817

## ***Internal elements***

1818

For the internal elements in the scenarios, a global value can often not be defined. For these elements, the waste stream models will define the values for each scenario using a "bottom-up" approach. This will require the estimation of future trends for each parameter and scenario for the product/waste groupings in each waste stream. Then, a global value can be calculated by taking a weighted average for each of the groups.

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The outcome of these estimations will be a range of values for each time series, for each parameter in each waste stream for each scenario.

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Figure 4.1 depicts a schema for the interconnection between the models for the quantification and implementation of the scenario elements.

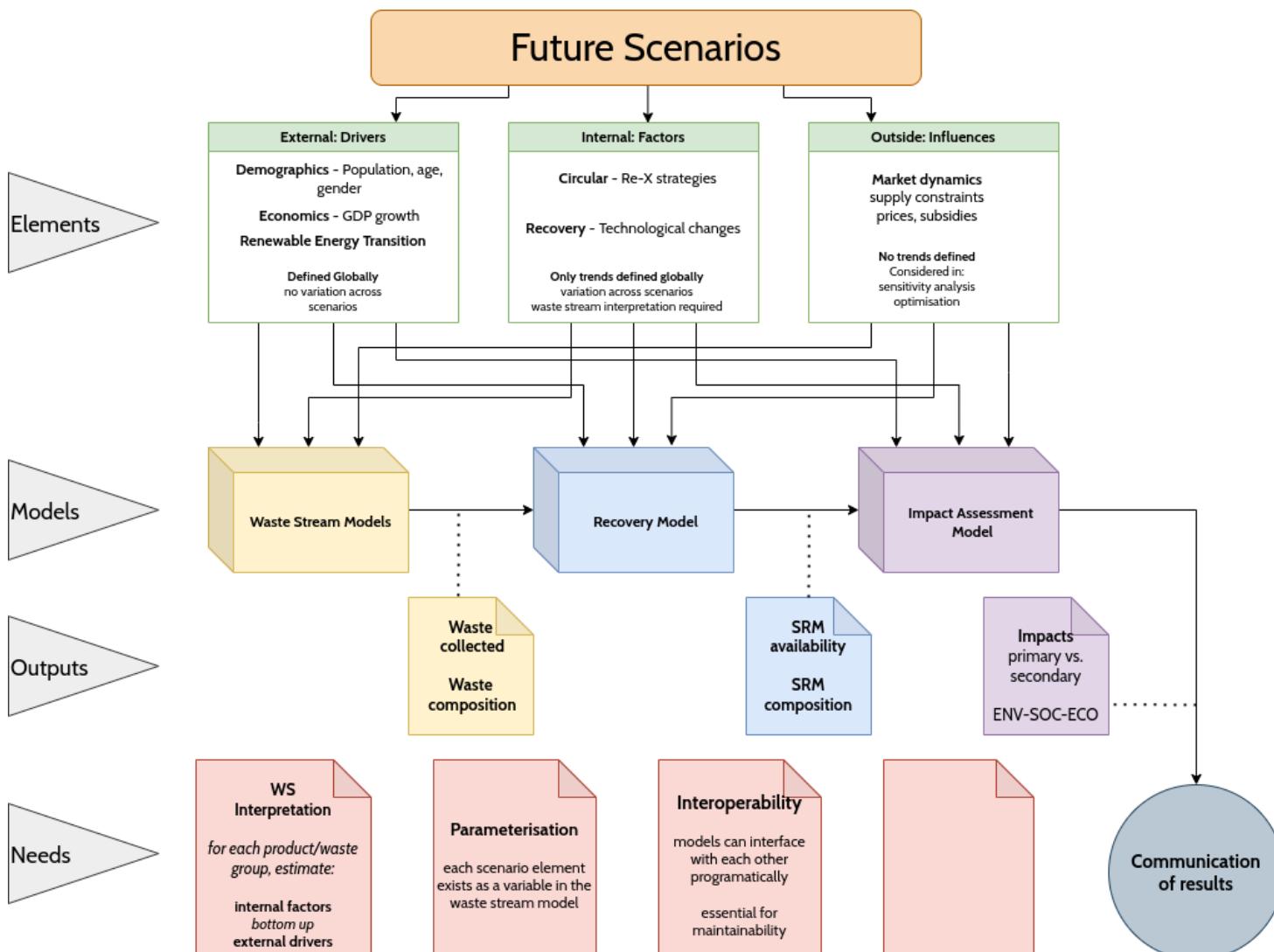


Figure 4.1: Quantification and Implementation of scenario elements in the models

## 1827 ***Methodology for quantification***

1828 The methodology for quantification of the scenario elements is as follows:

- 1829 1. Define the parameters for each waste stream model
- 1830 2. Define the parameters for each scenario element in relation to the parameters in the waste stream  
model
- 1831 3. Define the correlations between the scenario elements and the parameters
- 1832 4. Estimate the future trends for each parameter in each scenario for every set of product/waste group-  
ings
- 1833 5. Using the constraints of the waste stream parameter for each product group, define the coefficients  
of the functions between the scenario elements and the parameters

1835 Figure 4.2 depicts a schema for the development of correlations between elements and parameters  
1836 in the waste stream models and the scenarios. The values of the functions between the pairs need to be  
1837 defined.

# Interpretation

## - Waste -

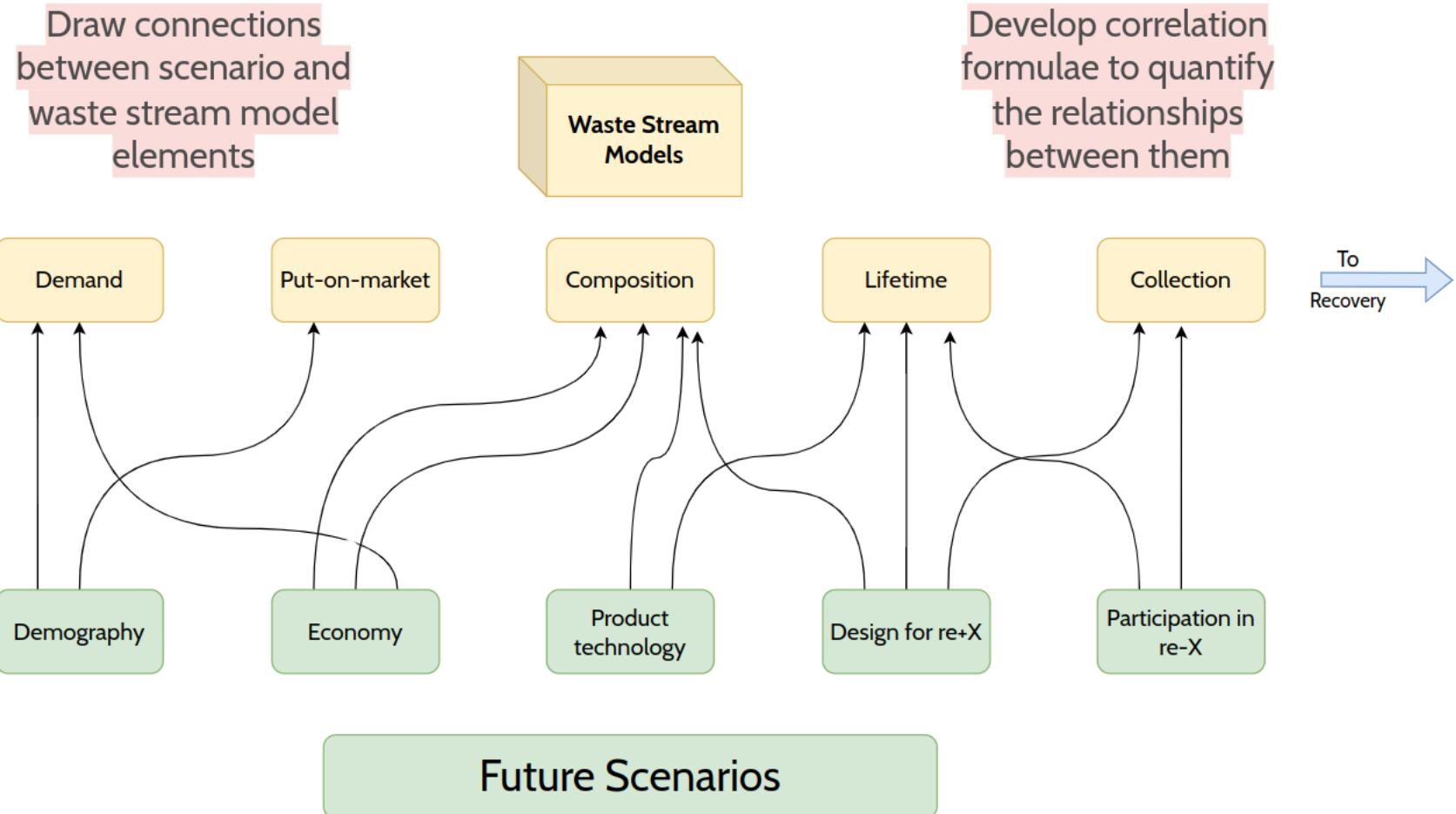


Figure 4.2: Development of correlations between elements and parameters in the waste stream models and the scenarios

## Methodology for estimating future trends

After the correlations between the scenario elements and the parameters in the waste stream models have been defined, the future trends for each parameter in each scenario for every set of product/waste groupings can be estimated.

For some parameters, the future trends can be estimated using a simple linear regression. For other parameters, the future trends will be estimated using a more complex model. The exact methodology for estimating the future trends for each parameter in each scenario for every set of product/waste groupings will be determined on a case-by-case basis.

Consideration of historical and current data, knowledge of the waste stream, and analysis of the scenarios will be used to determine the most appropriate modelling method.

An exact value is not to be sought, but rather a distribution, with constraints regarding the minimum and maximum values and the rate of change over time.

Using this, simple models can be approximated using the method of curve fitting. The choice of model (linear, exponential, etc.) will be determined by the data and the scenario. For example, a new technology or a rapid change in policy may result in an initial exponential change in the parameter, the beginning of the typical sigmoidal curve (or even a step change). This may then level off to a linear trend, then a logarithmic relationship as the technology or policy matures.

Figure 4.3 illustrates a sigmoidal curve with its characteristic three phases of growth. Typically, a sigmoidal curve (depicted as a solid black line) commences with an exponential phase, transitions into a linear phase (encompassing the inflection point where the growth rate peaks), and concludes with an asymptotic phase, where the curve nears a constant asymptote ' $a$ ' as time tends towards infinity. In certain instances, the initial exponential phase might be remarkably brief, to the point of seeming non-existent. However, the linear and asymptotic stages are consistent features across all sigmoidal curves. Attenuating curves share similarities but are distinct in that they do not have the initial exponential phase, resembling a sigmoidal curve that initiates at its inflection point around  $t_0$ . The logistic function is a special case of the sigmoidal function, with the inflection point at  $x=0$ .

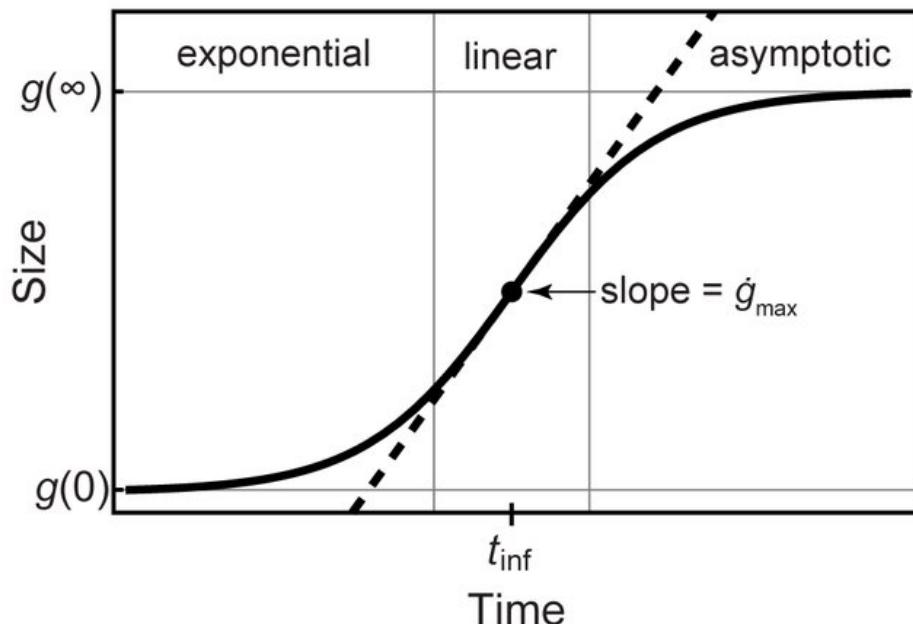


Figure 4.3: An example of a sigmoidal function (s-curve)

The s-curve is a generalisation of the logistic function, which is defined as:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}} \quad (4.1)$$

1867

where:

1868

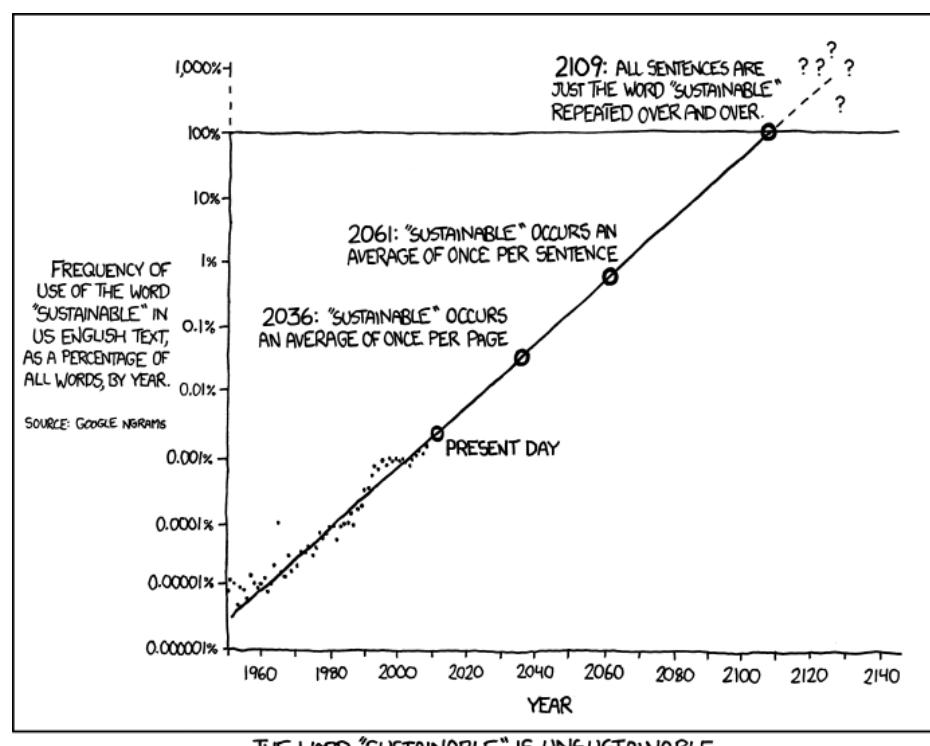
- $x_0$  = the x-value of the sigmoid's midpoint,
- $L$  = the curve's maximum value, and
- $k$  = the logistic growth rate or steepness of the curve.
- $e$  = the natural logarithm base (also known as Euler's number),

1872

Important to note here is that what, during some period, may appear to be a constant linear (or other) change, may in fact be a segment of a sigmoidal curve. This is important to consider when estimating future trends, for some changes, the period from 2020-2050 may be short enough that the nature of the transition does not change, although it would when viewed over a longer time range.

1876

The comic in Figure 4.4 plots the frequency of the usage of the term 'sustainable' over time, forecasting that by 2109, all sentences will consist only of the word 'sustainable', repeated again and again. 'Fittingly', the author also notes that '100 years is a lot longer than many of our resources will last'.



*Figure 4.4: The word 'sustainable' is unsustainable [157]*

1879

It is of course a generalisation to assume that all growth rates follow this trend, but it is mostly close enough to reality to be useful. This will be the standard approach for estimating future trends in the FutuRaM project unless there is reason to believe that the nature of the transition is different (which it often is!).

1882

Further details are provided in the relevant sections of this chapter and will be updated as the project progresses.

## 4.2. SUMMARY

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

1885

1886

## 4.3. EXTERNAL ELEMENTS

### 4.3.1. Introduction

| External drivers |   |
|------------------|---|
| 1887             | <b>Scenario elements</b>  |
| 1888             | <ul style="list-style-type: none"> <li>• <b>Demographic change:</b><br/>population, median age, urbanisation, gender</li> <li>• <b>Economic growth:</b><br/>GDP</li> <li>• <b>Renewable energy transition:</b><br/>energy mix</li> </ul>  |
| 1889             | <b>Waste model parameters include:</b>  |
| 1890             | <ul style="list-style-type: none"> <li>• Put-on-market</li> <li>• Composition</li> </ul>  |
| 1891             | <b>Recovery model parameters include:</b>   |
| 1892             | <ul style="list-style-type: none"> <li>• Recovery processes:<br/>market penetration of recovery technologies</li> <li>• Transfer coefficients:<br/>function of recovery technologies</li> <li>• Recovery system size:<br/>BAU - set by trends in BAU, CIR &amp; REC - defined by model outcomes within constraints</li> </ul> |
| 1893             | <b>Impact model parameters include:</b>   |
| 1894             | <ul style="list-style-type: none"> <li>• Foreground inventory:<br/>inputs and outputs of recovery system</li> <li>• Background inventory:<br/>energy mix, impact of primary production</li> </ul>   |

In the FutuRaM project, scenario elements are categorised based on their influence and relevance to the secondary raw material (SRM) system. This categorization aids in refining the focus of the scenarios and ensuring they are relevant, manageable and useful.

Following the process detailed in chapter 2, several scenario elements were classified as "external" or "outside".

The following "external" elements are incorporated into the scenarios as background information but are not directly modelled. They are assumed to be constant across the three scenarios, but change over time.

- Demographic change
- Economic growth
- Renewable energy transition

The following "outside" elements are not incorporated into the scenarios, but are considered important and will be explored in sensitivity analysis and optimisation.

- 1903     • Resource supply constraints
- 1904     • International trade and co-operation
- 1905     • Re-industrialisation of EU
- 1906     • Resistance to recovery projects ("NIMBY")

1907     These elements are detailed in Table 4.1.

Table 4.1: List of external scenario elements

| DOMAIN | ELEMENT  | INTERNAL | EXTERNAL | OUTSIDE | BAU | REC | CIR | MODEL PARAMETERS AFFECTED                                |
|--------|--|----------|----------|---------|-----|-----|-----|--|
| ECO    | Progress toward renewable energy targets           |          | ✓        |         | -   | -   | -   | composition, demand, waste generation, recovery impacts  |
| ECO    | Economic growth                                    |          | ✓        |         | -   | -   | -   | composition, demand, waste generation                    |
| SOC    | Population   |          | ✓        |         | -   | -   | -   | demand, waste generation                                 |
| ECO    | Primary vs. secondary raw material prices          |          | ✓        |         | ~   | ~   | ~   | considered in sensitivity analysis                       |
| ECO    | Energy prices                                      |          | ✓        |         | ~   | ~   | ~   | considered in sensitivity analysis                       |
| ECO    | Carbon price                                       |          | ✓        |         | ~   | ~   | ~   | considered in sensitivity analysis                       |
| ENV    | Resource supply constraints                        |          | ✓        |         | ~   | ~   | ~   | considered in sensitivity analysis:                      |
| ECO    | International trade and co-operation (vs. autarky) |          |          | ✓       | n/a | n/a | n/a | not model input (resource supply constraints is a proxy) |
| ECO    | Re-industrialisation of EU                         |          |          | ✓       | n/a | n/a | n/a | not model input  |
| SOC    | Resistance to recovery projects (NIMBY)            |          |          | ✓       | n/a | n/a | n/a | not model input (considered in UNFC assessments)         |

F

Back to ToC

## 4.3.2. Summary

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

## *Demographic change*

### INDEPENDENT VARIABLES

- Population
- Median age
- Urbanisation

### DEPENDENT VARIABLES

- Demand
- Waste generation
- Waste composition

## *Economic growth*

### INDEPENDENT VARIABLES

- GDP growth

### DEPENDENT VARIABLES

- Demand
- Waste generation
- Waste composition

## *Renewable energy transition*

### INDEPENDENT VARIABLES

- Energy mix

## 1930 DEPENDENT VARIABLES

- Demand
- Waste generation
- Waste composition
- Recovery impacts

## 1935 Resource supply constraints

### NOTE

This element is not forecast or modelled directly, but is considered in sensitivity analysis and optimisation.  
Supply constraint is independent of its cause (e.g. resource depletion, political instability), thus, it can act as a proxy for other elements such as international trade and co-operation.

## 1938 INDEPENDENT VARIABLES

- Resource availability

## 1940 DEPENDENT VARIABLES

- Resource prices
- Settings of the recovery system to counteract supply crunch
- Waste composition (incorporating lag and substitution effects)

## 1944 MARKET DYNAMICS

### NOTE

As with resource supply constraints, consideration of complex market dynamics are limited to sensitivity analysis and optimisation. General trend forecasts in supply and demand are considered in the scenarios, however, as functions of the other elements, such as GPD and population.

## 1947 INDEPENDENT VARIABLES

- Raw material prices
- Secondary raw material prices

## 1950 DEPENDENT VARIABLES

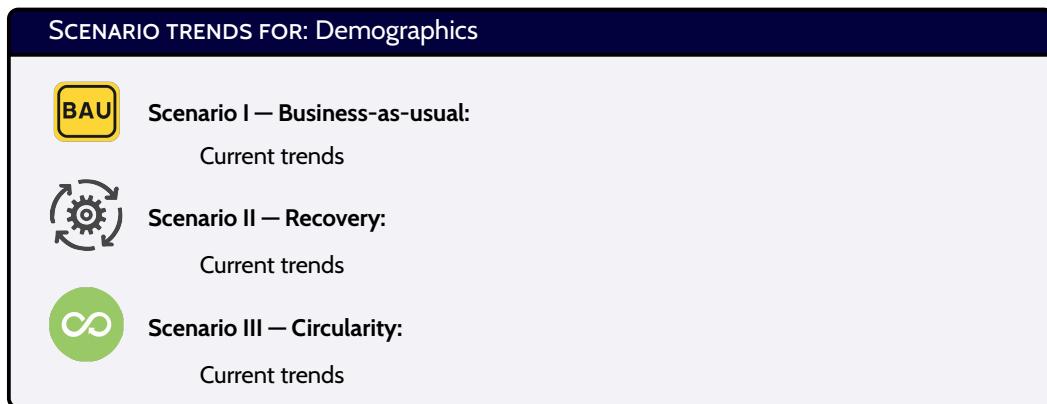
- 1951     • Recovery system settings
  - 1952     • Recovery system capacity
  - 1953     • Recovery system profitability
  - 1954     • Secondary raw material supply
-

### 4.3.3. Demographic factors: *Population, age, urbanisation*

#### **Definition**

Demographic factors encompass a range of population characteristics, including age distribution, population growth rates, urbanisation levels, migration patterns, and household composition. These factors are crucial determinants in forecasting demand patterns, labour market dynamics, and consumption trends, which in turn affect supply chains and resource management.

In the context of the scenarios and modelling within FutuRaM, demographic factors could influence the demand for certain commodities, the availability of labour for new recycling technologies, and the generation of waste materials. As populations grow and become more urbanised, the demand for electronics, energy, and transportation increases, which in turn raises the demand for critical raw materials necessary for these technologies. Age distributions can affect the workforce available for the recycling industry and potentially shift consumption patterns, as older populations might consume differently compared to younger demographics.



#### **Justification for setting as an external scenario factor**

Demographics undoubtedly exert a significant influence on supply and demand patterns within any resource environment. [39] As such, demographic factors play a role in shaping the demand for CRMs and the efficiency of waste management systems. However, within the scope of FutuRaM's scenario modelling, these demographic elements are treated as background variables.

A standard set of demographic projections is applied across all scenarios, contributing to the baseline assumptions but not serving as the primary driver of change in the model. By setting demographics as an external factor, FutuRaM's scenarios can abstract from the nuanced impacts of demographic changes, allowing for a clearer interpretation of how policy levers directly affect SRM outcomes.

Furthermore, the structure of FutuRaM's models is designed to be sufficiently adaptable to account for future demographic shifts. As new data become available, they can be integrated into the existing models, allowing for regular updates that keep pace with the evolving demographic landscape. This flexibility ensures that the model's outputs remain both relevant and grounded in the most current understanding of demographic factors, while the focus stays on the core objectives of resource management and the evaluation of policy efficacy.

### REVIEW NOTICE

Data for other demographic factors such as urbanisation, gender or persons per household can be added here if the waste stream models require it.

1986

1987

1988

## Population projections

1989

### Sources for demographic data

The population projections in this report have been produced from the most recent data provided by Eurostat and the UK Office of National Statistics (ONS) [63, 64, 105].

It was decided to 're-model' this data, rather than extract it from the population figures in the SSP2 baseline scenario datasets [106, 107] to which the background of FutuRaM's scenarios are (broadly) aligned. This allows the use of the most up-to-date and 'raw' data possible.

Figure 4.5 shows the normalised population projections for the EU27+3 and the UK. The index is set to 1 for the year 2020. An interactive figure can be viewed here [↗](#)

Normalised population forecasts for the EU27+4

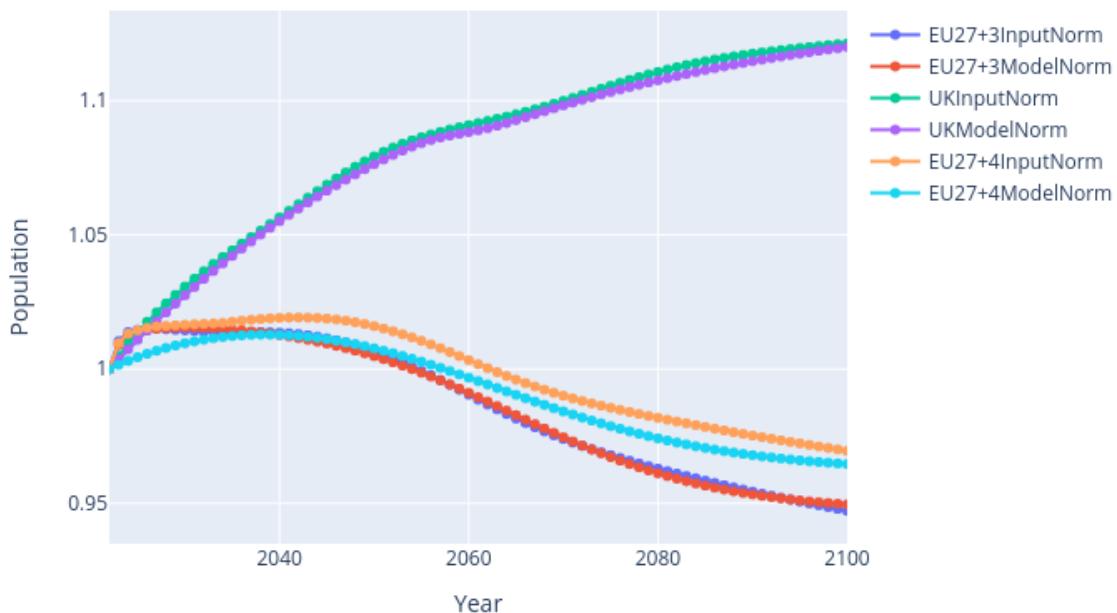


Figure 4.5: Population projections for the EU27+3 and the UK

1997

## EU27 + 4

1998

**Data source:** [63]

**POPULATION MODELLING RESULTS:**

The full results of the population modelling are presented in Table 4.2.

**HIGHLIGHTS:**

- The EU population is projected to rise from 446.7 million in 2022, peaking at 453.3 million in 2026 (+1.5%), before decreasing to 447.9 million in 2050 and further to 419.5 million in 2100.
- An increase of 5.8 years is expected in the median age of the EU population between 2022 and 2100.
- By 2100, the number of individuals aged 80 and over in the EU is projected to reach 64.0 million.

Populations evolve over time due to demographic factors: births, deaths, and migration. Each of these factors influences the population's structure. Presently, the EU is experiencing a trend of ageing in its population due to the prevailing levels of fertility and mortality.

EUROPOP2023 offers deterministic projections based on 'what-if' scenarios. These scenarios are formed on anticipated courses for fertility, mortality, and migration. A partial convergence is assumed among the countries in the EUROPOP2023 projection concerning fertility, mortality, and migration patterns. The methodology employed is primarily based on past projection exercises. Furthermore, this study accounts for the impact of the COVID-19 pandemic and the mass influx due to the conflict between Russia and Ukraine.

It is projected by Eurostat that all EU Member States and the three EFTA countries will experience continued population ageing. The population in 2100 is predicted to be lower than in 2022, with a decline in the working-age demographic. There's an observed trend of ageing within the elderly demographic itself. Migration can both alleviate and accelerate the ageing process. It depends on whether there's an influx or outflow of the working-age population. For instance, the search for better job opportunities can lead to a considerable outflow. Consequently, age dependency ratios are set to rise, posing challenges for public expenditure on pensions, healthcare, and long-term care.

**METHOD**

Eurostat provides international projections for the European Union (EU) and the European Free Trade Association countries, which include Iceland, Liechtenstein, Norway, and Switzerland. Unlike the UN's projections, Eurostat's are deterministic in nature. Their most recent projection, dating from 2020, presents a base variant along with four other variants, starting with the baseline year 2019. In the base variant, it is forecasted that the EU-27 population will decline by nearly 7 percent or about 30 million people by 2100. However, in the medium term, the population is expected to grow until 2025, reaching about 449 million people, before reducing to 416 million by 2100. Country-specific, sex, and age data are available in Eurostat's database.

The final projection starts with the 2022 population divided by sex and age. Mortality rates are applied to determine the number of deaths. Numbers for non-EU and EU immigrants are computed. For the years 2022 and 2023, refugees under TP are also included. Emigrants, including refugees under TP for the years 2024 to 2033, are then subtracted. Based on this, the end-of-year population and the working-age population are computed. Using these figures, additional non-EU immigrants are calculated, and the end-of-year population is re-assessed. This allows for the computation of live births, total deaths, immigration, and emigration for 2022.

**SCENARIOS**

Eurostat also considers five alternative scenarios besides the baseline for EUROPOP2023. These are:

lower fertility, lower mortality, zero net migration, decreased non-EU immigration, and increased non-EU immigration. For instance, the lower fertility scenario posits a total fertility rate that's 20% less than the baseline for each projection year (2023 – 2100). This implies fewer live births yearly compared to the baseline. The lower mortality scenario suggests a life expectancy at birth in 2100 that's two years more than the baseline. Migration scenarios include zero net migration, 33% less non-EU immigration each year, and 33% more non-EU immigration every year throughout the projection horizon.

## UK

### Data source: [64]

- New data will be released January 2024.
- No scenarios were developed due to the additional uncertainty in the underlying data related to the CoViD-19 pandemic-related fluctuations.

### POPULATION MODELLING RESULTS:

The full results of the population modelling are presented in Table 4.2.

### POPULATION PROJECTIONS

The UK population in mid-2020 was estimated at 67.1 million. Over the decade to mid-2030, it's projected to rise by 2.1 million (3.2% increase), in comparison to a 6.9% increase between 2010 and 2020. Over the next 25 years, the projected growth is 3.9 million (5.8%), less than the 15.6% growth between mid-1995 and mid-2020.

In contrast to the EU27+3, the UK population is projected to continue growing (slowly) until 2100, the end of the projection period, when it reaches 76 million.

### ASSUMPTIONS:

- Long-term averages are based on a 22-year period, excluding the 1990s.
- Long-term average falls within the ranges given by expert advisory feedback.
- Estimated international migration data is used for the years ending mid-2021 and mid-2022.
- Linear interpolation is used from mid-2022 up to mid-2026.
- A three-year average of data from mid-2020 to mid-2022 is used for starting the linear interpolation for mid-2022.
- UK completed family size to reach 1.59 children per woman by 2045.
- Annual improvement in UK mortality rates will be 1.2% for most ages by 2045.
- Net international migration to the UK will average +205,000 from mid-2027 onwards.

### METHODOLOGY

Projections are produced for successive years from one mid-year to the next. Age-based calculations are made to account for net migration, deaths, and births. Details such as migration timing, death rates, birth rates, and the ratio of male-to-female births are factored into the calculations. Projections are made for each UK country and then aggregated for broader regions.

## 2077 STRENGTHS AND LIMITATIONS

2078 Projections are based on the latest available data but are not forecasts. The inherent uncertainty in  
 2079 the data and the unpredictability of future events means projections may not align with future outcomes.  
 2080 Factors like political and economic changes can also impact population growth, and events like the UK  
 2081 leaving the EU or the COVID-19 pandemic are not explicitly factored in. While this bulletin focuses on  
 2082 projections up to mid-2045, the data includes projections up to mid-2120, which have greater inherent  
 2083 uncertainty.

## 2084 MERGING THE EU27+3 AND THE UK INTO A UNIFIED POPULATION MODEL

2085 As the world undergoes the demographic transition, the relevance of Verhulst's logistic model has  
 2086 resurfaced, providing an adequate representation of current population growth trends. This logistic population  
 2087 growth dynamic is critical for achieving global sustainable development.

2088 These projections are informed by the finite reserves of primary exhaustible resources and the ongoing  
 2089 trend of declining birth rates. These indications suggest a shift towards a new equilibrium state for  
 2090 the planet that aligns with heightened industrial and technological capacities and improved healthcare  
 2091 standards. By constructing logistic models that depict the growth dynamics of the global population and  
 2092 individual continents, we can forecast population sizes and their growth rates for the next two centuries. The  
 2093 insights garnered present opportunities for the regulation and optimal management of global demographic  
 2094 resources.

## 2095 *Projection Methodology*

2096 **Methodology source:** [105]

2097 Population projections underpin many political and economic decisions at various levels. Often, the  
 2098 users lack the expertise to fully grasp the methods and limitations of the projections they rely on.

2099 Population development is contingent upon three primary factors: fertility, net migration, and mortality.  
 2100 Usually, a projection starts with the age- and sex-specific numbers at a given time. Using estimates for the  
 2101 future development of the three determinants, the population is projected forward. Forecasts often refine  
 2102 mortality and migration by age and sex.

2103 Projection methodologies fall into deterministic and stochastic categories. Deterministic models, being  
 2104 the most widespread, set parameters in one or more scenarios. Their strengths lie in ease of use, adaptability  
 2105 to changes in parameters, and straightforwardness for non-experts. A prominent deterministic method is  
 2106 the cohort component method (CCM) which separately simulates fertility, migration, and mortality before  
 2107 integrating them into a projection. Given a population  $P_{t-1}$  at the end of period  $t - 1$ , the CCM updates  
 2108 this using births  $B_t$ , net migration  $M_t$ , and deaths  $D_t$  as:

$$P_t = P_{t-1} + B_t + M_t - D_t$$

2109 However, deterministic models face challenges. They:

- 2110 • Overlook the probabilistic nature of population processes.
- 2111 • Rely on rigid future assumptions with low individual probabilities of occurrence.
- 2112 • Limit the number of considered scenarios, inadequately reflecting future risk.
- 2113 • Lack probabilistic quantification for identified futures.
- 2114 • May be biased by experts' subjective assessments.

In contrast, stochastic models view parameters as random variables. While deterministic models might assume fixed values for determinants like  $G_t$ ,  $M_t$ , and  $S_t$  in certain scenarios, stochastic models see these as probabilistic, represented as:

$$\tilde{B}_t = \tilde{B}_{t-1} + \tilde{G}_t + \tilde{M}_t - \tilde{S}_t$$

Yet, it's essential to understand that no forecast offers absolute truth. Their aim isn't predicting unexpected events, but extrapolating core demographic trends. Both deterministic and stochastic methods exist to quantify forecast uncertainty.

Applying these results in real-world scenarios warrants a cautious approach. Past trends might not persist in the future. For instance, population growth isn't just about demographics but also infrastructure. Can a housing market accommodate growth? Will cities meet their limits? Projections inherently carry assumptions. For instance, regions must meet housing demands, and urban challenges arise from positive population growth, such as the need for expanded childcare or public transport infrastructure.

Predicting and managing future global population growth stands as a paramount challenge for humanity. Most contemporary researchers believe there's a ceiling to the planet's 'carrying capacity'. Come 2022, Earth's population is anticipated to hit the eight billion mark. UN predictions suggest that by 2100, this number will rise to ten billion. However, there's an observable trend towards smaller family sizes, with birth rates currently hovering around the replacement rate of 2.1 children per woman. Should global fertility rates align with family replacement levels (2.0) by 2100, Earth's population is projected to stabilise between ten and eleven billion. The emergence of new statistical data necessitates updates to global population growth models. Where once the Verhulst logistic model was deemed inadequate for characterising global population growth dynamics, the tapering growth rate now reaffirms its applicability. Many recent studies have leveraged the logistic growth model. Our analyses confirm that Earth's population growth rate aligns closely with a quadratic function, mirroring the Verhulst equation (Fig. 4). All subsequent computations will employ the Verhulst logistic model:

$$\frac{dY}{dt} = a \cdot Y - b \cdot Y^2 \quad (4.2)$$

The solution to equation (8) will be sought as a logistic function:

$$Y = g + \frac{b}{1 + A \exp(-a(t - t_0))} \quad (4.3)$$

Function  $Y(t)$  parameters were ascertained using the least squares method, ensuring maximal alignment between the function's value and the existing statistical data. The parameter  $g$  was presumed equal to the initial population size at the start of observations ( $t_0 = 1900$ ).

## CURVE FITTING EXPLANATION

Terms with subscript 1 describe the initial logistic component, charting population growth from 2022 to 2042.

Subscript 2 terms Correspond to the second logistic component, which outlines post-2042 population decline.

- b<sub>1</sub>** Represents the initial population at the start of the observation period - Europe's population in 1900 per the model's parameters.
- b<sub>1</sub>** Denotes the carrying capacity of population growth, effectively indicating the population apex achievable via the first logistic function.

- 2151     A<sub>1</sub>    Influences the gradient of the first growth phase. Higher values result in steeper population inclines.
- 2152     a<sub>1</sub>    Represents the growth rate of the initial logistic function, dictating how swiftly the population nears  
2153                the carrying capacity  $b_1$ .
- 2154     t<sub>1</sub>    Marks the inflection point in the first logistic phase, signifying the period of maximum growth  
2155                velocity.
- 2156     b<sub>2</sub>    Illustrates the decline's carrying capacity, indicating the population decrease as projected by the  
2157                second logistic function.
- 2158     A<sub>2</sub>    Determines the gradient of the decline phase, with larger values resulting in sharper declines.
- 2159     a<sub>2</sub>    Represents the rate of decline in the latter logistic function, determining the speed at which the  
2160                population reaches the decline's carrying capacity  $b_2$ .
- 2161     t<sub>2</sub>    Highlights the inflection point during the decline phase, marking the period where the decrease is  
2162                most rapid.

*Table 4.2: Population projections for the EU27+4*

| YEAR | MEDIAN AGE | EU27+4 (million) | EU27+3 (million) | UK (million) |
|------|------------|------------------|------------------|--------------|
| 2023 | 43         | 530.1            | 462.0            | 68.1         |
| 2024 | 43         | 531.9            | 463.4            | 68.4         |
| 2025 | 43         | 532.6            | 463.8            | 68.7         |
| 2026 | 44         | 533.1            | 464.1            | 69.0         |
| 2027 | 44         | 533.4            | 464.1            | 69.2         |
| 2028 | 44         | 533.5            | 464.0            | 69.4         |
| 2029 | 44         | 533.6            | 464.0            | 69.7         |
| 2030 | 45         | 533.7            | 463.9            | 69.9         |
| 2031 | 45         | 533.8            | 463.8            | 70.1         |
| 2032 | 45         | 533.9            | 463.7            | 70.3         |
| 2033 | 45         | 534.0            | 463.6            | 70.4         |
| 2034 | 45         | 534.1            | 463.5            | 70.6         |
| 2035 | 45         | 534.3            | 463.5            | 70.8         |
| 2036 | 46         | 534.5            | 463.6            | 71.0         |
| 2037 | 46         | 534.7            | 463.6            | 71.1         |
| 2038 | 46         | 534.9            | 463.6            | 71.3         |
| 2039 | 46         | 535.0            | 463.5            | 71.5         |
| 2040 | 46         | 535.1            | 463.4            | 71.6         |
| 2041 | 46         | 535.1            | 463.3            | 71.8         |
| 2042 | 46         | 535.1            | 463.2            | 72.0         |
| 2043 | 46         | 535.1            | 463.0            | 72.1         |
| 2044 | 46         | 535.1            | 462.8            | 72.3         |
| 2045 | 47         | 534.9            | 462.5            | 72.4         |
| 2046 | 47         | 534.8            | 462.2            | 72.6         |
| 2047 | 47         | 534.6            | 461.8            | 72.8         |
| 2048 | 47         | 534.3            | 461.4            | 72.9         |
| 2049 | 47         | 533.9            | 460.9            | 73.0         |
| 2050 | 47         | 533.6            | 460.4            | 73.2         |
|      |            |                  |                  |              |

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## Incorporation of demographic factors into individual waste stream models

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### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how the demographic parameters are incorporated into your stock and flow models

2168



#### BATT (BATTERY WASTE)

- X

2169



#### CDW (CONSTRUCTION AND DEMOLITION WASTE)

- X

2170



#### ELV (END-OF-LIFE VEHICLES)

- X

2171



#### MIN (MINING WASTE)

- X

2172



#### SLASH (SLAGS AND ASHES)

- X

2173



#### WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

- X

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2175

## Conclusion

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### REVIEW NOTICE

This conclusion will be compiled once the individual waste stream sections for each parameter are complete.



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## 2184 4.3.4. Economic factors: *GDP growth*

### 2185 *Definitions*

#### 2186 Gross Domestic Product (GDP) PPP

2187 A measure of a country's economic output that accounts for differences in price levels between  
 2188 countries. By using PPPs and the common currency of international dollars, GDP PPP is adjusted for  
 2189 price level differences across countries, providing a more accurate measure of the economic output  
 2190 and living standards, as it reflects the real purchasing power of the citizens.

#### 2191 Purchasing Power Parity (PPP)

2192 An economic theory that allows the comparison of the purchasing power of various world currencies  
 2193 to one another. It involves a comparison of the relative prices of a standard set of goods and services  
 2194 in different countries, thus providing a measure of the relative cost of living and enabling a more  
 2195 accurate comparison of economic well-being.



### 2198 Sources of data

2199 The GDP projections for FutuRaM's future scenarios are based on economic data from the OECD as well as  
 2200 population data from Eurostat and the UK's ONS [63, 64, 65]

### 2201 Results of projections

2202 As an 'external element', the GDP projections do not differ across the scenarios, only as a function of time.

2203 The results of the projections are shown in Figure 4.6. An interactive figure can be viewed here ↗

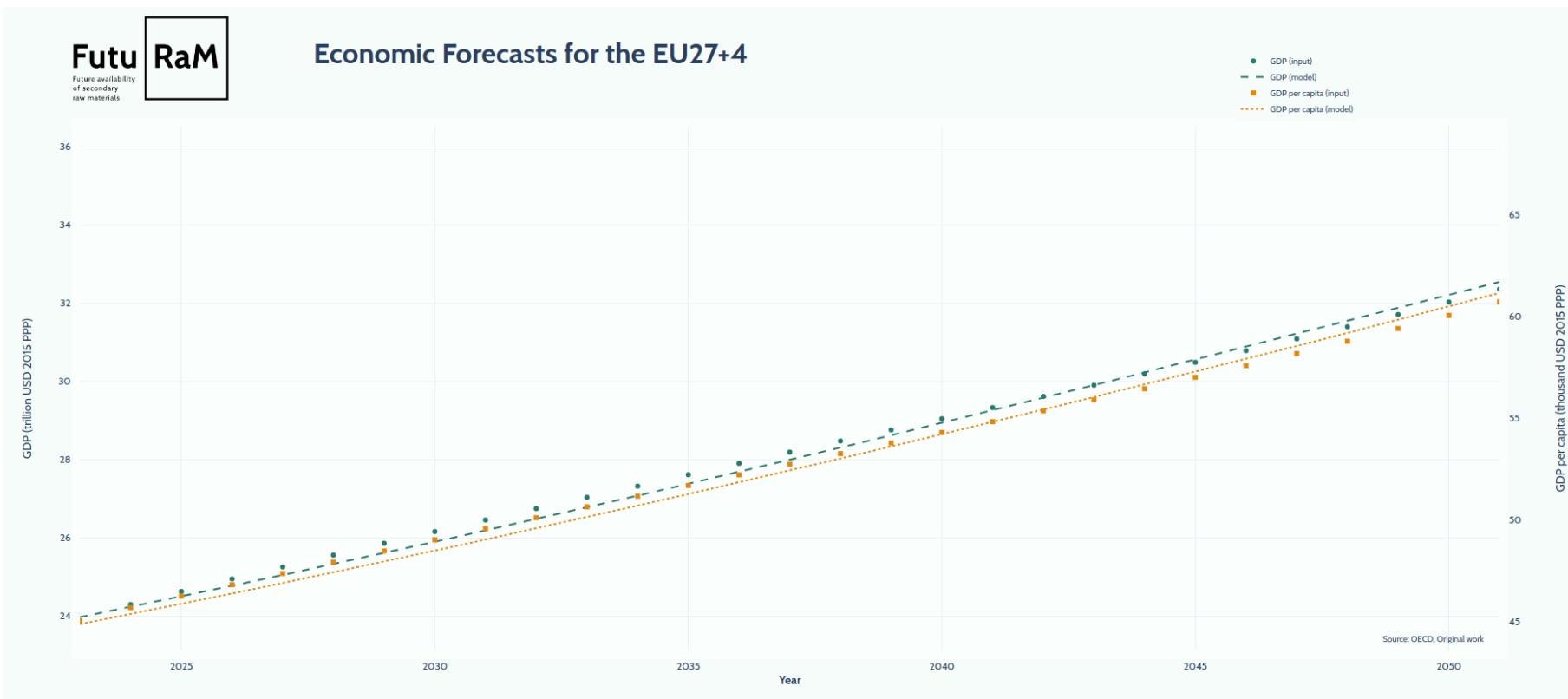


Figure 4.6: GDP projections for the EU27+4

## Methodological Overview of OECD's GDP Projection Framework

[65, 40, 108, 158]

The OECD's approach to projecting GDP is rooted in the principle that income levels across various nations will gravitate towards those observed in the most advanced economies, an idea put forth by [41, 74]. This convergence is modelled through an enriched version of the Solow growth model, factoring in a dual-sector configuration [109], which the OECD dubs the ENV-Growth model. Rather than focusing solely on convergence in income, the ENV-Growth model prioritises the growth factors that will drive GDP over time.

For GDP projections up to 2060, the OECD combines model-based assessments with expert evaluations, considering the economic dynamics of individual countries and the global market. These forecasts are denominated in the constant US dollars and PPPs of 2010, based on data from OECD and World Bank, which use the Atlas method for calculating PPPs [40, 66]. The data originate from the OECD Long-Term Baseline Scenario. This scenario, which is integral to the OECD Economic Outlook, serves as a comparative standard to gauge the possible effects of structural reforms, assuming a policy-neutral environment. Conversely, long-term projections diverge from the medium-term forecasting model, which is predominantly demand-driven, by focusing on a supply-side perspective that takes into account labour and capital availability and productivity growth rates.

## Determinants of Long-term Growth

[40, 110]

Recognizing the multifaceted nature of economic advancement, GDP growth projections consider an array of influences such as demographics, educational attainment, technological progress, energy access, and capital flow patterns. The MaGE framework facilitates GDP estimation by charting dynamic paths that reflect the structural interplay defining the economic landscape until 2050 [110].

The ENV-Growth model's projections span a century and include a wider selection of countries, enhancing the original methodologies developed by the OECD Economics Department [108, 158]. It introduces considerations for energy usage and resource revenue from oil and gas sectors, aligning with the enhanced sectoral approach for fossil fuels presented by [42].

The model's foundation lies in its projection of the five pivotal elements driving economic growth:

- Physical capital
- Employment, shaped by population trends, age demographics, participation rates, and unemployment scenarios
- Human capital, based on education and its consequential effect on labour productivity
- Energy demand and resource extraction for exporting countries
- Total factor productivity (TFP)

The determinants of growth are not restricted to these factors; they also encompass a spectrum of social, economic, and institutional influences, including workforce education, trade openness, institutional integrity, fiscal strategies, regulatory frameworks, and demographic shifts. The underlying potential for economic catch-up through technology transfer and innovation is underscored by the differential in income between each country and the global technology frontrunner.

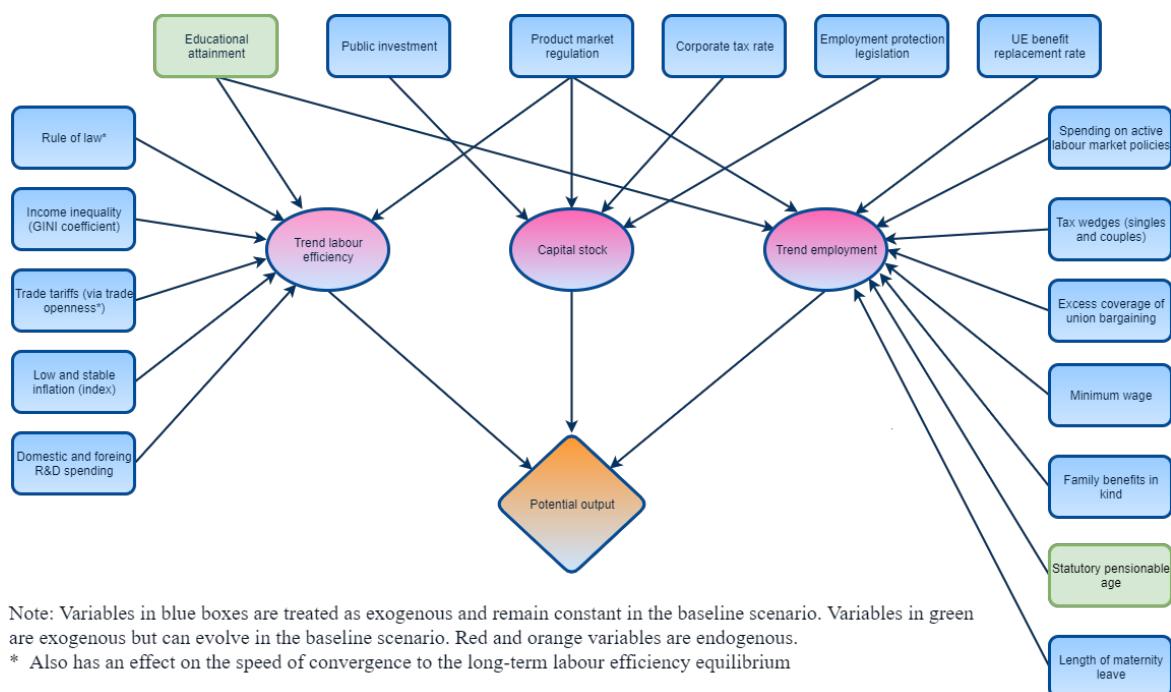
In the context of employment, projections from IIASA inform the total employment figures, combining time-specific participation rates for different age cohorts with projected unemployment trends. Education

assumptions translate gender and age-specific educational projections into a human capital index, which then informs labour productivity enhancements.

For physical capital, the model follows a standard capital accumulation methodology with a set depreciation rate, with the investment rate per unit of GDP edging towards a balanced growth path level determined by the production function's structural parameters.

Energy and natural resources are integrated as productive components for consumers and as extra income from specific oil and gas sectors for producer nations. The model calibrates domestic energy productivity to historical improvement rates, progressing towards an efficiency frontier indicative of cutting-edge energy appliances. The economic contribution of energy resources to producer countries is extrapolated from resource depletion models that describe the dynamics between reserves and resources and the temporal evolution of marginal production costs.

FutuRaM's economic forecasts, while not based directly on the SSP data, are consistent with the SSP2 baseline derived from similar sources and models [106, 107, 111, 112, 113, 114], offering a comprehensive picture of potential economic trajectories.



*Figure 4.7: Factors incorporated in the long-term GDP model [40]*

## 2259 **Implications of GDP Growth on FutuRaM's Waste Models**

2260 GDP growth has significant implications for models concerning secondary raw material recovery and waste  
2261 generation. For example, increasing GDP tends to lead to higher consumption levels, which can result in  
2262 more waste generation across various streams. However, higher income also provides greater resources for  
2263 investment in recovery technologies and infrastructure. Below are some examples for each of the specified  
2264 waste streams.



### 2265 **BATT (BATTERY WASTE)**

2266 As GDP grows, the demand for electronic devices and electric vehicles typically increases, leading  
2267 to a higher turnover of batteries. This could necessitate advancements in recovery methods for battery  
2268 components, such as lithium and cobalt, to reduce reliance on primary sources and mitigate environmental  
2269 impact.



### 2270 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2271 Economic growth often spurs construction activity, thereby increasing CDW. Increasing GDP as a ratio of  
2272 waste generation could lead to enhanced recycling processes, promoting the circular economy by converting  
2273 waste into secondary raw materials for new construction projects.



### 2274 **ELV (END-OF-LIFE VEHICLES)**

2275 The number of ELVs rises with economic prosperity, as people can afford newer vehicles more often.  
2276 This creates opportunities to recover valuable materials and components, necessitating more efficient  
2277 recycling processes.



### 2278 **MIN (MINING WASTE)**

2279 As economies expand, so does the demand for minerals, potentially increasing mining waste. With  
2280 increased GDP, there could be more investment in techniques to minimise waste generation and recover  
2281 valuable materials from mining by-products.



### 2282 **SLASH (SLAGS AND ASHES)**

2283 Higher GDP can correlate with increased industrial activity, producing more slags and ashes. Enhanced re-  
2284 covery techniques can transform these by-products into useful secondary raw materials, such as aggregates  
2285 in construction.



### 2286 **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

2287 GDP growth can lead to shorter replacement cycles for electronic goods, increasing the amount of WEEE.  
2288 There's a potential for improved recovery of precious metals and rare earth elements, driving innovation in  
2289 e-waste recycling technologies.

**Incorporation of economic growth into individual waste stream models****WASTE STREAM NOTICE**

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

**BATT (BATTERY WASTE)**

- X

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- X

**ELV (END-OF-LIFE VEHICLES)**

- X

**MIN (MINING WASTE)**

- X

**SLASH (SLAGS AND ASHES)**

- X

**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

- X

**Conclusion**

Economic growth can therefore act as both a driver of waste generation and a catalyst for innovation in the recovery of secondary raw materials. The challenge for models like FutuRaM lies in accurately predicting these trends and proposing effective strategies to balance economic benefits with environmental sustainability.

**REVIEW NOTICE**

This conclusion will be more completely compiled once the individual waste stream sections for each parameter are complete.

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## 4.3.5. The Renewable Energy Transition

### Definition

The term "energy transition" refers to the current global shift from fossil fuels to renewable energy sources to meet the urgent need to reduce greenhouse gas emissions, combat climate change, and enhance energy security. This transition encompasses a fundamental transformation of energy supply and consumption patterns, including the increased use of sustainable energy to achieve a low-carbon economy. Historical shifts in energy sources—from biomass to coal, and later to oil and natural gas—reflect the ongoing evolution of energy use. The present focus is on scaling up renewables such as solar and wind, which are becoming increasingly cost-competitive. Key aspects of the transition include adopting electric vehicles, improving public transportation, advancing energy-efficient technologies for building heating, and developing energy storage and grid solutions to support the integration of variable renewable energy sources.

### Future energy mix in the EU

The projected electricity mix for the EU is presented in Figure 4.8. An interactive figure can be viewed here [here](#)

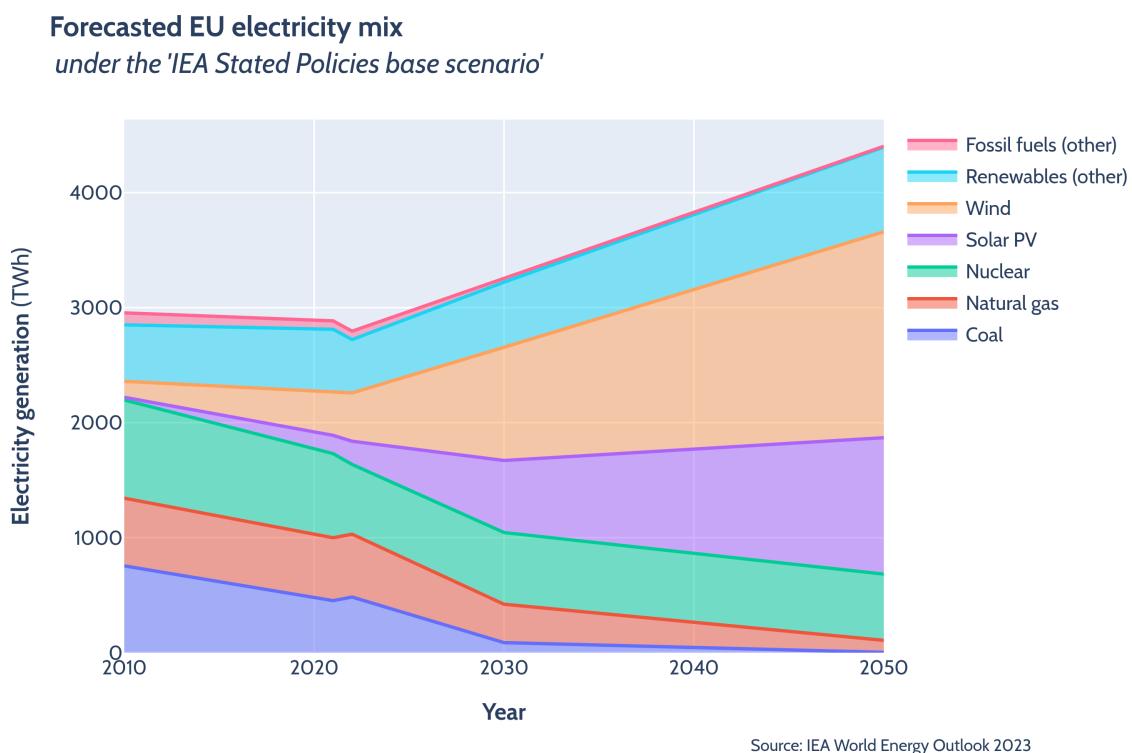


Figure 4.8: EU electricity mix forecast until 2050

### Brief context of renewable energy in the EU

Renewable energy is integral to the EU's shift towards a low-carbon economy and reducing reliance on imported fossil fuels—a response accentuated by the urgency to curtail dependence on Russian energy sources. The EU's strategic move is encapsulated in the REPowerEU Plan of Action, introduced in May

2332 2022, and agreed upon in 2023 which prescribes an aggressive uptake of renewables, emphasizing wind  
2333 and solar PV, alongside hydrogen, heat pumps, and batteries, vital for energy storage and transportation  
2334 decarbonisation [43, 14, 15, 44].

2335 In analysing the renewable sector in FutuRaM, the focus is on solar PV, wind turbines, electrolyzers,  
2336 batteries, and residential heat pumps. Other renewable sources like bioenergy, hydro, geothermal, and  
2337 ocean energy, while part of the portfolio, are expected to have minimal impact on critical materials demand  
2338 and are not central to this analysis.

### 2339 ***Justification for setting as an external scenario factor***

2340 The ongoing global energy transition is a profound shift that holds implications for almost every facet  
2341 of society, especially regarding CRMs, other raw materials and the system of waste management. This  
2342 transition from fossil fuels towards renewable energy sources demands a significant increase in various  
2343 CRMs, influencing their supply and demand curves extensively. In the development of FutuRaM's scenarios,  
2344 the energy transition is recognised as a fundamental driver of change. However, for the purposes of focussed  
2345 and strategic scenario modelling, it has been categorised as an external factor.

2346 This classification allows for a delineation between direct policy levers within the purview of SRM  
2347 systems and broader macro-environmental trends that, while influential, are not the primary subject of  
2348 analysis within FutuRaM. As such, the project's scenarios incorporate a consistent baseline projection of the  
2349 energy transition's effects, shared across the three scenarios, ensuring that the core analysis remains centred  
2350 on material-centric policy outcomes and targets of the CRM act. This ensures that the resulting insights  
2351 are actionable and tailored to the nuances of material management and recycling systems. It reflects a  
2352 strategic choice to maintain scenario tractability and avoid the dilution of policy implications that could  
2353 arise from an overly broad scope of variables.

2354 Moreover, the scenario architecture within FutuRaM is constructed with inherent flexibility, permitting  
2355 later incorporation of amendments to the background energy transition trends. This adaptability is essential  
2356 to ensure that, as the energy landscape evolves and new data becomes available, the scenarios can be  
2357 revised and updated, thereby preserving the relevance and accuracy of the project's findings over time.

### 2358 ***Relevant technologies in the renewable energy sector***

2359 The cornerstone technologies in renewable energy—batteries, electrolyzers, wind turbines, heat pumps, and  
2360 solar PV—play pivotal roles across various sectors (Figure 85). Heat pumps serve industrial processes, while  
2361 solar PV and batteries support ICT, defence, and mobility with energy and uninterrupted power supplies,  
2362 respectively [43].

2363 Wind energy, expected to surge, will benefit from cost-efficient, innovative turbines designed for  
2364 increased productivity in offshore and low-wind conditions. Projections from GECO present two scenarios:  
2365 a conservative estimate shows wind capacity expanding from 732 GW (2020) to 1,400 GW (2030), and to  
2366 4,050 GW by 2050. An optimistic forecast anticipates a rise to 2,500 GW by 2030 and 8,400 GW by  
2367 2050.

2368 Solar PV is poised for exponential growth due to advancements enhancing efficiency and lowering costs.  
2369 GECO's cautious scenario predicts growth from 710 GW (2020) to 2,950 GW (2030), reaching 7,500 GW  
2370 by 2050. The optimistic scenario projects a tenfold increase by 2030 and sixteenfold by 2050 compared  
2371 to 2020 levels.

2372 Addressing the intermittency of wind and solar power necessitates adequate storage solutions and  
2373 robust grid systems, with electrolyzers emerging as a crucial technology for renewable hydrogen production,  
2374 forecasted to exceed 1 GW capacity by the end of 2022 [45].

2375 Additionally, digitalisation, robotics, and 3D printing are set to boost the renewable sector's productivity

2376 and optimisation across its value chain. Heat pump sales are also on an upward trend, with a peak expected  
2377 in 2045, ranging between 15 million (low demand) and 38 million units (high demand) by 2050.

2378 Material demand in the renewable sector is dominated by wind turbines, electrolyzers, and solar PV,  
2379 with wind energy leading in consumption of critical materials.

## 2380 ***Supply Chain bottlenecks in renewable energy***

2381 Supply chain bottlenecks present a significant challenge in the deployment of renewable energy tech-  
2382 nologies, particularly for wind turbines, solar PV, electrolyzers, and heat pumps. The production of NdFeB  
2383 permanent magnets for wind turbines demands rare earth elements (REEs) like neodymium, dysprosium,  
2384 praseodymium, and terbium, with the EU being highly dependent on imports for both raw and processed  
2385 materials such as permanent magnet alloys and components like blades.

2386 Solar PV technologies necessitate strategic raw materials, including silicon metal and rare metals like  
2387 gallium and germanium, with China dominating the production of silicon ingots and wafers. This reliance  
2388 on imports extends across the value chain, including the crystalline silicon cell production where the EU's  
2389 contribution is minimal.

2390 The battery industry utilizes strategic raw materials such as lithium, manganese, and cobalt, with raw  
2391 materials and components largely imported. A shift is anticipated towards nickel-rich batteries or alternative  
2392 chemistries to reduce reliance on high-cobalt-content lithium-ion batteries (LIBs) due to the oligopoly  
2393 control of critical components in Asia.

2394 Electrolyzers for hydrogen production use a range of strategic raw materials, particularly from the  
2395 platinum group metals (PGMs), but also silicon metal, aluminium, copper, and magnesium, with the EU  
2396 facing challenges in sourcing these materials. For heat pumps, strategic raw materials needed include  
2397 magnesium and copper, but no significant bottlenecks have been identified, with most critical materials  
2398 used in microchips and IT controllers.

2399 Across all technologies analysed, a common pattern of heavy reliance on imports, particularly from  
2400 China, is observed at different stages of the value chains. The EU's primary sourcing and processing  
2401 capabilities for critical raw materials are notably low, creating dependencies at multiple levels. Despite  
2402 a strong manufacturing capacity for wind turbine assembly, the EU is entirely reliant on imports for the  
2403 value chain of rare-earth permanent magnets. Similarly, for solar PV, the dependence on imports is  
2404 comprehensive. The recent surge in Chinese manufacturing market share for heat pumps and the developing  
2405 value chain for batteries in the EU are also noteworthy.

2406 A breakdown of the materials required for each technology is given in Table 4.3.

Table 4.3: Raw materials essential to the renewable energy sector

| SUPPLY RISK | MATERIAL         | CRM | BATT | H2 | WIND | SOLAR (PV) | HEAT PUMPS |
|-------------|------------------|-----|------|----|------|------------|------------|
| 5.3         | HREE (rest)      | ●   |      | ●  |      |            |            |
| 4.8         | Gallium          | ●   |      |    |      | ●          |            |
| 4.4         | Niobium          | ●   |      | ●  | ●    |            |            |
| 4.1         | Magnesium        | ●   |      | ●  |      |            |            |
| 4.1         | REE (magnets)    | ●   |      | ●  | ●    |            | ●          |
| 3.8         | Boron            | ●   |      | ●  | ●    | ●          | ●          |
| 3.5         | LREE (rest)      | ●   |      | ●  |      |            |            |
| 3.3         | Phosphorus       | ●   | ●    |    |      | ●          |            |
| 2.7         | PGM              | ●   |      | ●  |      |            |            |
| 2.6         | Strontium        | ●   |      | ●  |      |            |            |
| 2.4         | Scandium         | ●   |      | ●  |      |            |            |
| 2.3         | Vanadium         | ●   |      | ●  |      |            |            |
| 1.9         | Lithium          | ●   | ●    |    |      |            |            |
| 1.8         | Geranium         | ●   | ●    |    |      | ●          |            |
| 1.8         | Natural graphite | ●   | ●    | ●  |      | ●          |            |
| 1.8         | Antimony         | ●   |      |    |      | ●          |            |
| 1.7         | Cobalt           | ●   | ●    | ●  |      |            |            |
| 1.6         | Arsenic          | ●   |      |    |      | ●          |            |
| 1.4         | Silicon metal    | ●   |      | ●  | ●    | ●          | ●          |
| 1.3         | Baryte           | ●   |      | ●  |      |            |            |
| 1.3         | Tantalum         | ●   |      | ●  |      |            |            |
| 1.2         | Manganese        | ●   | ●    | ●  |      |            | ●          |
| 1.2         | Tungsten         | ●   |      | ●  |      |            |            |
| 1.2         | Aluminium        | ●   | ●    | ●  | ●    | ●          | ●          |
| 1.1         | Fluorspar        | ●   | ●    | ●  |      | ●          | ●          |
| 0.9         | Tin              |     |      | ●  |      | ●          |            |
| 0.8         | Molybdenum       |     |      | ●  | ●    | ●          | ●          |
| 0.8         | Silver           |     |      | ●  |      | ●          | ●          |
| 0.8         | Zirconium        |     |      | ●  | ●    |            |            |
| 0.7         | Chromium         |     |      | ●  | ●    |            |            |
| 0.7         | Potash           |     |      | ●  | ●    |            | ●          |
| 0.6         | Indium           |     |      |    |      | ●          |            |
| 0.5         | Nickel           | ●   | ●    | ●  | ●    | ●          | ●          |
| 0.5         | Iron ore         |     | ●    | ●  | ●    | ●          | ●          |
| 0.5         | Titanium         |     |      | ●  |      |            |            |
| 0.4         | Gold             |     |      | ●  |      |            | ●          |
| 0.3         | Tellurium        |     |      | ●  |      | ●          |            |
| 0.3         | Limestone        |     |      |    |      |            |            |

Continued on next page

Table 4.3 – Continued from previous page

| SUPPLY RISK | MATERIAL   | CRM | BATT | H2 | WIND | SOLAR (PV) | HEAT PUMPS |
|-------------|------------|-----|------|----|------|------------|------------|
| 0.3         | Selenium   |     |      |    | ●    | ●          |            |
| 0.3         | Silica     |     |      |    | ●    | ●          |            |
| 0.2         | Cadmium    |     |      | ●  | ●    | ●          |            |
| 0.2         | Zinc       |     | ●    | ●  | ●    | ●          | ●          |
| 0.1         | Copper     | ●   | ●    | ●  | ●    | ●          |            |
| 0.1         | Aggregates |     |      |    | ●    |            |            |
| 0.1         | Lead       |     |      |    | ●    | ●          |            |

2407  
2408  
2409  
The integration of the energy transition has significant implications for the management of Critical Raw Materials (CRMs) across various waste streams due to changing material requirements and waste profiles [25, 43, 67, 46].

2410  
**For example:**

2411  
 **BATT (BATTERY WASTE)**

- 2412  
2413  
2414  
2415  
• Increased deployment of Li-ion batteries for energy storage will lead to a surge in waste batteries, necessitating improved recycling technologies to recover CRMs.  
• The transition to renewable energy sources may lead to changes in the battery composition, affecting recycling processes and the types of CRMs that need to be managed.

2416  
 **ELV (END-OF-LIFE VEHICLES)**

- 2417  
2418  
2419  
2420  
• The shift towards electric vehicles will transform the composition of ELVs, increasing the relevance of CRMs used in electric powertrains and batteries.  
• This transition requires the adaptation of ELV recycling infrastructure to efficiently process and recover new types of CRMs.

2421  
 **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

- 2422  
2423  
2424  
2425  
• As energy systems become more digitized and interconnected, WEEE will contain a broader array of CRMs, prompting the need for more sophisticated recycling methods.  
• The growing volume of WEEE will challenge current recycling capacity and technology, calling for significant innovation in CRM recovery techniques.

2426  
 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- 2427  
2428  
2429  
2430  
• Green building materials and energy-efficient technologies may introduce new CRMs into CDW, changing the material recovery landscape.  
• The promotion of deconstruction over demolition could preserve the integrity of materials containing CRMs, allowing for better recovery rates.

2431  
 **MIN (MINING WASTE)**

- 2432  
2433  
• The drive for clean energy technologies is expected to increase the mining of specific CRMs, potentially leading to higher volumes of mining waste that must be managed sustainably.

2434  
 **SLASH (SLAGS AND ASHES)**

- 2435  
2436  
• The energy transition could increase the generation of certain industrial wastes such as slags, which may contain valuable CRMs.

2437  
**Implementation in EU Law**

2438  
**FIT FOR 55 PACKAGE (2021)**

2439  
2440  
The "Fit for 55" package is a collection of policy initiatives proposed by the European Commission in July 2021 aimed at revising and updating EU legislation to reflect the increased ambition of reducing

net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels [16]. This target was a significant step up from the previous goal of a 40% reduction and is part of the European Union's plan to become climate-neutral by 2050 — an objective set out in the European Green Deal[3].

The package includes proposals to revise the EU Emissions Trading System (ETS), to increase the use of renewable energy, to improve energy efficiency, and to implement carbon pricing mechanisms, among other measures. The intention is to align existing laws with the 2030 climate target and to set the legal foundation for Europe's transition to a green economy. This includes changes across various sectors including transportation, building, and energy production to reduce emissions and promote sustainable practices.

## REPOWEU PLAN (2022)

The invasion of Ukraine by Russia has caused significant disruption to energy markets in Europe and globally. To eliminate reliance on an unreliable supplier, the European Commission has devised the REPowerEU plan [15]. This initiative focuses on energy conservation, the production of clean energy, and the diversification of energy sources, supported by financial and legal measures to develop Europe's necessary new energy infrastructure and systems.

**Accelerating Clean Energy** Renewable energy sources, being both cost-effective and environmentally friendly, can be produced locally, thereby reducing dependency on imported energy. The REPowerEU plan aims to expedite the green transition and trigger substantial investments in renewable energy. It also seeks to facilitate the rapid transition of industry and transport from fossil fuels, reducing both emissions and dependency.

This includes a variety of measures focused on renewable energy and energy efficiency, such as:

- Increasing the EU's 2030 renewable energy target of the 'Fit for 55 package' from 40% to 45%.
- Accelerating the deployment of photovoltaic (PV) energy.
- Introducing the European Solar Rooftop Initiative.
- Doubling the deployment rate of individual heat pumps.
- Decarbonising the industry by promoting electrification and renewable hydrogen.
- Speeding up renewable energy project and grid infrastructure permit processes.
- Increasing the EU's binding energy savings target for 2030 to 13%.

The May 2022 REPowerEU plan by the European Commission, in response to the energy market disruptions due to Russia's invasion of Ukraine, is designed to rapidly cut down on the EU's reliance on Russian fossil fuels. It raises the renewable energy target of the Fit for 55 package from 40% to 45%.

This ambitious goal for renewable energy use, coupled with REPowerEU's strategies to reduce energy demand, necessitates substantial increases in renewable capacity across the electricity, transport, and heating and cooling sectors. The Commission forecasts that to meet the 2030 objectives, renewable electricity should reach 69%, 32% in transport, and a yearly growth of at least 2.3 percentage points in heating and cooling.

## RENEWABLES ENERGY DIRECTIVE (2023)

The recent legislation strengthening the EU Renewable Energy Directive marks an advancement towards the European Green Deal and REPowerEU ambitions. With the provisional agreement, the EU's binding renewable energy target for 2030 is now at least 42.5%, aiming potentially to reach 45%. This target significantly surpasses the previous goal of 32% and is nearly double the present proportion of EU renewable

2482 energy.

2483 A distinct enhancement over the REPowerEU plan is the establishment of definitive binding targets for  
2484 renewable energy. The legislation optimises permitting procedures, acknowledges renewable energy as an  
2485 overriding public interest, and designates acceleration zones for expedited development in strategically  
2486 identified regions.

2487 The directive also introduces specific directives across various sectors:

- 2488
- 2489 • In heating and cooling, it sets forth progressive annual renewable targets and a 49% renew-  
able energy consumption benchmark in buildings by 2030.
  - 2490 • It for the first time includes the industrial sector under its ambit, establishing indicative and  
binding targets for the use of renewable energy and renewable hydrogen, respectively.
  - 2491 • For the transport sector, it specifies a reduction in greenhouse gas intensity and sets sub-  
targets for advanced biofuels and renewable fuels of non-biological origin, underpinning the  
2492 EU's renewable hydrogen objectives.
  - 2493 • It further enhances the "guarantees of origin" system to improve consumer information and  
2494 supports the integration of the energy system through electrification and waste heat capture.
- 2495

2496 In summary, the agreement accelerates the EU's strides towards energy autonomy, promises to reduce  
2497 energy costs over time, and decreases dependence on imported fossil fuels. It intensifies the EU's pledge  
2498 to a decarbonised economy and aligns with REPowerEU's broader goals but with specific, more ambitious  
2499 targets and refined processes for rapid renewable energy adoption.

2500 While the reinforced EU Renewable Energy Directive is a pivotal step towards the EU's "Fit for 55"  
2501 framework and the overarching European Green Deal goals, it has not been without its critics. The Directive's  
2502 ambitious targets for 2030 have spurred a range of responses from member states and institutions, with  
2503 concerns centered around feasibility, economic impact, and the varying capabilities of nations to meet  
2504 these objectives [17].

2505 The following is a summary of the key points raised by member states and the European Commission  
2506 in their statements on the directive [17]:

#### 2508 Belgium

2509 Belgium supports the directive while voicing "*serious concerns*" over the feasibility of increased  
2510 renewable energy targets, citing "*demographical and geographical limitations*" and the presence  
2511 of energy-intensive industries. The national contributions and sectoral sub-targets are deemed  
2512 "*extremely difficult to achieve*" and potentially "*unachievable*" within the proposed timeline.

#### 2513 Poland

2514 Poland boasts a rapidly growing renewable sector but cannot support the proposed directive, stating  
2515 it is unrealistic and could destabilize the energy grid and security. They assert that the targets lack  
2516 realism and flexibility, and stress that the energy transition should be "*accessible to society*" and in  
2517 favor of European industry.

#### 2518 Romania

2519 Romania is committed to decarbonisation but expresses concern that the high level of ambition  
2520 may lead to increased costs and discourage certain sectors, making them "*un-competitive*." They  
2521 highlight the importance of national specificities and energy mixes in setting targets and advocate  
2522 for technology neutrality.

#### 2523 Slovak Republic

2524 Slovakia finds the EU RES target for 2030 "*very ambitious*" and difficult, stressing that additional  
2525 contributions may not reflect the real potential for renewable development in the country. The  
2526 statement also points to concerns over hydrogen production support not being satisfactorily ad-  
2527 dressed.

**European Commission**

The Commission acknowledges the significant efforts required from Member States to meet the targets, noting the high adaptation costs for certain industries. It concedes that achieving the directive's objectives will involve significant public and private investment and national budget implications. The Commission emphasizes the need for complementary decarbonisation efforts involving other non-fossil energy sources.

***Challenges to the expansion of renewable energy in the EU***

In addition to the internal conflict among member states [17], a recent IEA analysis concluded that EU's renewable energy expansion is constrained by inadequate policy support, complex permitting, and grid upgrades' pace. [45]

Current forecasts indicate that the solar PV and wind capacity expansions fall short of the REPowerEU plan's renewable electricity targets for 2030. The European Commission Staff Working Document states that achieving a 69% share of renewable electricity requires 592 GW of solar PV and 510 GW of wind by 2030, translating to annual additions of 48 GW for solar PV and 36 GW for wind [47].

These figures significantly exceed the IEA's main case projections of 39 GW for solar PV and 17 GW for wind between 2022 and 2027, resulting in a renewable generation share of 54% in the electricity sector—15 percentage points below the desired 69% by 2030.

Therefore, to fulfill the necessary installed capacity for generating 69% of electricity from renewables by 2030, the annual net additions for solar PV need to increase by 22%, and for wind, more than double [159]. The EU estimates that the total amount required for these investments will exceed €360bn before 2030 [47].

**Policy Support:**

Uncertainty from infrequent auctions and limited visibility hampers utility-scale solar PV and distributed PV projects, with issues in current auction designs and support scheme extensions affecting growth and profitability.

**Permitting:**

A primary bottleneck due to complex regulations, land restrictions, social opposition, and permitting office inefficiencies increases costs and extends project lead times.

**Grid Congestion:**

Insufficient grid capacity and upgrade challenges caused by permitting hurdles, labour shortages, and opposition slow the integration of new renewable plants.

The IEA analysis states that improvements addressing these issues could boost solar and wind deployment by 30% by 2027. An accelerated case requires increased policy support, regulatory reforms, and quicker infrastructure development [159].

For utility-scale solar PV, competitive auctions must be introduced or extended, with revised auction designs to reflect current market conditions. Distributed PV could see growth with better support and remuneration for self-consumption.

Despite potential policy and regulatory advances, wind energy, particularly onshore, faces persistent permitting difficulties, and offshore wind is bogged down by grid connection delays.

Finally, market interventions and the energy crisis debate could influence renewable investments, stressing the need for careful reform processes involving all stakeholders to maintain investor confidence.

2569

## Incorporation of the energy transition into the FutuRaM scenarios

### REVIEW NOTICE

There will need to be a discussion about choice of energy scenario and the use of this data:

- (1) if it is to be used commercially, we will need a license from the IEA;
- (2) more detailed data is available for purchase
- (3) the choice of scenario and alignment with the WSs.

There are alternatives, such as the EU reference scenario [48] and the POTEnCIA central scenario, which is similar, although somewhat outdated [49]

2570

2571

2572 In light of the information presented above, as well as the nature of the three scenarios, FutuRaM will  
 2573 use a moderate growth scenario for the energy transition. The data for this is sourced from the projections  
 2574 of the International Energy Agency (IEA) using the "base case" of their "Stated Policies (STEP)" scenario [68].

2575 The IEA's World Energy Outlook 2023 presents a range of scenarios, including the Stated Policies (STEP)  
 2576 scenario, the Sustainable Development Scenario (SDS) — which is the IEA's pathway to achieving the Paris  
 2577 Agreement goals — and the Net Zero Emissions scenario. Full details of the scenarios are available in the  
 2578 documentation of the IEA's Global Energy and Climate (GEC) Model [160].

2579 A comparison of the IEA's projections for the renewable energy transition in the EU under the STEP and  
 2580 APS scenarios is presented in Table 4.4.

*Table 4.4: Normalized renewable energy supply in the EU using the year 2010 as a base reference*

| Year | Historical | Stated Policies | Announced Pledges |
|------|------------|-----------------|-------------------|
| 2010 | 1.00       | —               | —                 |
| 2021 | 1.66       | —               | —                 |
| 2022 | 1.66       | —               | —                 |
| 2030 | —          | 3.33            | 3.69              |
| 2050 | —          | 5.69            | 7.23              |

2581

A summary of the IEA's scenarios is presented in Table 4.5.

*Table 4.5: Definitions and Objectives of the GEC Model 2023 Scenarios*

|                    | Net Zero Emissions by 2050 Scenario  | Announced Pledges Scenario   | Sce-  | Stated Policies Scenario                                      |
|--------------------|--|--|---|---|
| <b>Definitions</b> | A pathway to achieve net zero CO2 emissions by 2050 within the energy sector, updated fully by 2030. Universal access to electricity and clean cooking achieved by 2030. | Assumes all climate policies in place or under development as of end of August 2023, including NDCs and net zero targets, August 2023 and planned 2023. Universal access to are met on time. | Reflects energy-related developments and limitations of the 1.5 °C global warming limit, current policies, highlighting CO2 emissions by 2050 showing the ambition gap and other sustainable development goals. | Universal access to capacities for clean energy technologies. |
| <b>Objectives</b>  | To detail sector-specific actions needed to achieve net zero energy-related CO2 emissions by 2050 and other sustainable development goals.                               | To assess how pledges align with the 1.5 °C global warming limit, current policies, highlighting the gap in implementation and the steps needed for universal energy access.                 | To benchmark the achievements and limitations of the 1.5 °C global warming limit, current policies, highlighting the gap in implementation and the steps needed for universal energy access.                    | To meet decarbonisation targets.                              |

2582

## THE STATED POLICIES SCENARIO (STEP)

2583      The Stated Policies Scenario (STEPS) is an energy model that offers a conservative projection based on  
2584      existing and developing energy policies, without assuming full achievement of governments' announced  
2585      goals. It undertakes a detailed, sector-by-sector assessment including a variety of factors such as pricing,  
2586      efficiency standards, and infrastructure projects as of the end of August 2023.

2587      Although it incorporates far-reaching governmental targets, such as net zero emissions and complete  
2588      energy access, these are not presumed to be fully implemented without evaluating the regulatory, financial,  
2589      and infrastructural context of each country.

2590      The STEPS assumes that current time-bound policies will be continued with similar measures but does  
2591      not speculate on the future intensification or reduction of policies unless there is evidence to suggest this.  
2592      For the first time in 2023, it also accounts for industry actions, such as the manufacturing capacities for  
2593      clean energy technologies and their market impact.

2594      Overall, the STEPS indicates that while existing commitments can make a substantial impact, there  
2595      remains a significant gap to reach the ambitions of the Announced Pledges Scenario or the Net Zero  
2596      Emissions by 2050 Scenario.

## 2597 THE FUTURE ENERGY MIX IN THE EU

2598 In a global sense, the energy transition manifests in FutuRaM's forecasts by way of the background  
 2599 energy mix. In Figure 4.8 is the IEA's projection of the energy mix in the EU for the Stated Policies scenario.  
 2600 Additional forecasts for rare earth elements (REEs) supply and demand related to wind energy and e-  
 2601 mobility are offered by the JRC [67].

## 2602 IMPACT OF THE ENERGY TRANSITION ON THE FUTURAM SCENARIOS

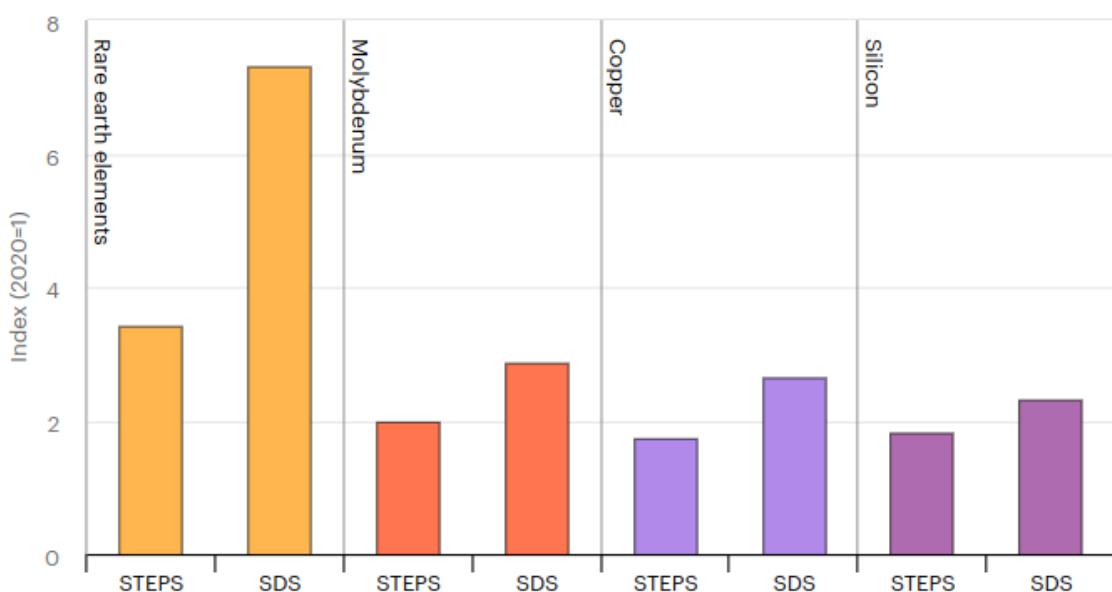
### REVIEW NOTICE

- Many more details to be added later once we have confirmed the scenario choice and the alignment with the WSs
- One advantage of the IEA data is that it is aligned with other data sets, such as CRM supply and demand forecasts
- The figures below are just an example of some of the impacts that we could portray here. Better figures will be generated later.

2603

2604

2605 The following figures illustrate some of the impacts that scenario choice can have on raw material  
 2606 demand forecasts [25]



2607 *Figure 4.9: Change in demand for selected elements*

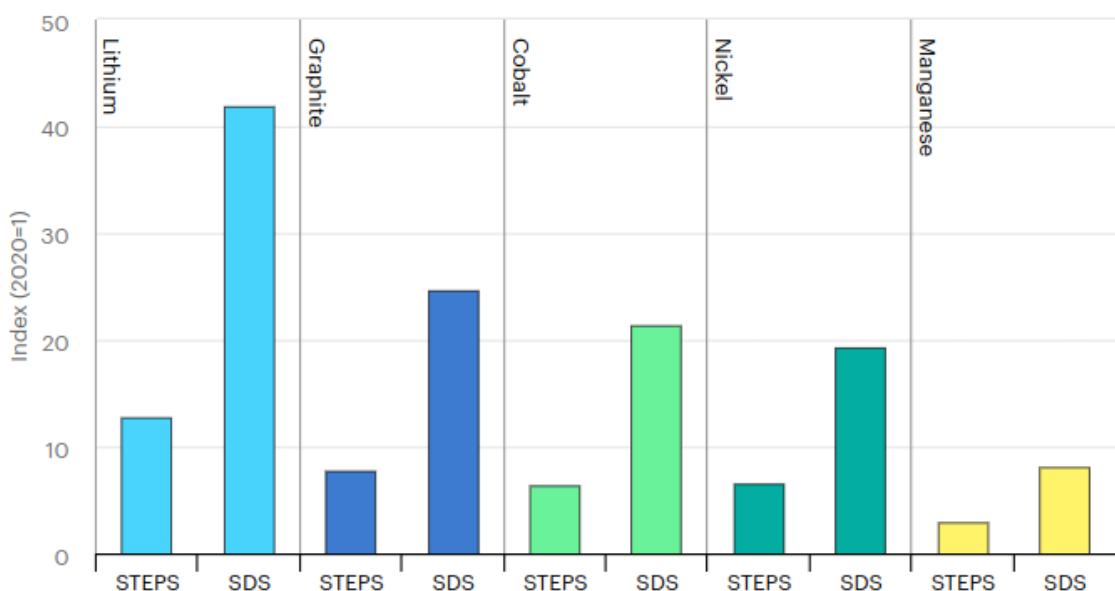


Figure 4.10: Change in demand for battery relevant elements

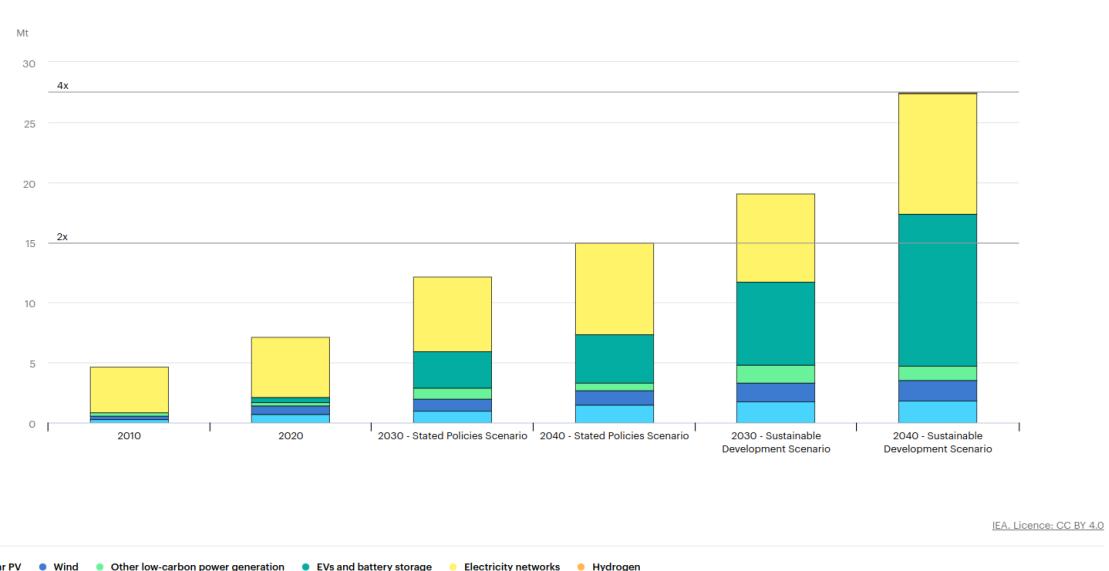


Figure 4.11: Global mineral demand (total) under various scenarios

2608  
2609

## ***Incorporation of the energy transition into individual waste stream models***

2610

### WASTE STREAM NOTICE

2611

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

2612

 **BATT (BATTERY WASTE)**

- 2613
- X

2614

 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- 2615
- X

2616

 **ELV (END-OF-LIFE VEHICLES)**

- 2617
- X

2618

 **MIN (MINING WASTE)**

- 2619
- X

2620

 **SLASH (SLAGS AND ASHES)**

- 2621
- X

2622

 **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

- 2623
- X

## 4.3.6. Supply constraints and market dynamics

### REVIEW NOTICE

The precise methodology to be applied to determine the effects of hypothetical supply constraints and market dynamics on the model's outcomes has not yet been determined. This will be developed once the precise structure of the model has been finalised.

### ***Introduction***

Supply constraints refer to limitations in the availability of resources that can impact industries and markets. These constraints can arise from various sources, such as natural resource depletion, geopolitical issues, economic factors, or environmental regulations. In the context of waste generation, collection, and recovery, supply constraints can significantly affect the dynamics of the entire system.

Market dynamics refer to the interactions between supply and demand that determine the prices of goods and services. These dynamics are influenced by various factors, such as the availability of resources, technological change, the state of the economy, and governmental policies.

Incorporating these economic factors into waste management models is essential to understand and predict the behavior of waste systems under different economic conditions. Accurate modeling can aid in making informed decisions regarding waste management policies and practices.

The following section details the importance of supply constraints and market dynamics and introduces the proposed strategy for incorporating these 'outside' elements in the modelling work in FutuRaM.

### ***Impacts of supply constraints and market dynamics***

#### **IMPACT ON WASTE GENERATION**

Constraints on the supply of materials can lead to alterations in waste composition. For instance, scarcity in a particular raw material can decrease the production and subsequent waste of products made from that material.

#### **IMPACT ON COLLECTION AND RECOVERY SYSTEMS**

The availability of resources dictates the priorities of waste collection and recovery systems. Material scarcity can shift the focus towards recycling, while abundance might lead to alternative materials being preferred.

#### **LAG TIMES TO RECOVERY**

The scarcity of materials can extend the time products remain in use before entering the waste stream, affecting the timing and efficiency of waste recovery systems.

## 2653 **Economic Factors Influencing Waste Management**

2654 Economic aspects like prices, subsidies, and taxation play a crucial role in waste management, especially in  
2655 the context of supply constraints.

### 2656 **INFLUENCE OF RAW MATERIAL PRICES**

2657 High prices for primary raw materials can incentivize the recycling of secondary materials. This economic  
2658 motivation can lead to advancements in recycling technology and increased recycling efforts.

### 2659 **SECONDARY RAW MATERIAL PRICING**

2660 The pricing of secondary raw materials, often influenced by the availability and price of primary materials,  
2661 affects their attractiveness for recycling. Competitive pricing of secondary materials can promote their use  
2662 over primary materials.

### 2663 **GOVERNMENTAL POLICIES: SUBSIDIES AND TAXATION**

2664 Policies involving subsidies for recycling activities or taxation on primary raw materials can shape the  
2665 waste management landscape. These fiscal tools can encourage or discourage recycling based on their  
2666 design and application.

### 2667 **MARKET DYNAMICS AND POLICY INTERVENTIONS**

2668 Market dynamics, influenced by policy interventions, can also impact waste management. For example,  
2669 a policy promoting the use of recycled materials can alter market preferences and boost recycling efforts.

## 2670 *Incorporation of supply constraints and market dynamics into the model*

### 2671 **SENSITIVITY ANALYSIS**

2672 Sensitivity analysis is an instrumental approach in modelling to ascertain the impact of supply constraints  
2673 and market dynamics on the waste management system. This technique involves systematically varying  
2674 parameters within the model and observing the resultant effects on the output. It is particularly beneficial  
2675 in identifying which variables have the most significant influence on the system's behaviour.

2676 Global Sensitivity Analysis, an extension of this concept, examines the entire parameter space, offering  
2677 a comprehensive view of potential model responses to changes in input factors. This method is crucial in  
2678 revealing the relative importance of different variables and can highlight areas where the system is most  
2679 susceptible to economic fluctuations.

2680 By utilising sensitivity analysis, decision-makers can better understand the robustness of their systems  
2681 and formulate strategies that are resilient to economic uncertainties.

**EXAMPLE****Impact of Raw Material Prices and Government Subsidies on Recovery System:****Scenario:**

The model tests scenarios with significant fluctuations in raw material prices. In certain scenarios, a government subsidy is introduced to set a minimum price for recycled materials, ensuring their economic viability.

**Analysis:**

Sensitivity analysis evaluates the effect of raw material price changes on the profitability and viability of the recovery system. It also tests the impact of government subsidies in stabilising the system against these fluctuations.

**Outcome:**

This analysis can reveal the dependency of recovery operations on raw material market prices and the effectiveness of government subsidies in mitigating associated risks.

2682

2683

**EXAMPLE****Reduction of a Valuable Material in the Waste Stream:****Scenario:**

The model explores a situation where a previously abundant and valuable material becomes scarce in the waste stream.

**Analysis:**

This sensitivity analysis investigates the impact of reduced availability of this valuable material on the overall profitability of the waste management system.

**Outcome:**

It identifies critical thresholds where a reduction in material significantly affects the system's financial viability, guiding strategies for diversifying material recovery or exploring alternative revenue sources.

2684

2685

2686

**OPTIMISATION**

Optimisation techniques are employed to identify the most efficient operational settings for the waste management system under diverse economic conditions. By modelling various local scenarios that encapsulate different economic realities — such as varying levels of resource scarcity, price dynamics of primary versus secondary materials, and the impact of subsidies or taxes — the model aims to find the optimal balance. This balance could be in terms of cost-effectiveness, resource utilization, environmental impact, or a combination of these factors. Optimization provides a framework to make data-driven decisions that can enhance the efficiency and sustainability of the waste management system.

Multi-Objective Optimisation is a key aspect of this process, where multiple conflicting objectives are considered simultaneously. This approach is essential in waste management systems, where there is often a need to balance economic goals with environmental sustainability.

By employing optimisation techniques, particularly Multi-Objective Optimisation, the model can provide insights into the trade-offs and synergies between different objectives, thereby facilitating more informed and balanced decision-making in waste management policies and operations.

**EXAMPLE****Responding to Sudden Demand Increase for a Previously Less Valuable Material (Element X):****Scenario:**

The model simulates a sudden increase in demand and price for a specific material (Element X) that was previously less valuable.

**Analysis:**

The system's response is optimized to maximise profitability under this new market condition, involving adjustments in collection and processing priorities towards Element X.

**Outcome:**

The optimisation indicates the most effective strategies for reallocating resources and operations to capitalise on the increased demand for Element X, enhancing profitability.

2700

2701

**EXAMPLE****Optimizing for Environmental and Economic Goals amid Rising Carbon Emission Costs:****Scenario:**

The model considers a significant increase in the cost of carbon emissions, impacting the expense of recovery operations.

**Analysis:**

The optimisation aims to balance environmental impact (carbon footprint) with economic viability, exploring operational adjustments like adopting more carbon-efficient recovery processes or prioritising materials with higher primary carbon footprints (offsets and substitution).

**Outcome:**

This approach yields insights into effective strategies for maintaining profitability while minimising environmental impact, aiding the system in achieving a dual bottom line of environmental sustainability and financial health.

2702

2703

2704

2705  
2706

## **Relevance of supply constraints and market dynamics for FutuRaM's waste streams**

2707

### **BATT (BATTERY WASTE)**

- 2708  
2709
- Fluctuating availability and prices of lithium and cobalt can significantly impact the recycling value and processes for batteries.
  - Governmental policies on battery disposal and recycling can alter the landscape of battery waste management, influencing recycling rates and methodologies.
- 2710  
2711

2712

### **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- 2713  
2714
- Variations in the construction market and raw material prices can influence the generation and composition of construction and demolition waste.
  - Economic incentives and regulatory frameworks for sustainable construction practices can drive the recycling and reuse rates of CDW.
- 2715  
2716

2717

### **ELV (END-OF-LIFE VEHICLES)**

- 2718  
2719
- Changes in the metal market, particularly for steel and aluminium, can impact the profitability of recycling ELVs.
  - Environmental regulations on vehicle disposal and recycling can shape the recovery strategies for ELV waste.
- 2720  
2721

2722

### **MIN (MINING WASTE)**

- 2723  
2724
- Market demand for specific minerals can influence the focus and intensity of recovery efforts from mining residues.
  - Policy changes regarding mine waste management can lead to shifts in recovery and disposal practices for mining residues.
- 2725  
2726

2727

### **SLASH (SLAGS AND ASHES)**

- 2728  
2729
- The variability in the composition of slags and ashes due to different industrial processes and raw materials can significantly influence recovery and recycling strategies.
  - Market conditions for secondary raw materials derived from slags and ashes, such as metals, can greatly affect the economic viability of their recovery and recycling processes.
- 2730  
2731

2732

### **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

- 2733
- Fluctuations in precious metal prices can affect the economics of recycling electronic waste.
  - Evolving technology and product lifecycles can influence the generation and composition of WEEE, affecting recycling strategies.
- 2734
- 2735
- 
- 2736

2737  
2738

**Incorporation of supply constraints and market dynamics into individual waste stream models**

2739  
2740

**WASTE STREAM NOTICE**

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

2741

 **BATT (BATTERY WASTE)**

- 2742
- X

2743

 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- 2744
- X

2745

 **ELV (END-OF-LIFE VEHICLES)**

- 2746
- X

2747

 **MIN (MINING WASTE)**

- 2748
- X

2749

 **SLASH (SLAGS AND ASHES)**

- 2750
- X

2751

 **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

- 2752
- X

2753

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## 4.3.7. Conclusion

### REVIEW NOTICE

This conclusion will be compiled once the individual waste stream sections for each parameter are complete.

2754

2755

2756

## 4.4. INTERNAL ELEMENTS — TECHNOLOGICAL CHANGE

### 4.4.1. Introduction

| Technological Change |  |
|----------------------|--|
| 2757                 | <b>Scenario elements</b> <ul style="list-style-type: none"> <li>• Product technology (composition)</li> <li>• Recovery technology</li> <li>• Recovery system development</li> </ul>  |
| 2758                 | <b>Waste model parameters include:</b> <ul style="list-style-type: none"> <li>• <b>Lifetimes:</b><br/>function of product technology</li> <li>• <b>Composition:</b><br/>function of product composition, durability, design-for-repair, etc.</li> </ul>  |
| 2759                 | <b>Recovery model parameters include:</b> <ul style="list-style-type: none"> <li>• <b>Recovery processes:</b><br/>market penetration of recovery technologies</li> <li>• <b>Transfer coefficients:</b><br/>function of recovery technologies</li> <li>• <b>Recovery system size:</b><br/>BAU - set by trends in BAU, CIR &amp; REC - defined by model outcomes within constraints</li> </ul> |
| 2760                 |  |
| 2761                 | Product technology and recovery technology development will differ across scenarios and across product groups in each waste stream. These differences must be integrated into individual stock-flow models through interpretations of the scenarios and the conversion of these into estimations of the changes.   |
| 2762                 |  |
| 2763                 |  |
| 2764                 | recognising the need for assumptions about technological advancements in products and recovery processes. The document stresses the importance of addressing product technology development until 2050, as this will vary in importance across different waste streams.  |
| 2765                 |  |
| 2766                 |  |
| 2767                 | <h3>4.4.2. Methodology</h3>  |
| 2768                 | <b>1. Scenario Analysis:</b>   |
| 2769                 | Different future scenarios are explored to understand how technological development might unfold.  |
| 2770                 | This includes examining existing and new technologies, their properties over time, and how they are diffused into the market.  |
| 2771                 |  |
| 2772                 | <b>2. Waste Stream Focus:</b>  |
| 2773                 | The approach varies in importance across different waste streams like EEE, ELV, BATT, CDW, and SLASH. For each stream, specific assumptions and approaches need to be tailored.  |
| 2774                 |  |
| 2775                 | <b>3. Data Collection:</b>   |
| 2776                 | Gathering data from various sources, including patents, scientific publications, business reports, and expert opinions, to inform assumptions about technology development.  |
| 2777                 |  |
| 2778                 | <b>4. Modelling Approach:</b>  |
| 2779                 | Utilizing dynamic Material Flow Analysis (dMFA) for modelling, covering a timeline from 2000 to  |

2780 2050. This includes historical data analysis and future projections based on assumptions.

2781 **5. Technology Diffusion:**

2782 Understanding the rate and manner in which technologies gain market share, depicted through  
2783 S-curves. This involves considering factors like price, legislation, and organizational support.

2784 **6. Assumptions on Technology Development:**

2785 Outlining specific assumptions at the level of each waste stream and aligning these assumptions  
2786 across streams where possible.

2787 **7. Integration into SF Models:**

2788 Incorporating the assumptions about product and recovery technology development into SF models  
2789 to reflect the scenario-based variations.

2790 **8. Transparency and Communication:**

2791 Ensuring that the chosen approaches and assumptions are clearly stated for transparency and ease  
2792 of understanding.

2793 The methodology is designed to provide a comprehensive understanding of how future technology  
2794 developments can impact various aspects of waste management and resource recovery in a circular  
2795 economy context.

### 4.4.3. Summary

#### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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## 4.4.4. Future product and waste composition: *Description*

Future compositions, technologies and products will be assessed based on technology outlooks and stakeholder interviews and may include sector-specific Delphi surveys. Information needs and availability for composition data as well as the type of relevant recoverable embodied SRMs varies across the waste streams. Thus, specific data collection strategies will be developed and used for each waste stream.

### Task 2.2 and 2.3

Following the scenarios from T2.1, the material compositions and future products for each sector will be determined based on the product and commodity demand and technology realisation (T2.2). This task will be coupled to the data collection in WP3 and WP4

### Definition

#### SCENARIO TRENDS FOR: Future product and waste composition



##### Scenario I – Business-as-usual:

Stable



##### Scenario II – Recovery:

Strong shift toward design for recycling, remanufacturing, recovery



##### Scenario III – Circularity:

Strong shift toward durability and design for re-X, especially re-use, repair

### Method

The general method for determining future product and waste composition will be based on the following steps:

- **Step 1:** Collection of data on current product and waste composition (WP3)
- **Step 2:** Grouping of code lists into broader categories (WP3)
- **Step 3:** Identification of future products based on technology outlooks, literature review, and stakeholder interviews
- **Step 4:** Estimation of constraints for market entry, replacement, and market share of future products (WP2) in each scenario
- **Step 5:** Modelling of future product and waste composition based on the results of steps 1-4

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2820

## **Relevance of future product and waste composition to Critical Raw Materials in Waste Streams**

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The integration of future product and waste composition has implications for the management of Critical Raw Materials (CRMs) across various waste streams, such as BATT (waste batteries), ELV (end-of-life vehicles), WEEE (waste electrical and electronic equipment), and CDW (construction and demolition waste).

2824

### **BATTERIES (BATT)**

2825

•

2826

### **END-OF-LIFE VEHICLES (ELV)**

2827

•

2828

### **WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)**

2829

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### **CONSTRUCTION AND DEMOLITION WASTE (CDW)**

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## 4.4.5. Future product and waste composition: *Scenarios*

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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### **Summary**

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

2840

X

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**BATT (BATTERY WASTE)**

2842

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2843

**ELV (END-OF-LIFE VEHICLES)**

2844

**MIN (MINING WASTE)**

2845

**SLASH (SLAGS AND ASHES)**

2846

**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Scenario II: Recovery

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X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

2853



**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

2856





### Scenario III: Circularity

2858

X

2859

**BATT (BATTERY WASTE)**

2860

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2861

**ELV (END-OF-LIFE VEHICLES)**

2862

**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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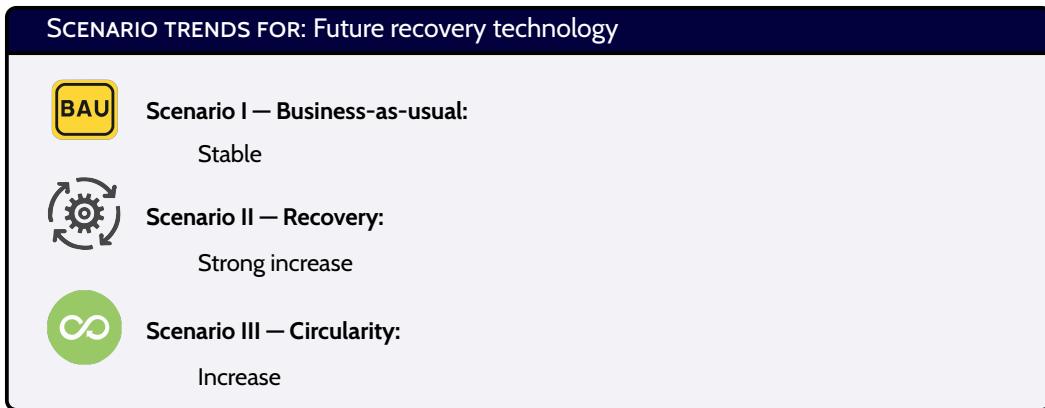
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## 4.4.6. Future recovery technology: Description

### Definition

This task will review current and emerging technologies used in the various sectors for product manufacturing and end-of-life handling, with a special emphasis on material production, use, and recycling. Together with the storylines developed in Task 2.1, it will adapt the market share of these technologies for each sector to determine the future development of each sector.



### Context

Resource efficiency hinges on the effective integration and optimisation of product lifecycles, end-of-life (EOL) processing, the quality of recycled materials, recycling practices, and metallurgical technologies. The extent to which materials are diverted from landfills—owing to their complex make-up precluding economic recovery—is a key measure of this efficiency [115]. Landfills, often the result of creating recyclates lacking economic viability, signify lapses in material management. While the second law of thermodynamics sets recyclability boundaries, these inefficiencies are frequently the consequence of preventable errors such as substandard product design, inefficient collection systems, and lack of process refinement.

To perpetuate resource availability and facilitate the flow of materials into sustainable products, it is imperative to establish well-conceived systems that reclaim these resources from EOL items and repurpose them. Grasping the influence of product design and the efficacy of recycling systems on closing material loops necessitates holistic methodologies that align with fundamental tenets, as delineated in this article.

To shape policy and engineer resource supply and recycling infrastructures, one requires an in-depth comprehension of recycling and high-temperature processing technologies, alongside insights into product design impacts and potential shifts in products and consumer behaviours. The formulation of a resilient system design is critical to amplifying resource efficiency—for instance, by minimising reliance on landfills—while also guaranteeing a consistent supply of metals for products within the renewable energy domain and other sectors pivotal to sustainability.

Resource efficiency is ultimately gauged by the proficiency in interlinking products, EOL processing, quality of recyclates, recycling, and metallurgical technology, and thereby determining how much material ends up in landfill due to its complex composition that negates economic value. Instances of poor material stewardship leading to landfills are attributed to the inability to generate economically feasible recyclates. While the second law of thermodynamics dictates the limitations of recyclability, such shortcomings are also attributable to avoidable blunders such as inadequate product design, collection systems, and process optimisation.

## Method

The general method for determining future recovery technology will be based on the following steps:

- **Step 1:** Collection of data on current recovery technology (WP4)
- **Step 2:** Identification of future recovery technology based on technology outlooks, literature review, and stakeholder interviews
- **Step 3:** Estimation of constraints for process data, market entry, replacement, and market share of future recovery technology in each scenario
- **Step 4:** Modelling of future recovery technology based on the results of steps 1–4

## **Relevance of future recovery technology to Critical Raw Materials in Waste Streams**

The integration of the future recovery technology has implications for the management of Critical Raw Materials (CRMs) across various waste streams, such as BATT (waste batteries), ELV (end-of-life vehicles), WEEE (waste electrical and electronic equipment), and CDW (construction and demolition waste).



### **BATT (Battery waste)**

•



### **ELV (End-of-Life Vehicles)**

•



### **WEEE (Waste Electrical and Electronic Equipment)**

•



### **CDW (Construction and Demolition Waste)**

•



### **MIN (Mining Waste)**

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### **SLASH (Slags and Ashes)**

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## 4.4.7. Future recovery technology: Scenarios

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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## Summary

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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**Scenario I: Business-as-usual**

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X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

2942

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## Scenario II: Recovery

2943

X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

2947

**MIN (MINING WASTE)**

2948

**SLASH (SLAGS AND ASHES)**

2949

**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### **Scenario III: Circularity**

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X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2955

**ELV (END-OF-LIFE VEHICLES)**

2956

**MIN (MINING WASTE)**

2957

**SLASH (SLAGS AND ASHES)**

2958

**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Conclusion

### REVIEW NOTICE

This conclusion will be compiled once the individual waste stream sections for each parameter are complete.

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## 4.5. INTERNAL ELEMENTS — THE CIRCULAR ECONOMY

### 4.5.1. Introduction

**Main sources:** [87, 11, 50, 116, 18, 117, 51, 118, 75, 52, 119]

| Circular Strategies   |
|---|
| <b>Scenario elements</b>  |
| <ul style="list-style-type: none"> <li>• <b>RO-2:</b><br/>Refuse, Reduce, Reuse (including 'sharing economy')</li> <li>• <b>R3:</b><br/>Repair</li> <li>• <b>R4-5:</b><br/>Refurbish and Remanufacture</li> </ul>   |
| <b>Waste model parameters include:</b>  |
| <ul style="list-style-type: none"> <li>• <b>Put-on-market:</b><br/>function of consumer behaviour (internal)</li> <li>• <b>Lifetimes:</b><br/>function of repair rate, durability, design-for-repair</li> <li>• <b>Waste composition:</b><br/>function of product composition, durability (weight), design-for-repair, etc.</li> <li>• <b>Collection rate:</b><br/>function of consumer engagement in re-X strategies, collection infrastructure, legislation, export rate</li> </ul> |
| <b>Recovery model parameters include:</b>   |
| <ul style="list-style-type: none"> <li>• <b>Transfer coefficients:</b><br/>function of design-for-(re-X) strategies, recovery technology (internal)</li> <li>• <b>Recovery system size:</b><br/>function of collection rate</li> </ul>  |

### The Circular Economy and its re-X strategies

The re-X strategies underpin the circular economy, embodying a range of actions and approaches. These strategies are conceptualised in various ways, depending on the focus and perspective of different authors. The description that follows is based on the framework provided by [119], with a detailed mapping of these strategies illustrated in Figure 4.12.

#### RO: Refuse

— This concept is applied both in consumer and producer contexts. For consumers, it means choosing not to buy or use products or services that are not needed or are unsustainable, thereby preventing waste creation. For producers, it involves refusing the use of specific hazardous materials and designing production processes to avoid waste. This approach is integral to shifting towards a more post-material lifestyle and reducing packaging waste.

#### R1: Reduce

— Reduce is used in a consumer-oriented, producer-oriented, and generic sense. It encompasses using products less frequently, with more care, and for longer, and making repairs for life extension.

2986 For producers, it involves using less material per unit of production, a concept known as dematerialization. It also includes participation in the sharing economy through pooling and sharing  
2987 products.  
2988

2989 **R2: Resell/Reuse**

2990 — Resell and Reuse involve bringing products back into the economy after initial use, either by  
2991 reselling or reusing them for the same or a different purpose. This concept includes direct reuse of  
2992 products such as second-hand sales and reuse in fabrication like refurbishment and remanufacturing.  
2993 Quality inspections, minor repairs, and online consumer-to-consumer auctions are part of this  
2994 strategy.

2995 **R3: Repair**

2996 — Repair aims to extend the product's lifespan by bringing it back to working order, fixing minor  
2997 defects, or replacing broken parts. It can be performed by various actors, including the customer,  
2998 repair companies, or through non-commercial peer-to-peer repair workshops. Planned repairs and  
2999 ad-hoc repairs are both included under this concept.

3000 **R4: Refurbish**

3001 — Refurbishing typically applies to large multi-component products where many components are  
3002 replaced or repaired, resulting in an overall upgrade of the product. This process brings the product up  
3003 to a state-of-the-art level using newer, more advanced components, and is often seen in industries  
3004 like aviation and construction.

3005 **R5: Remanufacture**

3006 — Remanufacture involves disassembling, checking, cleaning, and replacing or repairing the full  
3007 structure of a product in an industrial process. It is distinguished from refurbishing by the extent of  
3008 disassembly and replacement of components, often resulting in a product that is like new but with a  
3009 shorter expected lifespan due to the use of recycled components.

3010 **R6: Repurpose**

3011 — Repurposing involves adapting discarded goods or components for another function, giving  
3012 the material a distinct new lifecycle. This can result in both low and high-value end-products  
3013 and is popular in industrial design and art communities. Examples include transforming defective  
3014 microchips into jewellery or plastic sheeting into handbags.

3015 **END OF CIRCULAR STRATEGIES**

3016 — The following strategies belong to the recovery system

3017 **R7: Recycle Materials**

3018 — Recycling involves processing mixed streams of post-consumer products or post-producer waste  
3019 streams using technological equipment to capture pure materials. It usually results in secondary  
3020 materials that do not maintain any of the original product structure and can be re-applied anywhere.  
3021 Recycling typically requires high energy inputs for collection and re-processing.

3022 **R8: Recover (energy)**

3023 — Recovery primarily refers to capturing energy embodied in waste, linking it to incineration combined  
3024 with producing energy, or the use of biomass. It is also used to describe the collection of used products  
3025 for disassembly, sorting, and cleaning for utilization, and the extraction of elements or materials  
3026 from end-of-life composites.

3027 **R9: Re-mine**

3028 — Re-mining involves the retrieval of materials after the landfilling phase, including extracting  
3029 valuable parts from disposed products and mining valuable resources stored in old landfills or urban  
3030 mining. This practice is becoming more lucrative with technological advancements, allowing for the  
3031 effective extraction of resources from waste stock.

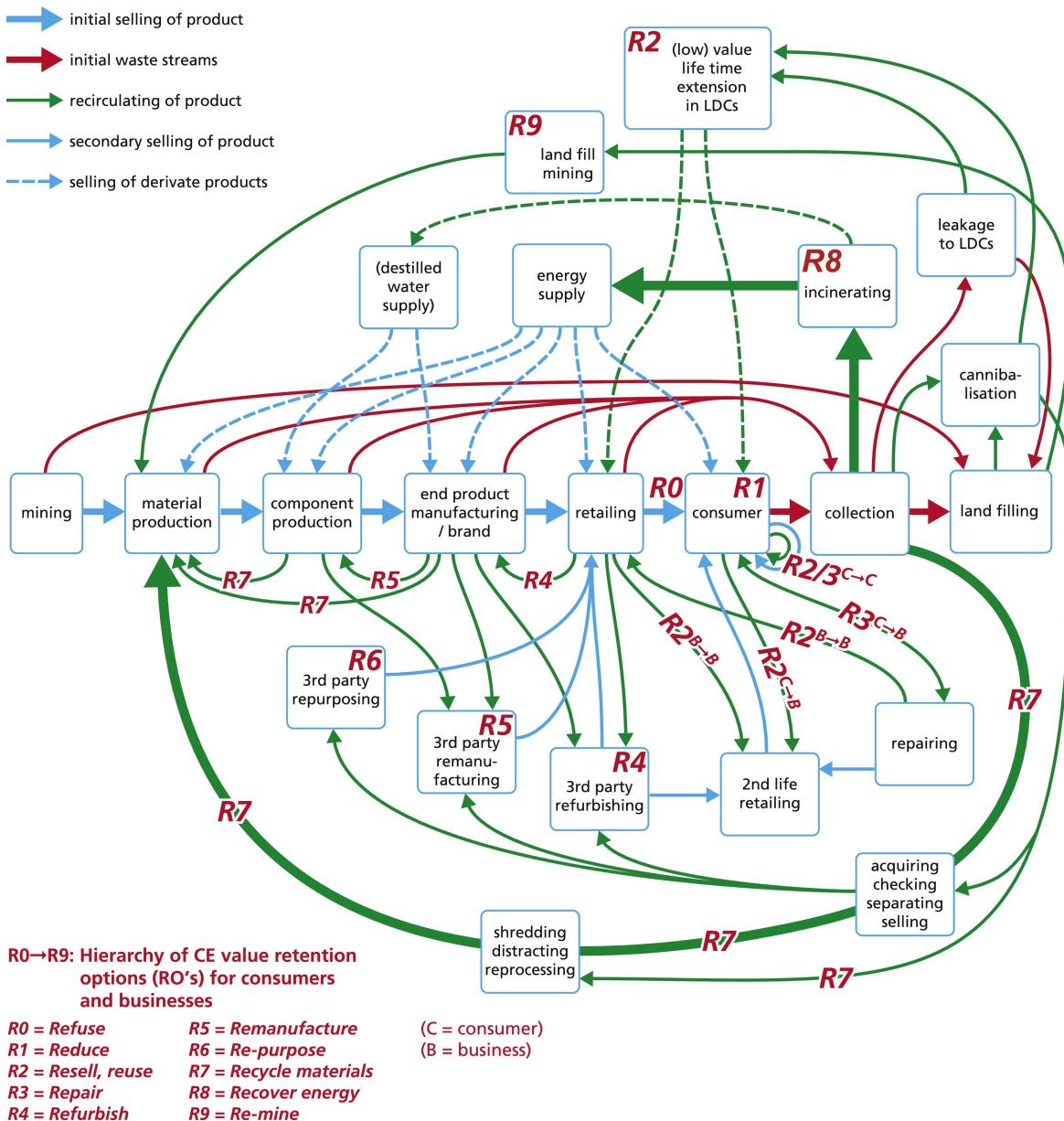


Figure 4.12: A detailed mapping of the re-X strategies in the circular economy [119]

### EU CIRCULAR ECONOMY INDICATORS (CEIs)

See the EU working documents [18] and [19] for more detailed assessment of progress relating to the CEIs. Table 4.6 presents an overview of the EU's CEIs including their target for 2023.

Table 4.7 lists the relevant EU circular indicators (CEIs) along with their significance for FutuRaM's models and their changes between 2000–2022.

| <b>Indicator</b>  | <b>Sub-indicators</b>   | <b>2030 target or direction for improvement</b>   |
|---|---|---|
| <b>Production and consumption</b>                           |   |   |
| 1 Material consumption                                      | 1a Material footprint<br>1b Resource productivity   | Reduce<br>Increase – decoupling   |
| 2 Green public procurement                                  |   |   |
| 3 Waste generation  | 3a Total waste generation per capita<br>3b Total waste generation (excluding major mineral waste) per GDP<br>3c Generation of municipal waste per capita<br>3d Food waste<br>3e Generation of packaging waste per capita<br>3f Generation of plastic packaging waste per capita | Significantly reduce total waste generation<br><br>Halve the amount of residual (non-recycled) municipal waste<br><br>Reduce (target proposal by 2023)<br><br>Reduce by 5% compared to 2018<br><br>Reduce |
| <b>Waste management</b>                                     |   |   |
| 4 Overall recycling rates                                   | 4a Recycling rate for municipal waste<br>4b Recycling rate for all waste excluding major mineral waste  | 60%   |
| 5 Recycling rates for specific waste streams                | 5a Recycling rate for overall packaging waste<br>5b Recycling rate for plastic packaging waste<br>5c Recycling rate for electrical and electronic equipment waste that is separately collected  | 70%<br><br>55%  |
| <b>Secondary raw materials</b>                              |   |   |
| 6 Contribution of recycled materials to raw-material demand | 6a Circular material-use rate<br>6b End-of-life recycling input rates   | Double  |
| 7 Trade in recyclable raw materials                         | 7a Imports from outside the EU<br>7b Exports to outside the EU<br>7c Intra-EU trade   |   |
| <b>Competitiveness and innovation</b>                       |   |   |
| 8 Private investments, jobs and gross value added*          | 8a Private investments<br>8b Employment<br>8c Gross value added   | Increase  |
| 9 Innovation  | 9 Patents related to waste management and recycling   | Increase  |
| <b>Global sustainability and resilience</b>                 |   |   |
| 10 Global sustainability from circular economy              | 10a Consumption footprint<br>10b GHG emissions from production activities   | Reduce to remain within the PB**<br><br>Reduce  |
| 11 Resilience from circular economy                         | 11a Material import dependency<br>11b EU self-sufficiency for raw materials   | Decrease<br><br>Increase  |

Notes: \* in circular-economy sectors. \*\* PB: Planetary boundaries for all impact categories

Table 4.6: EU Circular Economy Indicators (CEIs) and their targets for 2023 [19]

Table 4.7: EU circular indicators (CEIs) and their significance for FutuRaM's models

| CODE           | TITLE  | WS MODEL RELEVANCE                              | RECOVERY MODEL RELEVANCE | RATIO<br>2022:2000 |
|----------------|--|---|--------------------------|--------------------|
| CEI_CIE011     | Persons employed in circular economy sectors   | Product technology, lifetimes, collection rates | Capacity                 | 1.28               |
| CEI_CIE012-GVA | Gross added value related to circular economy sectors                                      | Product technology, lifetimes, collection rates | Capacity                 | 1.4                |
| CEI_CIE012-INV | Private investment related to circular economy sectors                                     | Product technology, lifetimes                   | Process technology       | 0.8                |
| CEI_CIE020     | Patents related to recycling and secondary raw materials                                   | Product technology, lifetimes                   | Process technology       | 0.8                |
| CEI_PCO20      | Material footprint   | Demand  | Efficiency               | 0.89               |
| CEI_PCO30      | Resource productivity  | Demand  | Capacity                 | 1.38               |
| CEI_PCO31      | Generation of municipal waste per capita   | Waste generation                                | Capacity                 | 1.03               |
| CEI_PCO32      | Generation of waste excluding major mineral wastes per GDP unit                            | Waste generation                                | Capacity                 | 0.86               |
| CEI_PCO34      | Waste generation per capita  | Waste generation                                | Capacity                 | 0.93               |
| CEI_SRM030     | Circular material use rate   | Collection rates                                | Capacity                 | 1.41               |
| CEI_WMO10      | Recycling rate of all waste excluding major mineral waste                                  | Collection rates                                | Capacity                 | 1.09               |
| CEI_WMO11      | Recycling rate of municipal waste  | Collection rates                                | Efficiency               | 1.78               |
| CEI_WMO60      | Recycling rate of waste of electrical and electronic equipment (WEEE) separately collected | Collection rates                                | Efficiency               | 0.99               |

3037      Figure 4.13 depicts the CEIs, their trends from 2000-2022, and their linear forecasts until 2050. An  
3038      interactive figure can be viewed here [🔗](#). Note that the linear trends are not deemed to be representative of  
3039      the actual future values, but are used to illustrate the trends and the magnitude of the changes. There will  
3040      be constraints defined to limit and shape the growth of the CEIs in each of the scenarios. The settings for  
3041      this will be determined from the waste stream quantification and the scenario storylines.

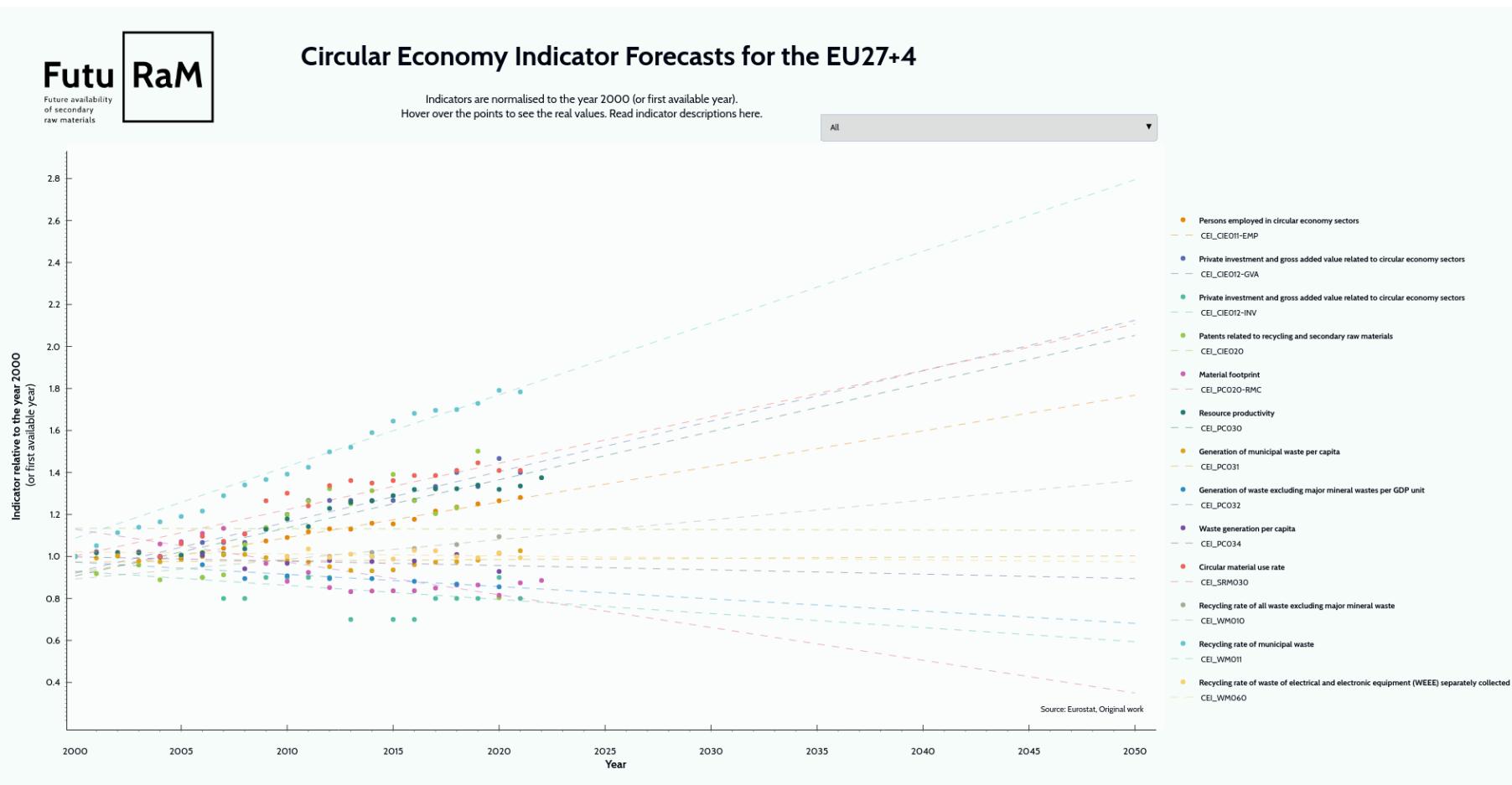


Figure 4.13: EU Circular Economy Indicators (CEIs) - trends from 2000-2022 and linear forecasts



## 4.5.2. Summary

The environmental and socio-economic impacts of raw material use are most effectively addressed at the product group level. Examining a product group as a whole, rather than focusing on individual resources or materials, allows for a comprehensive understanding and management of its utilisation and the environmental impacts across the production chain and product lifecycle [52].

Additionally, setting impact targets for product groups aligns more closely with the capacity of stakeholders within the chain to modify resource usage or mitigate related environmental impacts.

Although the nature and magnitude of raw material use impacts can differ significantly among product groups, necessitating tailored impact targets, there is also a need for simplicity in target setting. A manageable and communicable approach for governments is to aim for a significant reduction, such as halving the environmental impact at the product group level.

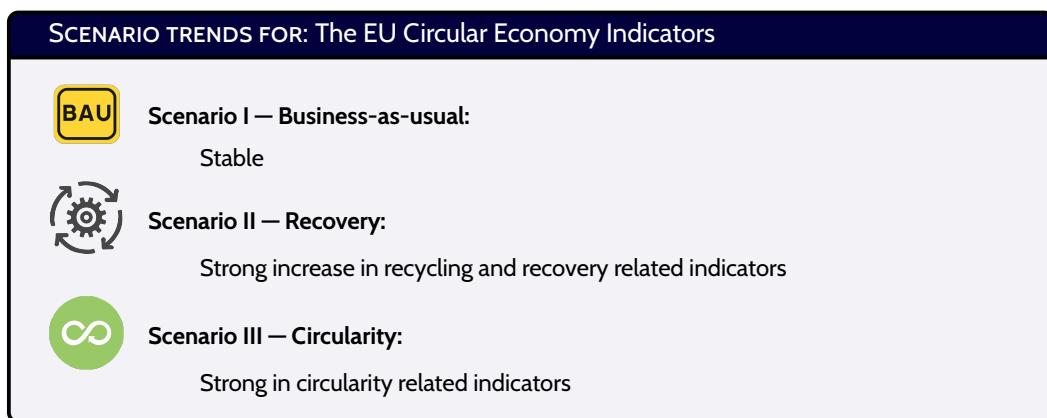
The benefit of establishing more general effect targets lies in the flexibility it offers for varying focuses across different product groups. A target set at the product group level is not only clear and easily communicable but also acknowledges the complexity and diversity inherent in a circular economy.

### REVIEW NOTICE

This section will be completed once the individual waste stream sections for each parameter are complete.

### 4.5.3. The EU Circular Economy Indicators: Description

3059  
3060 Main sources: [18, 19, 69]



#### Economic Indicators

3063  
3064 CEI\_CIE011:

3065 PERSONS EMPLOYED IN CIRCULAR ECONOMY SECTORS &

3066 CEI\_CIE012:

3067 PRIVATE INVESTMENT AND GROSS ADDED VALUE RELATED TO CIRCULAR ECONOMY SEC-  
3068 TORS

3069 Indicator metadata: ↗

##### 3070 Context:

3071 Targets economic activities that contribute to the circular economy, delineating those activities through  
3072 established environmental policy frameworks and classifications.

##### 3073 Indicator Description:

3074 The indicator encompasses “Private investments”, “Persons employed” and “Gross value added”. Eurostat  
3075 has developed a method to derive these key economic variables, incorporating a multi-step approach:  
3076 establishing a conceptual framework based on international environmental policy definitions, mapping  
3077 and classifying relevant activities against an integrated system of economic classifications (using NACE,  
3078 CPA, and PRODCOM codes), and finally compiling data using defined estimation procedures. The primary  
3079 outputs of this process are the measurements of employment in FTE, gross value added at factor cost, and  
3080 investments in tangible goods, each quantified in million euros.

##### 3081 Unit:

3082 Economic metrics are presented in million euros, with employment figures given in full-time equivalents  
3083 (FTE); both sets of figures are also contextualised as percentages of GDP and total employment, respectively.

##### 3084 Source Data:

3085 Data is sourced from a combination of Structural Business Statistics, National Accounts, Prodcom  
3086 surveys, and the Labour Force Survey, enriched by additional sector-specific statistics.

#### 3087 CEI\_CIE020: PATENTS RELATED TO RECYCLING AND SECONDARY RAW MATERIALS

**Indicator metadata:** ↗**Context:**

This indicator is integral to the Circular Economy set, focusing on 'competitiveness and innovation' and serving to gauge progress towards a more circular economy.

**Indicator Description:**

The indicator enumerates the number of patent families pertinent to recycling and secondary raw materials, leveraging the Cooperative Patent Classification to ensure unique counts.

**Unit:**

The unit of measure is the number of patent families, with a secondary metric of patents per million inhabitants.

**Source Data:**

Sourced from the European Patent Office (EPO), the data are extracted and analyzed by the Joint Research Centre (JRC), using the PATSTAT database.

**CEI\_PCO30: RESOURCE PRODUCTIVITY****Indicator metadata:** ↗**Context:**

Embedded within the Circular Economy indicator suite, this metric tracks progress in 'Production and consumption', emphasizing material use efficiency to gauge economic growth relative to resource use.

**Indicator Description:**

Resource productivity is articulated as GDP over DMC, showcasing the efficiency of material utilization within an economy. This indicator assists in understanding the dynamics between economic performance and environmental pressure.

**Unit:**

Measured in three distinct units: euro per kg in chain-linked volumes (2015), PPS per kg, and as an index (2000=100) for temporal and spatial comparisons.

**Source Data:**

The European Statistical System (ESS) supplies the data, with Eurostat disseminating information on DMC and GDP, derived from the Material Flow Accounts and GDP and main components datasets, respectively.

**Waste and Material Indicators****CEI\_PCO20: MATERIAL FOOTPRINT****Indicator metadata:** ↗**Context:**

The 'Material footprint' indicator is a critical component of the Circular Economy monitoring framework, highlighting the 'production and consumption' thematic area. It reflects the EU's impact on global resources, pertinent to the EU's consumption exceeding its production, especially concerning goods manufactured in Asia and consumed in Europe.

**Indicator Description:**

This indicator assesses the global demand for material extraction driven by EU consumption and investment. The Material Footprint provides insight into the environmental burden shifted to other regions

due to the EU's consumption patterns. It is expressed through the Raw Material Consumption (RMC) metric, indicating the material extraction required for goods consumed within the EU.

**Unit:**

The unit of measure is tonnes per capita.

**Source Data:**

Data source: European Statistical System (ESS) Data provider: Statistical Office of the European Union (Eurostat). Material flow accounts in raw material equivalents – modelling estimates (env\_ac\_rme). ↗ Material flow accounts in raw material equivalents by final uses of products - modelling estimates (env\_ac\_rmfed). ↗

**CEI\_PC031: GENERATION OF MUNICIPAL WASTE PER CAPITA****Indicator metadata:** ↗**Context:**

The 'Generation of municipal waste per capita' indicator is integral to the Circular Economy indicator set, falling under the 'production and consumption' thematic area. It underscores efforts to sustain product and material value in the economy, minimize waste generation, and drive waste prevention strategies in alignment with the Waste Hierarchy.

**Indicator Description:**

This indicator tracks municipal waste generated and managed by local authorities or entities appointed by them. It predominantly accounts for household waste, although it may include waste from commercial activities, offices, and public institutions, reflecting consumer behaviour and the impact of waste reduction measures.

**Unit:**

The unit of measure is kilograms per capita, based on the annual average population.

**Source Data:**

The data is provided by Eurostat, consistent with the high-quality standards of the European Statistical System (ESS), deriving from the Municipal waste by waste operations report, collected under the OECD/Eurostat Joint Questionnaire. Data submission is voluntary, known as a 'gentlemen's agreement'.

**CEI\_PC032:****GENERATION OF WASTE EXCLUDING MAJOR MINERAL WASTES PER GDP UNIT****Indicator metadata:** ↗**Context:**

The 'Generation of municipal waste per capita' indicator is integral to the Circular Economy indicator set, falling under the 'production and consumption' thematic area. It underscores efforts to sustain product and material value in the economy, minimize waste generation, and drive waste prevention strategies in alignment with the Waste Hierarchy.

**Indicator Description:**

This indicator tracks municipal waste generated and managed by local authorities or entities appointed by them. It predominantly accounts for household waste, although it may include waste from commercial activities, offices, and public institutions, reflecting consumer behaviour and the impact of waste reduction measures.

**Unit:**

The unit of measure is kilograms per capita, based on the annual average population.

**Source Data:**

The data is provided by Eurostat, consistent with the high-quality standards of the European Statis-

tical System (ESS), deriving from the Municipal waste by waste operations report, collected under the OECD/Eurostat Joint Questionnaire. Data submission is voluntary, known as a gentlemen's agreement.

### CEI\_PC034: WASTE GENERATION PER CAPITA

Indicator metadata: 

#### Context:

The 'Waste generation per capita' indicator is a key component of the Circular Economy monitoring framework, aimed at assessing the effectiveness of EU policies focused on waste reduction and resource efficiency within the 'production and consumption' thematic area.

#### Indicator Description:

This indicator reflects the total waste generation within a country, including major mineral wastes from all economic activities and households. It is an essential measure for evaluating the impact of waste prevention measures, allowing comparison of Member States' performance over time.

#### Unit:

The unit of measure is kilogram per capita

#### Source Data:

The data originates from the European Statistical System (ESS), specifically Eurostat, which collates information reported by countries under the Waste Statistics Regulation (EC) No 2150/2002.

### CEI\_SRM030: CIRCULAR MATERIAL USE RATE

Indicator metadata: 

#### Context:

As a core metric within the Circular Economy indicator set, the 'Circular material use rate' is crucial for monitoring advancements in the utilization of 'secondary raw materials'. It encapsulates the circular economy's goal to enhance material recycling, reduce waste, and curb the reliance on primary raw material extraction.

#### Indicator Description:

This indicator assesses the proportion of recycled material re-entering the economy against the overall material consumption, serving as a benchmark for the 'circularity rate'. It signifies the efficiency of resource use by contrasting the circular use of materials against the aggregate domestic material consumption (DMC), adjusted for waste trade.

#### Unit:

The indicator is presented as a percentage, depicting the share of recycled material in total material usage, reflecting the level at which secondary materials replace primary resources.

#### Source Data:

Data is sourced from the European Statistical System (ESS) and Eurostat, employing a trio of statistical resources: waste treatment statistics, material flow accounts, and international trade data.

### CEI\_WMO10: RECYCLING RATE OF ALL WASTE EXCLUDING MAJOR MINERAL WASTE

Indicator metadata: 

#### Context:

This indicator is pivotal for measuring advancements in 'waste management'. It gauges the efficiency of resource use by monitoring the volume of materials recycled and reincorporated into the economy, thus encapsulating the essence of material conservation and loss reduction.

**Indicator Description:**

The recycling rate is formulated by the proportion of waste recycled versus the total waste treated, excluding significant mineral waste, rendered in percentage terms. It encompasses both hazardous and non-hazardous waste across all sectors, including household and secondary waste from waste treatment processes, thereby providing a comprehensive snapshot of the national recycling efforts.

**Unit:**

Expressed in percentage

**Source Data:**

Eurostat, under the aegis of the ESS, supplies this data. It incorporates waste treatment information aligned with the Waste Statistics Regulation, fine-tuned with international trade data, to accurately reflect the recycling of domestically produced waste.

**CEI\_WM011: RECYCLING RATE OF MUNICIPAL WASTE****Indicator metadata:** **Context:**

As an integral part of the Circular Economy indicators, this measure serves as a barometer for the progression towards a more circular economy, with a focus on 'waste management'. It assesses the re-utilisation of consumer waste in the economy, capturing the complexities inherent in the diverse composition of municipal waste.

**Indicator Description:**

This indicator quantifies the proportion of municipal waste that is recycled, relative to the total amount of municipal waste produced, presented as a percentage. The breadth of municipal waste includes household refuse and similar commercial and public waste, representing a snapshot of the waste management quality from a consumer perspective.

*"In order to comply with the objectives of this Directive, and move to a European circular economy with a high level of resource efficiency, Member States shall take the necessary measures designed to achieve the following targets: (a) by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight;" — Article 11.2 of the Waste Framework Directive. [10]*

**Unit:**

The metric of evaluation is a percentage

**Source Data:**

Data source: European Statistical System (ESS) Data provider: Statistical Office of the European Union (Eurostat) based on data reported by the countries: Municipal waste by waste operations  collected via a subset of the OECD/Eurostat Joint Questionnaire, section waste. Data are provided under a so-called gentlemen's agreement.

**CEI\_WMO60: RECYCLING RATE OF WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) SEPARATELY COLLECTED****Indicator metadata:** **Context:**

This indicator is a crucial component of the Circular Economy suite, offering insights into the progression towards enhanced sustainability in 'waste management'. WEEE, or e-waste, is a rapidly expanding waste stream within the EU that encapsulates items like computers, TVs, refrigerators, and mobile phones. Given the valuable materials found in e-waste, improving recycling processes is of paramount importance.

**Indicator Description:**

The indicator measures the efficiency of WEEE recycling by calculating the ratio of the weight of WEEE processed for recycling/re-use against the total weight of WEEE collected separately, in compliance with Article 11(2) of the WEEE Directive 2012/19/EU [5, 6]. The indicator's transition from 'Recycling rate of e-waste' to its current form is to align more closely with the CE monitoring framework revisions.

The applicability of Directive 2012/19/EU is twofold:

- Applicable up to the year 2018 for EEE classified under 10 product categories as outlined in Annex I of the Directive, with Annex II providing a corresponding indicative product list.
- Applicable from the year 2019 forward, where all EEE will be classified within 6 product categories as delineated in Annex III.

**Unit:**

The percentage serves as the unit of measure

**Source Data:**

Data procurement is executed by the ESS and supplied by Eurostat. The indicator's underlying data stems from:

- For WEEE by waste operations: (env\_waselee) ↗.
- For WEEE by waste management operations - open scope, 6 product categories (from 2018 onwards): (env\_waseleeos) ↗.

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## 4.5.4. The EU Circular Economy Indicators: *Scenarios*

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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### **Summary**

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## **Scenario II: Recovery**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### **Scenario III: Circularity**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

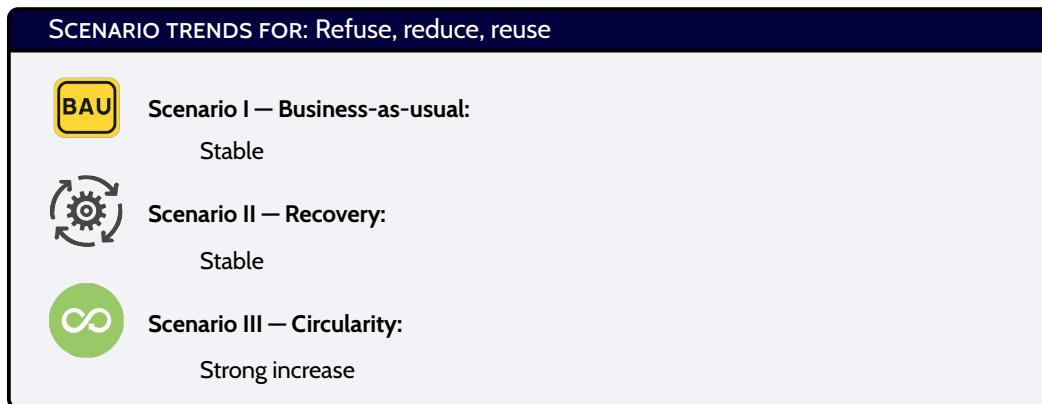
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## 4.5.5. Refuse, Reduce, Reuse: Description

Refuse, Reduce, and Reuse are the first three short loops (R0-2) in the circular economy scheme. They exist close to the consumer and can be linked to commercial or non-commercial actors engaged in extending the product's lifespan [120].



These strategies are pivotal in the circular economy, effectively reducing the environmental impact of products or services.

- **R0 – Refuse:** Choosing not to purchase products or services that are unnecessary or unsustainable.
- **R1 – Reduce:** Decreasing the quantity of products or services used or needed.
- **R2 – Reuse:** Utilising products or services again for the same or a different purpose.

These strategies will be incorporated into FutuRaM's modelling framework through:

- Waste volume reduction from:
  - Reduction in overall demand, that is, the put on market (POM) of a product or service.
  - Reduction in the amount of material used in a product or service (efficiency).
  - Extension of the lifetime of products from reuse.
- Changes in the composition of waste, as some products are more amenable to being refused or reused than others.

### Definitions

#### REFUSE

Refuse encompasses consumer and producer decisions aimed at minimising waste creation and reducing environmental impact. For consumers, it involves choosing not to purchase products that are not environmentally friendly and reducing overall consumption. In the production context, it signifies the deliberate avoidance of certain materials or processes to enhance circularity, such as eschewing hazardous substances or designing to minimise waste. Refuse, as a concept, prioritises waste prevention at the source and is integral to fostering a more circular economy [119].

## REDUCE

Reduce refers to strategies aimed at minimising the use of natural resources, including energy, raw materials, and thereby reducing waste generation. This concept is multifaceted:

- For consumers, it involves using products less frequently, caring for and repairing products to extend their life, and participating in the sharing economy.
- For producers, it focuses on using less material per production unit, often referred to as 'de-materialisation', and incorporating these principles early in the Concept and Design Life Cycle.

Reduction is also linked to the notion of Reuse, as decreasing the quantity of products (like cars) can incentivise their reuse. Policy measures to enforce reduction, such as banning single-use plastics or imposing environmental taxes, are essential for effective implementation [121].

## REUSE

Reuse is about extending the life of products in their original form for as long as possible, thus conserving resources and energy. It involves maintaining and repairing products to keep them in use and developing business models that support these practices. Examples include:

- Reusable packaging initiatives in various industries.
- Encouraging the reuse of items like clothing, furniture, and electronics.
- Deposit-refund systems that incentivise product return and reuse.

Reuse strategies are vital for reducing the consumption of new products and avoiding the dichotomy of 'new for the rich, reused for the poor', promoting equitable and sustainable consumption patterns [116].

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## 4.5.6. Refuse, Reduce, Reuse: Scenarios

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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## Summary

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### **Scenario III: Circularity**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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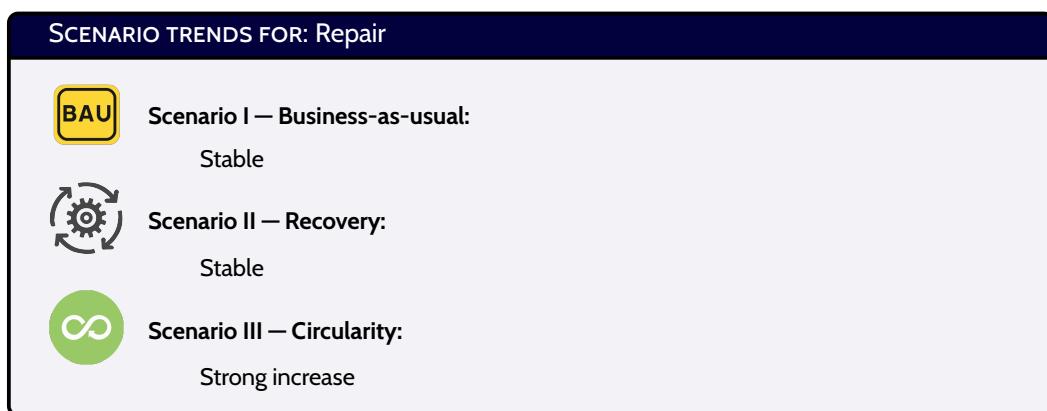
## 3398 4.5.7. Repair: Description

3399 [122, 123, 124, 125, 53]

### 3400 Definition

3401 Right to repair refers to the concept that end users, business users as well as consumers, of (generally) technical, electronic or automotive devices should be allowed to freely repair these products. Four requirements  
 3402 are of particular importance:

- 3404 • The device should be constructed and designed in a manner that allows repairs to be made  
 3405 easily;
- 3406 • End users and independent repair providers should be able to access the original spare parts  
 3407 and necessary tools (software as well as physical tools) at fair market conditions;
- 3408 • Repairs should, by design, be possible and not be hindered by software programming; and
- 3409 • The repairability of a device should be clearly communicated by the manufacturer.



### 3412 Context

3413 Discarded products are often viable goods that can be repaired but are often tossed prematurely, resulting  
 3414 in 35 million tons of waste, 30 million tons of resources and 261 million tons of greenhouse gas emissions  
 3415 in the EU every year [54]

3416 Repairing is one of the most relevant strategies within the Circular Economy (CE) concept since it  
 3417 contributes to waste prevention and extends product and components' lifespan. Thus, reparability becomes  
 3418 an essential issue from the early product design phases, where materials, geometries, and joints are defined.  
 3419 Despite some repairability indicators that can be found in the literature and are applied worldwide, there is  
 3420 a lack of connection between reparability and the early decision-making process for improving it from the  
 3421 design of components or subsystems of a product.

3422 However, repair is often seen as difficult by consumers. The 'right to repair' initiative complements  
 3423 several other proposals presented by the Commission to achieve sustainable consumption throughout the  
 3424 entire lifecycle of a product, setting the framework for a true 'right to repair' across the EU. Obstacles to  
 3425 owner repair can lead to higher consumer costs or drive consumers to single-use devices instead of making  
 3426 repairs.

The right to repair is a legal right for owners of devices and equipment to freely modify and repair products such as automobiles, electronics, and farm equipment. This right is framed in opposition to restrictions such as requirements to use only the manufacturer's maintenance services, restrictions on access to tools and components, and software barriers.

A right to repair can exist either in a closed access system, where the consumer is restricted to the repair services provided by the manufacturer or authorized repairers — a situation closer to the current reality. Or, a right to repair can evolve in an open access system, which implies full access to spare parts, tools, repair manuals and digital permission to repair. Policy options for a right to repair differ based on whether they encourage one or the other approach. Some argue an open access system is the only form of right to repair that is consumer-empowering and can yield the expected benefits. Others argue for a more complex system, moving towards open access but with some safeguards on a sectoral or product category basis. A cost-benefit analysis could help identify the sectors or product categories where a full open-access system would be most beneficial.

The goals of the right to repair are to favour repair instead of replacement and make such repairs more affordable leading to a more sustainable economy and reduction in waste.

## ***International and European Right to Repair Initiatives***

[124, 125, 53]

- **Availability of Spare Parts and Repair Information:**

- US state-level legislation includes laws like Massachusetts' requirement for car manufacturers to provide repair tools and information.
- The EU has measures like France's mandate for sellers to inform about the availability of spare parts, and Slovenia's requirement for maintenance and spare parts for at least 3 years after guarantee expiration.

- **Legal Guarantees:**

- European legal guarantee periods often exceed the EU directive's minimum, encouraging repair culture.
- For example, Sweden has a 3-year guarantee period, and Finland ties the period to the expected lifespan of the product.

- **Design Requirements:**

- Legislation like Washington State's (USA) proposed fair repair bill is aimed at promoting repairable product designs by prohibiting the creation of electronics that obstruct repairability.

- **Financial Incentives:**

- Cities like Graz offer subsidies for electronic device repairs and countries like Belgium provide écochèques to incentivize repair over replacement.

- **Copyright Law Exemptions:**

- In the US, certain copyright law exemptions facilitate repairability, such as the ability to unlock phones, although the exemption renewal process is cumbersome.

- **Consumer Information:**

- France's reparability index helps inform consumers by rating products on repairability criteria, promoting repair-friendly designs.

- **Voluntary Labels and Green Public Procurement:**

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- Ecolabels such as EPEAT and various national labels incorporate repairability to different degrees.
  - Green Public Procurement practices push the market towards sustainable, repairable products.

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- **Communication and Awareness:**

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- Initiatives include repair-focused websites, awareness campaigns, and the establishment of repair hubs to build a repair-oriented culture.

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## **Implementation in EU Law**

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[54, 20]

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European Product Policy has to date focused on the environmental performance of products via the Ecodesign and Ecolabelling Directives. The Ecodesign Directive sets minimum standards of performance for products, which results in poorly performing products being removed from the market whilst also driving innovation in the design and manufacture of new products to improve their performance. The Ecolabelling Directive provides consumers with clear information on product performance to inform their buying decisions. Originally cast for energy-using products, the directives have been extended to energy-related products and the assessment methodologies have been developed to include other aspects including materials and water consumption.

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Further measures considered include:

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- Amending Directive 2005/29/EC to prohibit presenting products as allowing repair when such repair is not possible, as well as omitting to inform consumers that it is not possible to repair goods in accordance with legal requirements.
  - Amending Directive 2005/29/EC to prohibit omitting to inform the consumer that the good is designed to limit its functionality when using consumables, spare parts, or accessories that are not provided by the original producer.
  - Traders to provide, before the conclusion of the contract, for all types of goods, where applicable, the reparability score of the good as provided by the producer in accordance with Union law, to allow consumers to make an informed transactional decision and choose goods that are easier to repair.
  - Ensuring information such as on the availability of spare parts and a repair manual, should no reparability score be available at the Union level.
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To this end, new 'Digital Product Passports' providing information about products' environmental sustainability, will empower consumers and businesses to make informed choices when purchasing products, facilitate repairs and recycling, and improve transparency about products' lifecycle impacts on the environment. The passports also help public authorities to better perform checks and controls.

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In addition, as part of the implementation of the EU Circular Economy Action Plan [2], the European Commission has carried out a study for the analysis and development of a possible scoring system to inform about the ability to repair and upgrade products [53] and has an ongoing project in the Product Bureau to develop and propose new metrics [161, 55].

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## **Development of a metric for reparability**

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[53, 54, 20, 161, 55, 126, 127, 128]

The trend in consumer goods towards reduced durability and repairability has been contributing to an increase in waste electronic and electrical equipment (WEEE). The Organization for Economic Co-operation and Development has suggested that extending product lifetimes through enhanced durability and repairability is a viable solution to this growing issue. The European Commission's Circular Economy Action Plan reinforces this viewpoint, advocating for maintaining the value in products for as long as possible by imposing durability and repairability requirements. In response, several scoring systems for repairability have been developed to guide standardization efforts, aid market surveillance authorities, and inform consumer decision-making.

For a scoring system to be effective, it should provide an objective evaluation of repairability that aligns with the established design principles in the literature. Comparative analyses of various repairability scoring systems for different products have been undertaken in previous studies. However, the thoroughness of these systems is sometimes not fully evaluated, and some of the most recent systems have not been comprehensively reviewed.

Literature on the subject identifies specific design features and principles that significantly affect product repairability, and these should be central to any scoring system aimed at accurately measuring repairability. Assessing these design elements against selected scoring systems can shed light on their inclusiveness.

The objectivity of these scoring systems is another critical aspect, evaluated by examining their scoring methodologies. Selection criteria for these systems include their availability in English, the use of quantitative or semi-quantitative assessment methods to enable objective comparison, and their recognition as the most current versions from their respective issuing organizations or groups.

In 2021, France took a pioneering step by integrating the reparability index into national legislation. [21] This move compels producers to transparently communicate the repairability of their products through consumer labelling. The reparability index stands as a key development in empowering consumers to make informed choices regarding the repairability of products. The widespread issue of repairing common electronic devices like laptops and smartphones often stems from the unavailability of tools, spare parts, or repair instructions.

An exemplary repair index would encompass elements such as product design, the availability of repair information, and additional services like the availability of spare parts. These aspects are crucial for the repair process. Data indicates that a substantial number of electronic product repairs are hindered by the lack of available spare parts.

France's method mandates transparency regarding product repairability, yet relies on producers' self-assessment, prompting questions about the objectivity of such evaluations. The rapid implementation is advantageous, but the credibility of self-assessment remains a concern.

With sustainability becoming increasingly important, France's reparability index marks an assertive step towards the broader adoption of such measures. Looking ahead, enhancements like a durability index may offer greater insights into the long-term usability of products.

In parallel, organizations such as TÜV SÜD are actively supporting the repairability testing landscape, aligning with standards like the French Repairability Scoring Index to ensure products fulfil specified repairability criteria [148]. Their approach factors in documentation, disassembly, and the availability of spare parts and repair services, highlighting a practical, though less detailed, framework compared to France's comprehensive index.

## Benefits and risks

### ENVIRONMENTAL BENEFITS AND RISKS

[53, 129]

The implementation of the right to repair holds considerable promise for the reduction of environmental impacts if applied appropriately. It must be recognized that electronic equipment replacement often occurs not solely due to product failure. Influencing factors such as perceived obsolescence contribute significantly, as evidenced by a study in Austria revealing only 30% of replacements were attributable to malfunctioning products [123].

Direct measurement of the impact of a right to repair is challenging, with the need to consider additional variables such as obsolescence perception, device performance, and consumer behaviour trends in determining potential extensions in consumer electronics' average lifespan.

Moreover, the environmental benefit of repair is contingent not only on the increased product lifespan post-repair but also on the environmental footprint of the spare parts required for repair. Circuit boards, for example, carry substantial environmental impacts, and their replacement could still result in significant environmental costs. Common repairs typically involve less impactful components such as screens, casings, batteries, or software [122].

Cordella et al. [122] report that compared to the baseline of replacing smartphones every two years, extending the device's life through repair can substantially diminish the carbon footprint. A one-year extension, with a battery change, can reduce greenhouse gas (GHG) emissions by 29%, and by 44% with a two-year extension.

With 472 million Europeans owning a mobile phone, there are 8.11 Mt CO<sub>2</sub>-eq. in annual emissions solely from phones. Extending the life of a mobile phone by just one year, including component replacements, could reduce emissions to 6.23 Mt CO<sub>2</sub>-eq. annually [54]. A further extension by an additional year could decrease emissions to 4.91 Mt CO<sub>2</sub>-eq., effectively removing the equivalent of over 2 million cars from European roads.

Nevertheless, these potential reductions should be interpreted with caution as they are based on estimations and may not account for potential rebound effects. For instance, economic savings from prolonged use of electronic devices could lead to rebound effects where savings are offset by additional consumption stemming from the economic savings [130].

Finally, repair activities offer a more energy-efficient alternative within the Circular Economy compared to recycling and remanufacturing, which demand extensive energy input and high material throughput. When feasible, repair should be prioritized over other circular economy strategies [53].

## MANUFACTURERS' PERSPECTIVE

- Compliance with eco-design standards could reduce profit margins.
- Risk of increased liability and the need to ensure long-term availability of spare parts.
- Potential decrease in turnover due to extended product lifecycles.
- Reduction in EU imports could foster the EU's technological independence, as per the EU Chips Act.
- Loss in turnover potentially offset by repair services and spare parts supply.

## BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

- Right to Repair could enhance competitiveness by increasing product longevity and added value.
- Positive impact on professional repair services, spare parts provision, and tool providers.
- SMEs and local repair shops likely to benefit significantly.

- 3594
- Potential for the development of new European leaders in repair services.
  - A more repairable design could improve recycling processes and increase component harvesting.
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## ***Relevance of Repairability to Critical Raw Materials in Waste Streams***

3598 The integration of the 'Right to Repair' ethos and the promotion of repairability has implications for the  
3599 management of Critical Raw Materials (CRMs) across various waste streams, such as BATT (waste batteries),  
3600 ELV (end-of-life vehicles), WEEE (waste electrical and electronic equipment), and CDW (construction and  
3601 demolition waste).

3602

### **BATTERIES (BATT)**

3603 Batteries are a crucial repository of CRMs like lithium, cobalt, and nickel. Enhancing their repairability  
3604 can lead to:

- 3605
- Refurbishing batteries for second-life applications.
  - Design modifications for easier replacement of battery cells.
  - Reduced extraction of new raw materials, mitigating the environmental footprint.
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### **END-OF-LIFE VEHICLES (ELV)**

3609 Vehicles are a significant source of CRMs such as platinum and palladium (catalytic converters) and rare  
3610 earth elements (electronics and magnets). 'Right to Repair' can:

- 3611
- Influence design changes for modularity and ease of part replacement.
  - Prolong the utility of CRMs and lessen new resource extraction.
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### **WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)**

3614 The WEEE stream contains valuable CRMs like gold, silver, and rare earth elements. Promoting  
3615 repairability results in:

- 3616
- Prolonged life spans for electronic devices.
  - A reduction in the volume of CRMs entering the waste stream.
  - Conservation of valuable materials through repair and refurbishment.
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3619

### **CONSTRUCTION AND DEMOLITION WASTE (CDW)**

3620 CRMs feature in many building materials as well as wind turbines which are part of this waste stream,  
3621 and advocating for repairability in construction can:

- 3622
- Lead to buildings designed for deconstruction, not demolition.

3623 The emphasis on repairability and 'Right to Repair' legislation can lead to reduced CRM demand, de-  
3624 creased environmental impact through less mining, creation of economic incentives for repair industries,

3625 and improved resource security by minimizing reliance on raw material extraction. This approach is in line  
3626 with fostering a circular economy, aiming for a sustainable management of resources within the EU.

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## 4.5.8. Repair: Scenarios

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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## Summary

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### Scenario III: Circularity

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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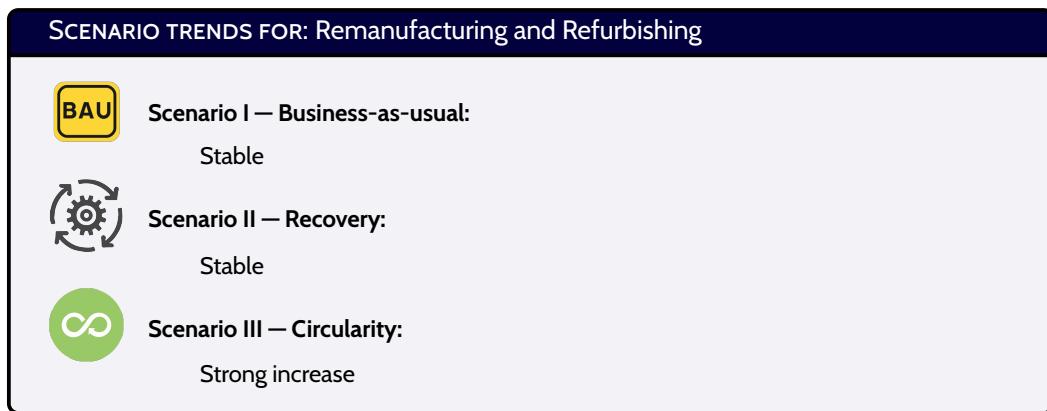


## 4.5.9. Remanufacturing and Refurbishing: Description

### Definition

Remanufacturing involves disassembling the full structure of a multi-component product, inspecting, cleaning, repairing, or replacing necessary parts, and reassembling it to its original state or better. This process can include both reused and new components, aiming to achieve a quality level that meets or exceeds the new product [119, 131, 132].

Refurbishing, often confused with remanufacturing, is the process where the overall structure of a large multi-component product remains intact, while components are replaced or repaired, resulting in an overall 'upgrade' of the product. It aims to bring the product up to a specified quality, possibly incorporating newer, more advanced components [119].



### Context

Remanufacturing and refurbishing are essential strategies in the circular economy, aimed at extending product lifecycles and reducing waste. They are particularly relevant in the medium loops (R4-R6) of product recovery, where they serve as business activities indirectly linked to the consumer [56].

### International and European Trends

Remanufacturing is gaining momentum globally, particularly in the U.S. and Europe. Governments are legislating manufacturers to assume responsibility for their products post-use, emphasizing recyclability and waste reduction. The market for environmentally friendly products, valued at over USD 200 billion, is driving corporations to adopt remanufacturing and other green practices [133, 57].

### Implementation in EU Law

EU laws increasingly mandate manufacturers to engage in product recovery, including remanufacturing. This aligns with the EU's broader goals of sustainable development, resource efficiency, and transitioning to a circular economy [3, 56].

## Economic Scale and Regional Focus in Europe

The remanufacturing industry in Europe generates around €30bn in turnover and employs about 190,000 people. Key regions like Germany, the UK, Ireland, France, and Italy have significant remanufacturing activities. Germany leads in remanufacturing turnover, particularly in aerospace, automotive, and heavy-duty off-road (HDOR) sectors [56].

## Benefits and Risks

### Environmental Benefits and Risks:

Remanufacturing significantly reduces environmental impact by conserving raw materials and energy, while risks may include the potential for resource-intensive processes if not efficiently managed.

### Manufacturers' Perspective:

For manufacturers, remanufacturing offers economic benefits, with costs typically 40–60% lower than manufacturing new products. It also enhances corporate image and competitive advantage in a market increasingly sensitive to environmental concerns [133].

### Broader Economic and Environmental Implications:

Remanufacturing contributes to a sustainable economy, offering a less resource-intensive alternative to new production. It supports employment, innovation, and reduces dependency on raw material extraction.

## Benefits and Risks

### Environmental Benefits and Risks:

Remanufacturing significantly reduces environmental impact by conserving raw materials and energy. However, risks may include the potential for resource-intensive processes, especially if not managed efficiently, and the need for effective sorting and inspection policies to decide on the remanufacturability of returned products [134].

### Manufacturers' Perspective:

For manufacturers, remanufacturing offers economic benefits, with costs typically 40–60% lower than manufacturing new products. It also enhances corporate image and competitive advantage in a market increasingly sensitive to environmental concerns. Additionally, manufacturers' identity, brand reputation, and technological capabilities play a crucial role in the success of remanufacturing initiatives [133, 134].

### Broader Economic and Environmental Implications:

Remanufacturing contributes to a sustainable economy, offering a less resource-intensive alternative to new production. It supports employment, innovation, and reduces dependency on raw material extraction. Key factors such as government regulations, collection strategies, and public awareness about environmental benefits are crucial in promoting remanufacturing. Moreover, design for remanufacturing and skilled labor are essential for efficient remanufacturing processes [134].

### Market Dynamics:

Factors like consumer purchase intentions, pricing strategies, and the fear of cannibalization significantly influence the market for remanufactured products. Consumers' willingness to return used products and their perception of remanufactured products also play a crucial role in shaping the remanufacturing market [134].

### Regulatory and Strategic Aspects:

Government regulations, such as take-back laws and extended producer responsibility, incentivize remanufacturing. Strategic elements like inventory control, scheduling, and material matching are

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vital for operational efficiency in remanufacturing. Management prescience is required to spearhead remanufacturing business and maintain circularity in the economy [134].

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Figure 4.14 illustrates an example of a remanufacturing process (in this case, for vehicle components), highlighting the key steps and the inputs and outputs [135].

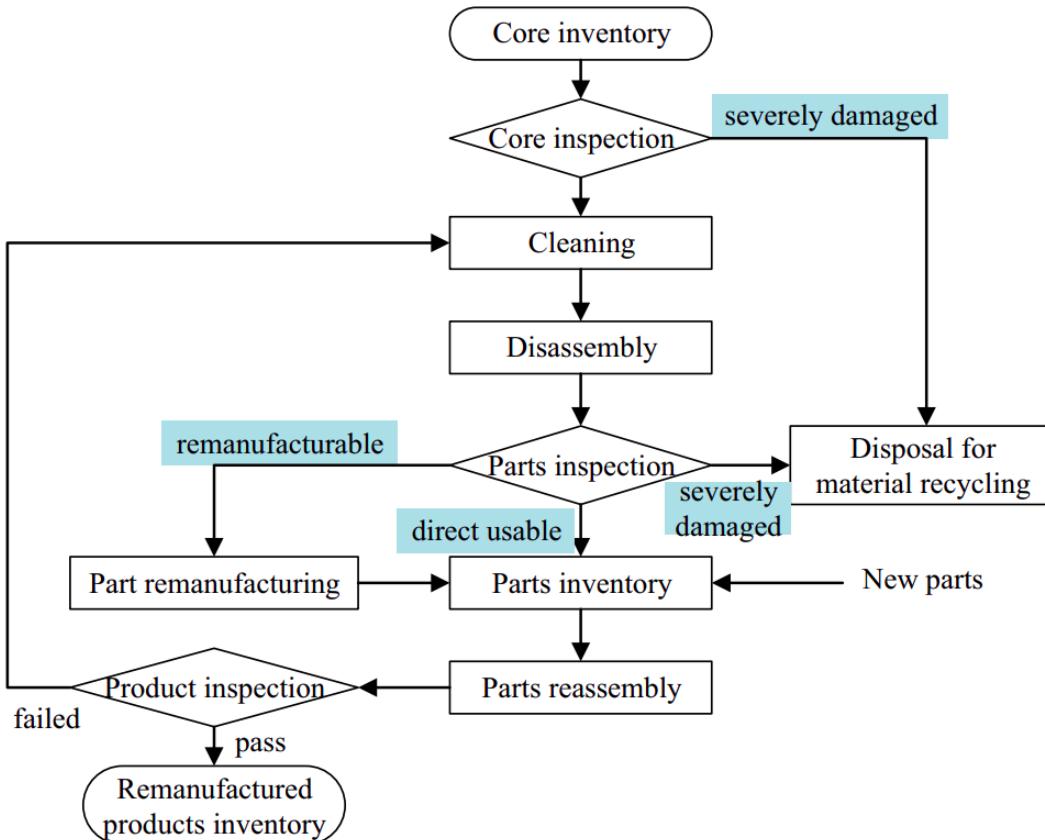


Figure 4.14: An example of a generic remanufacturing process for vehicle components [135]

## Relevance of Remanufacturing and Refurbishing in FutuRaM's Waste Streams



### BATT (Battery waste)

- Electric Vehicle Batteries: Remanufacturing can involve replacing degraded cells or modules to extend their lifespan, thereby conserving lithium and cobalt.
- Laptop Batteries: Through remanufacturing, individual cells within the battery pack can be replaced or upgraded, enhancing the overall battery life and efficiency.



### ELV (End-of-Life Vehicles)

- Automotive Engines: Remanufacturing can include refurbishing engine components, such as pistons and bearings, to restore performance and efficiency.
- Transmission Systems: Rebuilding transmission systems with replaced or refurbished gears and bearings can significantly extend the life of the vehicle.



### WEEE (Waste Electrical and Electronic Equipment)

- Smartphones: Remanufacturing can involve replacing batteries, screens, and other components to restore them to like-new condition.
- Printers and Copiers: Components such as toner cartridges, drums, and fusers can be remanufactured to extend their service life and improve functionality.



### CDW (Construction and Demolition Waste)

- Structural Steel Elements: In construction and demolition, steel beams and columns can be refurbished and reused in new construction projects.
- Wooden Beams and Flooring: Wooden elements can be remanufactured through processes like sanding, treating, and reinforcing for reuse in construction.



## 4.5.10. Remanufacturing: Scenarios

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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### ***Global trends***

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### ***Summary***

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### Scenario III: Circularity

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## 4.5.11. The Sharing Economy: Description

[136, 58, 59, 60, 61, 137]

### Definition

The sharing economy is a socio-economic system that emphasizes the collaborative sharing of goods and services via community-based online platforms. It represents a shift from traditional ownership, where assets were exclusively leased, to a flexible model allowing for both personal use and lease. This flexibility is a hallmark of the sharing economy, which has grown significantly in response to advancements in technology, such as e-commerce and mobile connectivity, coupled with a societal push for more sustainable living and efficient resource use.



### Context

As the concept of ownership transforms, particularly among the younger generation, the sharing economy has increasingly taken root in the EU market. This shift towards more communal and cost-effective ways of accessing goods and services is supported by a new wave of consumer behavior, underpinned by technological innovation and a pressing need to reduce environmental waste and resource duplication.

While the sharing economy is broad and its definition fluid, it is often associated with collaborative consumption, though the two can differ in motives and mechanisms. Collaborative consumption may span consumer-to-consumer and business-to-consumer interactions, whereas the sharing economy typically operates within the consumer-to-consumer sphere. The sharing economy is thereby defined as an innovative marketplace where entities engage in the distribution and utilization of products and resources, with scalability achieved through technological means.

This socio-economic model has not only disrupted traditional business sectors but has also brought new value to the global economy, with rapid and profound market penetration. Financial forecasts have been bullish, with revenue for sharing platform providers expected to increase from USD 18.6 billion in 2017 to an estimated USD 40.2 billion in 2022. Moreover, the overall value of the global sharing economy is projected to expand significantly, from USD 14 billion in 2014 to USD 335 billion in 2025, reflecting an unprecedented growth trajectory over a mere twelve years[137]. Such growth reflects the substantial economic potential and transformative power of the sharing economy in contemporary markets.

## 3832 Scope within the EU Economy

3833 The sharing economy has made a significant economic contribution to the EU, with an estimated €26.5  
3834 billion added to the GDP in 2016 [58]. This figure is expected to grow, indicating the sharing economy's  
3835 increasing importance within the EU's economic structure.

## 3836 Environmental Prospects

3837 [136, 58, 60]

3838 See [137] Table 2 for a summary of the studies on the environmental impacts of the sharing economy.

3839 The sharing economy has the potential to reshape consumption behaviors and reduce environmental  
3840 impacts by promoting the sustainable use of resources. This economic paradigm encourages the efficient  
3841 employment of underutilised goods, which can lead to a decrease in the need for new products, thus  
3842 conserving resources and mitigating greenhouse gas emissions. It fosters a lifestyle that lessens the adverse  
3843 environmental effects of consumption while improving quality of life.

3844 Central to the sharing economy is the promotion of moderate consumption patterns. This approach aims  
3845 to reduce the excessive purchasing habits of certain populations to alleviate ongoing environmental harm.  
3846 The sharing economy's alignment with green consumption practices encompasses waste reduction, energy  
3847 conservation, and the adoption of sustainable resources, all while managing and moderating excessive  
3848 consumption.

3849 The impact on the fast fashion industry serves as a pertinent example, with the sector's frequent turnover  
3850 to keep pace with changing trends leading to significant textile waste. Collaborative consumption through  
3851 the sharing economy can mitigate this waste by encouraging the reuse and extension of clothing's service  
3852 life. Clothing libraries are an example of how the sharing economy can provide environmental benefits by  
3853 prolonging the usable life of garments.

3854 Eco-efficiency is enhanced when environmental resources are utilised more effectively, leading to an  
3855 increased use of products with minimal environmental burden. This is exemplified in collaborative fashion  
3856 consumption, which could reduce the prevalent overconsumption in the fashion industry. By facilitating the  
3857 exchange of underused clothing, the sharing economy can increase the lifecycle of garments and encourage  
3858 the production of more durable products.

3859 Beyond the realm of fashion, car sharing and shared accommodation are other aspects of the sharing  
3860 economy with notable environmental benefits. Car sharing can significantly reduce the number of vehicles  
3861 needed, thereby lowering exhaust emissions. Similarly, shared accommodations have been associated with  
3862 significantly lower carbon dioxide emissions compared to conventional hotel stays.

3863 However, the question of whether the sharing economy indeed delivers environmental benefits remains  
3864 contested. [137, 138] Detractors highlight the potential for an increase in environmental burdens, particularly  
3865 if the heightened usability of shared goods escalates greenhouse gas emissions. The environmental and  
3866 socio-economic impacts engendered by the collaborative economy are intricate and highly variable across  
3867 different business models. Generally speaking, collaborative consumption models that optimise the use of  
3868 existing assets tend to exhibit a lower environmental footprint compared to their traditional counterparts.  
3869 Nevertheless, there is a risk that the financial savings afforded by collaborative consumption could spur  
3870 additional spending and consumption, which might negate the direct environmental savings. Despite such  
3871 reservations, the prevailing view is that the sharing economy, by transforming consumption from ownership  
3872 to communal use, can yield considerable environmental advantages.

## 3873 Implications for Waste Streams

3874 The adoption of sharing economy principles can influence various waste streams, including:

- 3875 • **BATT (Waste Batteries):** As devices are shared and utilized more efficiently, the frequency of  
3876 battery disposal could decline, mitigating the waste battery stream.
- 3877 • **CDW (Construction and Demolition Waste):** The sharing of construction equipment and  
3878 machinery could potentially slow down the turnover rate of these items, reducing associated  
3879 waste.
- 3880 • **WEEE (Waste Electrical and Electronic Equipment):** Sharing electronic devices extends their  
3881 lifecycle and reduces the rate at which they are discarded, thereby impacting electronic waste  
3882 volumes.
- 3883 • **ELV (End-of-Life Vehicles):** A shift towards car-sharing services could reduce the demand for  
3884 manufacturing new vehicles, potentially leading to a downturn in the generation of automo-  
3885 tive waste.

3886 The trajectory of the sharing economy indicates a shift towards collective usage patterns. Its continuing  
3887 evolution could play a critical role in the future of critical raw material recovery systems by affecting demand  
3888 and the lifecycle of products, which, in turn, influences waste stream outputs. The broader implications for  
3889 the raw materials sector are significant, suggesting a possible recalibration of recovery strategies for critical  
3890 raw materials in light of emerging consumption patterns.

### 3891 ***Challenges in Measuring Sharing Economy Growth***

3892 Identifying a universal metric for the growth of the sharing economy is challenging due to its diverse and  
3893 dynamic nature. Current measures, such as STOXX Global sharing economy indices, Solactive Sharing  
3894 Economy Index and the INDXX US Sharing Economy Index, largely revolve around the market sizes of  
3895 prominent sharing economy companies, such as Uber and Airbnb. These indices, while useful, predom-  
3896 inantly reflect the scalability of these businesses rather than the sharing economy's broader impacts on  
3897 production and waste reduction.

3898 In the absence of a standardised metric, the assessment of the sharing economy's expansion is often  
3899 best approached through product-specific data. This involves examining the adoption rates and usage  
3900 trends of sharing services at the product level to infer growth patterns. Such a detailed, product-centric  
3901 analysis allows for a closer inspection of the sharing economy's implications on resource utilisation and  
3902 waste generation, offering insights that aggregate economic data may overlook.

## 4.5.12. The Sharing Economy: Scenarios

### WASTE STREAM NOTICE

This section will be filled out with the details of exactly how this parameter is incorporated into your stock and flow models

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### Summary

### REVIEW NOTICE

This summary will be compiled once the individual waste stream sections for each parameter are complete.

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### **Scenario I: Business-as-usual**

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#### **BATT (BATTERY WASTE)**

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#### **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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#### **ELV (END-OF-LIFE VEHICLES)**

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#### **MIN (MINING WASTE)**

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#### **SLASH (SLAGS AND ASHES)**

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#### **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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### **Scenario III: Circularity**

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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**ELV (END-OF-LIFE VEHICLES)**

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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**WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

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## Conclusion

### REVIEW NOTICE

This conclusion will be compiled once the individual waste stream sections for each parameter are complete.

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## 4.6. CONCLUSION

### REVIEW NOTICE

This conclusion will be compiled once the individual waste stream sections for each parameter are complete.

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# Interpretation

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## REVIEW NOTICE

This section will be constructed at a later stage of the project.

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# Modelling: Waste generation

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## REVIEW NOTICE

Development of the codebase for the waste generation models is ongoing.  
This section will be constructed at a later stage of the project.

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# Modelling:

# Recovery system

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## REVIEW NOTICE

Development of the codebase for the recovery model is ongoing.  
This section will be constructed at a later stage of the project.

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# Modelling: Integration

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## REVIEW NOTICE

This section will be constructed at a later stage of the project.

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# Impacts

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## Task 2.4

Quantify environmental and socioeconomic impacts of SRM recovery under each scenario (ULEI, TUB, Empa, UNITAR, WEEE Forum, BRGM, UCL, LMU) (M18-M36)  
This task will use the information generated in Tasks 2.1–2.3, together with the material flow analysis from WP4, to quantify the future environmental and socioeconomic feedbacks for each waste sector and scenario according to future recovery technology.

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# Bottlenecks

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## Task 2.5

Assess the environmental and socioeconomic impacts and bottlenecks of future SRM recovery (ULEI, TUB, Empa, UNITAR, Chalmers, UNITAR, WEEEcycle) (M37-M47)  
This task will develop a report based on an assessment on the pressures and bottlenecks associated with environmental and socioeconomic issues related to each waste sector, including the associated changes and impacts on imports and of primary raw materials production (D2.1).

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## REVIEW NOTICE

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# Conclusion

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## REVIEW NOTICE

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# References

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4011 Literature referred to in section 13.4 is excluded from the following lists of references, except for those titles  
4012 cited elsewhere in the report.

4013

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# Appendices

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## 13.1. TERMINOLOGY

4449 The following is a suggested terminology for use in our discussions and reports related to scenarios.

4450 This glossary is modelled on that used by [92]. Some additional definitions were sourced from [149].

Table 13.1: Terminology

| TERM                     | DEFINITION  | LEVEL/CONTEXT        | ALSO CALLED                       | SOURCE               |
|--------------------------|---|----------------------|-----------------------------------|----------------------|
| Normative scenario       | Goal-oriented scenario: identify decisions and investments that must be made to achieve desired future outcomes. Example: Constraining cumulative emissions   | Scenario type        | Backcasting                       | [92]                 |
| Exploratory scenario     | Exploration of plausible alternative developments to test whether decision-making is robust against different outcomes. Generally, involving a qualitative storyline about a possible future, complemented by quantitative analysis. Example: Socio-economic scenarios  | Scenario type        | Plausible scenarios               | [92]                 |
| Outlook                  | To provide a most likely estimate of future trends as a guide for decision-making   | Scenario type        | Forecast, projection              | [92]                 |
| Scenario characteristics | A combination of the vague attributes that make up the qualitative storyline for a scenario. For example, in WEC (2019) the scenario titled Modern Jazz is described as: “A market-led, digitally disrupted world with faster-paced and more uneven economic growth. Recent signals suggest that this entrepreneurial future might accelerate clean energy access on both global and local scales, whilst presenting new systems integration, cyber security and data privacy challenges” | Scenario description | Qualitative storyline descriptors | [92]                 |
| Scenario scale           | Description of the spatial extent or temporal extent of a scenario. For us, mostly EU toward 2050.  | Scenario component   |                                   | [149]                |
| Scenario dimensions      | Uncertainties around which scenarios are constructed, represented as axes in some methods. In our case they might end up being, level of circularity, free-trade/autarky, progress in energy transition   | Scenario component   |                                   | [149]                |
| Scenario literature      | Journal articles, grey literature, etc., from which data is sourced that can be used to justify decisions in scenario development   | Scenario component   |                                   | [92]                 |
| Scenario logics          | Methods for structuring the relationships between different drivers and assumptions in scenarios  | Scenario component   |                                   | [149]                |
| Time horizon             | End date of the scenario's forecast   | Scenario attribute   |                                   | [92]                 |
| Snapshot                 | The position of scenario/s at a particular point of time  | Scenario attribute   |                                   | [92]                 |
| Storyline and simulation | Combination of qualitative narrative development and quantitative modelling   | Scenario component   |                                   | [139, 140], in [149] |

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Table 13.1 – Continued from previous page

| TERM              | DEFINITION   | LEVEL/CONTEXT                   | ALSO CALLED        | SOURCE         |
|-------------------|--|---------------------------------|--------------------|----------------|
| Marker scenario   | Generally, a widely accepted scenario which can be used a guide or to provide background information. E.g., SSP1-5, and the GEC models from the IEA. If applicable, these can be extended upon or combined to help build our models.   | Scenario description            | Basis scenario     | [92]           |
| SSP               | Shared Social Pathways. They “describe plausible major global developments that together would lead in the future to different challenges for mitigation and adaptation to climate change. The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fuelled development, and middle-of-the-road development. The long-term demographic and economic projections of the SSPs depict a wide uncertainty range consistent with the scenario literature.” | Marker scenario examples        |                    | [62]           |
| Drivers           | Underlying causes of system change that are external from the system of analysis. They come from higher scales and are not affected by what happens within the system.   | Scenario component              | Factors            | [79], in [149] |
| Factors           | Causes of system change that are internal from the system of analysis. Can be (hopefully) quantified, or at least estimated  | Scenario component (internal)   |                    | [92]           |
| Factor variables  | Discrete elements which are subject to change and have effects on one or more factors  | Factor component                |                    | [92]           |
| Factor parameters | Discrete elements which are NOT subject to change (possibly based on assumptions and simplifications) and have effects on one or more factors  | Factor component                |                    | [92]           |
| Trends            | An inclination in a particular direction   | Attribute of drivers or factors | System development | [92]           |
| Likelihood        | The likelihood of an occurrence, an outcome, or a result, where this can be estimated probabilistically  | Attribute of drivers or factors | Probability        | [149]          |
|                   |  |                                 |                    |                |

## 13.2. LIST OF RELEVANT POLICY ACTIONS

4452  
The following table contains a description of policy actions that are relevant to the future of secondary raw  
4453 material supply in the EU.  
4454

Table 13.2: List of relevant policy actions

| POLICY  | STATE          | YEAR | STATUS    | JURISDICTION  | LINK              |
|---|----------------|------|-----------|---------------|-------------------|
| European Institute of Innovation and Technology: Raw Materials Project Call   | European Union | 2023 | Announced | International | <a href="#">🔗</a> |
| Minerals Security Partnership   | European Union | 2022 | Announced | International | <a href="#">🔗</a> |
| Resilience for the future: The UK's critical minerals strategy  | United Kingdom | 2022 | In force  | National      | <a href="#">🔗</a> |
| Circular Economy Action Plan  | Spain          | 2021 | In force  | National      | <a href="#">🔗</a> |
| Horizon Europe Strategic Plan (2021 – 2024)   | European Union | 2021 | In force  | International | <a href="#">🔗</a> |
| National Battery Strategy 2025  | Finland        | 2021 | In force  | National      | <a href="#">🔗</a> |
| National Planning Policy Framework  | United Kingdom | 2021 | In force  | National      | <a href="#">🔗</a> |
| EU Sustainable Batteries Regulation   | European Union | 2020 | Announced | Regional      | <a href="#">🔗</a> |
| Green Deal: Circular Economy Action Plan  | European Union | 2020 | In force  | International | <a href="#">🔗</a> |
| Battery fund: 3.2 billion euros for research and innovation   | European Union | 2019 | In force  | International | <a href="#">🔗</a> |
| Resources for France Plan   | France         | 2018 | In force  | National      | <a href="#">🔗</a> |
| European Battery Alliance   | European Union | 2017 | In force  | National      | <a href="#">🔗</a> |
| National Strategy for Energy Research   | France         | 2016 | In force  | National      | <a href="#">🔗</a> |
| Horizon 2020: Climate action, environment resource efficiency and raw materials   | European Union | 2013 | Ended     | International | <a href="#">🔗</a> |
| Resource Security Action Plan   | United Kingdom | 2012 | In force  | National      | <a href="#">🔗</a> |
| Supply of Mineral Resources (SoS MinErls)   | United Kingdom | 2012 | In force  | National      | <a href="#">🔗</a> |
| Finland's Minerals Strategy   | Finland        | 2010 | In force  | National      | <a href="#">🔗</a> |
| Royal Decree 975/2009 about extractive industries waste management and the protection and rehabilitation of areas affected by mining activities | Spain          | 2009 | In force  | National      | <a href="#">🔗</a> |
| EU Directive 2006/66/EC Battery Directive   | European Union | 2006 | In force  | International | <a href="#">🔗</a> |
|   |                |      |           |               |                   |

### 13.3. SCENARIO DEVELOPMENT METHODS

4456  
4457 Table 13.3 provides an overview of the methods and tools considered, along with a brief description of each and its relevance to the specific context and objectives of the FutuRaM scenario development process.

Table 13.3: Scenario development methods

| METHOD                 | DESCRIPTION   | KEY CHARACTERISTICS   | LIMITATIONS  | APPLICATION   |
|------------------------|---|---|--|---|
| Delphi                 | Structured expert consultation to gather and distil knowledge and judgments   | Iterative rounds of surveys/questionnaires, Expert consensus building                     | Time-consuming process, May be influenced by dominant opinions or group dynamics           | Policy development, Technology foresight, Long-term planning            |
| MCA                    | Decision-support technique to evaluate and rank scenarios based on criteria   | Consideration of multiple dimensions in quantifying qualitative factors                   | Policy assessment, Project evaluation, Strategic planning                                  |   |
| Forecasting            | Use of historical data and statistical methods to predict future trends   | Reliance on quantitative models, Time series analysis                                     | Assumption of future patterns based on past data, Sensitivity to data quality and accuracy | Economic forecasting, Demand/supply projections, Financial planning     |
| Backcasting            | Working backward from a desired future vision to identify necessary steps   | Focus on desired outcomes and future targets, Identification of necessary actions         | Uncertainty in future outcomes, Difficulty in determining feasible pathways                | Sustainable development planning, Policy design, Long-term goal setting |
| Scenario Planning      | Development of multiple future scenarios to understand the range of possibilities   | Identification of key drivers and uncertainties, Narrative construction for each scenario | Subjectivity in scenario construction, Lack of predictive accuracy                         | Strategic management, Risk assessment, Policy analysis                  |
| Morphological Analysis | Exploration of different combinations of variables/factors  | Matrix-based exploration of variables and combinations                                    | Complexity in analysing a large number of variables and combinations                       | Technology assessment, Innovation analysis, System design               |
| Cross-Impact Analysis  | Analysis of interdependencies and interactions between variables/factors  | Identification of relationships and cross-impacts   | Assumptions about causal relationships, Difficulty in capturing complex dynamics           | Policy analysis, Risk assessment, System modelling                      |
| Morphological Box      | Systematic exploration of the potential combinations of different components  | Identification of component options and combinations                                      | Complexity in analysing a large number of components and combinations                      | Technology assessment, Innovation analysis, Decision-making             |
| Gausemeier approach    | Scenario development method involving the identification of future developments, evaluation of influencing factors, and determination of desired and undesired developments | Systematic analysis of future developments and factors                                    | Relies on expert judgment and subjective assessments                                       | Strategic planning, Innovation management                               |

Continued on next page

Table 13.3 – Continued from previous page

| METHOD                              | DESCRIPTION   | KEY CHARACTERISTICS   | LIMITATIONS                                  | APPLICATION                         |
|-------------------------------------|---|---|--|-------------------------------------|
| Schwartz' 8-Step Scenario Model     | Scenario building model consisting of eight steps: identify the focal issue, determine the key forces, construct the scenario framework, identify driving forces, assess the uncertainties, develop the scenarios, analyze the scenarios, and monitor and adjust the scenarios                  | Systematic progression through stages of scenario development | Requires detailed data and analysis          | Strategic planning, Decision-making |
| Schoemaker's 10-Step Scenario Model | Scenario building model consisting of ten steps: identify the focal issue, determine the scope, identify the key driving forces, develop the scenarios, define the scenario logic, assess the scenarios, refine the scenarios, examine implications, formulate actions, and communicate results | Emphasis on thorough analysis and evaluation of scenarios     | Can be time-consuming and resource-intensive | Strategic planning, Risk management |

## 13.4. MARKER SCENARIO MAPPING

4459 Table 13.4 below presents an overview of the marker scenarios that were considered in the scenario development phase of the FutuRaM project. The table is not intended to be exhaustive, but rather to provide an  
4460 overview of the different scenarios that have been developed in the field of waste management, resource  
4461 recovery, and circular economy.  
4462

*Table 13.4: Overview of marker scenarios*

| LITERATURE   | TYPE     | WASTE STREAM     | TEMPORAL COVERAGE   | LOCATION | NUMBER OF SCENARIOS   | LINK              |
|--|----------|------------------|---------------------|----------|---|-------------------|
| The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview                           | Academic | All (narratives) | Scenario to 2100    | Global   | 5 SSPs  | <a href="#">🔗</a> |
| Environmental Impacts of Global Offshore Wind Energy Development until 2040  | Academic | CDW              | Scenario: 2019–2040 | Global   | 4 (based on IEA)  | <a href="#">🔗</a> |
| Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060                           | Academic | CDW              | Scenario: 2020–2060 | Global   | 2 (based on SSP2)   | <a href="#">🔗</a> |
| Modelling global material stocks and flows for residential and service sector buildings towards 2050   | Academic | CDW              | Scenario: 2020–2060 | Global   | 1 (SSP2)  | <a href="#">🔗</a> |
| The evolution and future perspectives of energy intensity in the global building sector 1971–2060  | Academic | CDW              | Scenario: 2020–2060 | Global   | 1 (SSP2)  | <a href="#">🔗</a> |
| Tracking Construction Material over Space and Time Prospective and Geo-referenced modelling of Building Stocks and Construction Material Flows | Academic | CDW              | Scenario to 2060    | Global   | 6 scenarios concerning per-capita floor area, building stock turnover, and construction material. | <a href="#">🔗</a> |
| Global construction materials database and stock analysis of residential buildings between 1970–2050   | Academic | CDW              | Scenario to 2060    | Global   | 1 (SSP2)  | <a href="#">🔗</a> |
| A comprehensive set of global scenarios of housing, mobility, and material efficiency for material cycles and energy systems modelling         | Academic | CDW              | Scenario to 2060    | Global   | Low energy demand, SSP1, SSP2   | <a href="#">🔗</a> |
| Global scenarios of resource and emission savings from material efficiency in residential buildings and cars                                   | Academic | CDW, ELV         | Scenarios to 2050   | Global   | SSP1, SSP2  | <a href="#">🔗</a> |
| Matching global cobalt demand under different scenarios for co-production and mining attractiveness  | Academic | BAT              | 2050                | Global   | 5   | <a href="#">🔗</a> |
| Copper at the crossroads: Assessment of the interactions between low-carbon energy transition and supply limitations                           | Academic | Copper           | 2050                | Global   | 2: 2°C and 4°C  | <a href="#">🔗</a> |
| The impact of climate policy implementation on lithium, cobalt and nickel demand: The case of the Dutch automotive sector up to 2040           | Academic | ELV, Batteries   | Scenario: 2019–2040 | NL       | 2 (Based on policies)   | <a href="#">🔗</a> |
| The rise of electric vehicles—2020 status and future expectations  | Academic | ELV, BAT         | up to 2050          | Global   | various   | <a href="#">🔗</a> |

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Table 13.4 – Continued from previous page

| LITERATURE   | TYPE     | WASTE STREAM         | TEMPORAL COVERAGE | LOCATION | NUMBER OF SCENARIOS                                       | LINK              |
|--|----------|----------------------|-------------------|----------|---|-------------------|
| Scenarios for the Return of Lithium-ion Batteries out of Electric Cars for Recycling   | Academic | ELV, Battery         | Scenario to 2050  | Global   | 2   | <a href="#">🔗</a> |
| The dynamic equilibrium mechanism of regional lithium flow for transportation electrification  | Academic | ELV, BAT             | Scenario to 2050  | Global   | 1 (projection)  | <a href="#">🔗</a> |
| Future material demand for automotive lithium-based batteries  | Academic | ELV, BAT             | Scenario to 2050  | Global   | 4 (based on IEA)  | <a href="#">🔗</a> |
| Analysis of the Li-ion battery industry in light of the global transition to electric passenger light-duty vehicles until 2050             | Academic | ELV, BAT             | Scenario to 2050  | Global   | Combination of SSPs and RCPs                              | <a href="#">🔗</a> |
| Circular economy strategies for electric vehicle batteries reduce reliance on raw materials  | Academic | ELV, BAT             | Scenario to 2050  | Global   | Reference + 4 technologies                                | <a href="#">🔗</a> |
| Summary and critical review of the International Energy Agency's special report: The role of critical minerals in clean energy transitions | Academic | Energy               | 2050              | Global   | n/a   | <a href="#">🔗</a> |
| Review of critical metal dynamics to 2050 for 48 elements  | Academic | Energy               | Scenario to 2050  | Global   | 1 compiled from various renewable technologies            | <a href="#">🔗</a> |
| Major metals demand, supply, and environmental impacts to 2100: A critical review  | Academic | Energy               | Scenario to 2100  | Global   | 1 review of 197 studies                                   | <a href="#">🔗</a> |
| Requirements for Minerals and Metals for 100% Renewable Scenarios  | Academic | Energy               | Scenario to 2050  | Global   | 1.5 degree scenario                                       | <a href="#">🔗</a> |
| The 3-machines energy transition model: Exploring the energy frontiers for restoring a habitable climate                                   | Academic | Energy               | 2100              | Global   | 20, rapid transition stabler 1.5 °C and return to 350 ppm | <a href="#">🔗</a> |
| Modelling the demand and access of mineral resources in a changing world   | Academic | Energy, Construction | 2060              | Global   | RTS, BD2S IEA   | <a href="#">🔗</a> |
| Rare earths in the energy transition: what threats are there for the 'vitamins of modern society'?   | Academic | Rare earths          | 2050              | Global   | 2: 2°C and 4°C  | <a href="#">🔗</a> |
| A slag prediction model in an electric arc furnace process for special steel production  | Academic | SLASH                | None              | Global   | n/a   | <a href="#">🔗</a> |
| Decarbonising the iron and steel sector for a 2°C target using inherent waste streams  | Academic | SLASH                | Scenario to 2050  | Global   | 1 (2 degree climate goal)                                 | <a href="#">🔗</a> |
| Environmental Implications of Future Demand Scenarios for Metals: Methodology and Application to the Case of Seven Major Metals            | Academic | Various              | Scenario to 2050  | Global   | 4 (UN GEO-4)  | <a href="#">🔗</a> |

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Table 13.4 – Continued from previous page

| LITERATURE   | TYPE        | WASTE STREAM | TEMPORAL COVERAGE | LOCATION | NUMBER OF SCENARIOS                    | LINK              |
|--|-------------|--------------|-------------------|----------|--|-------------------|
| Resource Demand Scenarios for the Major Metals   | Academic    | Various      | Scenario to 2050  | Global   | 4 (UN GEO-4)                           | <a href="#">🔗</a> |
| Raw material depletion and scenario assessment in European Union – A circular economy approach                 | Academic    | Various      | None              | EU       | n/a                                    | <a href="#">🔗</a> |
| Material bottlenecks in the future development of green technologies   | Academic    | Various      | Scenario to 2050  | Global   | 1 (BAU)                                | <a href="#">🔗</a> |
| Reuse assessment of WEEE: Systematic review of emerging themes and research directions                         | Academic    | WEEE         | None              | Global   | n/a                                    | <a href="#">🔗</a> |
| A systematic literature review on the circular economy initiatives in the European Union                       | Academic    | Circularity  | None              | EU       | Circular strategies                    | <a href="#">🔗</a> |
| Material Flow Accounting: Measuring Global Material Use for Sustainable Development                            | Academic    | Various      | Scenario to 2100  | Global   | 1 (BAU)                                | <a href="#">🔗</a> |
| Circular Economy Action Plan   | Action plan | Various      | Scenario to 2050  | EU       | 35 actions to climate neutrality       | <a href="#">🔗</a> |
| Construction and demolition waste: challenges and opportunities in a circular economy                          | Report      | CDW          | None              | EU       | n/a                                    | <a href="#">🔗</a> |
| IEA world energy model   | Report      | Energy       | Scenario to 2050  | Global   | 4                                      | <a href="#">🔗</a> |
| Bloomberg scenarios  | Report      | Energy       | Scenario to 2050  | Global   | 3                                      | <a href="#">🔗</a> |
| The Role of Critical Minerals in Clean Energy Transitions  | Report      | Energy       | None              | Global   | n/a                                    | <a href="#">🔗</a> |
| Transitions to 2050 decide now act for climate   | Report      | Energy       | Scenario to 2050  | France   | 4 to reach 2.1C by 2100                | <a href="#">🔗</a> |
| Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system | Report      | Energy       | Scenario to 2050  | EU       | low and high material demand scenarios | <a href="#">🔗</a> |
| Inventaires des besoins en matière, énergie, eau et sols des technologies de la transition énergétique         | Report      | Energy       | Scenario to 2050  | France   | 1                                      | <a href="#">🔗</a> |
| Minerals in the future of Europe   | Report      | MinW         | Scenario to 2050  | EU       | 3 (2050 net-zero, digital, circular)   | <a href="#">🔗</a> |
| Minerals, Critical Minerals and the US Economy   | Report      | MinW         | None              | US       | n/a                                    | <a href="#">🔗</a> |
| Minéraux stratégiques – État des lieux et propositions pour une vision partagée                                | Report      | MinW         | None              | FR       | n/a                                    | <a href="#">🔗</a> |

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Table 13.4 – Continued from previous page

| LITERATURE   | TYPE     | WASTE STREAM | TEMPORAL COVERAGE | LOCATION | NUMBER OF SCENARIOS | LINK |
|--|----------|--------------|-------------------|----------|---------------------|------|
| The Critical Raw Materials (CRM) initiative – Underpinning the strategic approach to the EU's raw materials policy | Report   | MinW         | None              | EU       | n/a                 |      |
| Towards the Circular Economy: Accelerating the scale-up across global supply chains                                | Report   | Circularity  | None              | Global   | n/a                 |      |
| The Circular Economy in Europe   | Report   | Circularity  | None              | EU       | n/a                 |      |
| Global material flows and resource productivity: Forty years of evidence   | Report   | Circularity  | None              | Global   | n/a                 |      |
| The circular economy concept: contextualisation and multiple perspectives  | Report   | Circularity  | None              | Global   | n/a                 |      |
| Global material flows database   | Database | Various      | None              | Global   | n/a                 |      |
| International Resource Panel   | Reports  | Various      | None              | Global   | n/a                 |      |
| World Business Council for Sustainable Development   | Reports  | Various      | None              | Global   | n/a                 |      |
| Ellen MacArthur Foundation   | Reports  | Various      | None              | Global   | n/a                 |      |
| European Environment Agency  | Reports  | Various      | None              | EU       | n/a                 |      |
| International Energy Agency  | Reports  | Energy       | None              | Global   | n/a                 |      |
| United Nations Environment Programme   | Reports  | Various      | None              | Global   | n/a                 |      |
| United Nations Industrial Development Reports  | Reports  | Various      | None              | Global   | n/a                 |      |
| World Bank   | Reports  | Various      | None              | Global   | n/a                 |      |
| World Economic Forum   | Reports  | Various      | None              | Global   | n/a                 |      |

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## 13.5. DRIVERS AND FACTORS IDENTIFIED IN THE INITIAL COLLECTION PHASE

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Table 13.5 lists the elements that were identified in the initial phase of driver/factor collection.

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Table 13.5: Drivers and factors identified in the initial collection phase

| METHOD  | DESCRIPTION  |
|---|--|
| Stricter environmental regulations            | Increased regulations and policies aimed at reducing environmental impact    |
| Inflation                                     | Increase in the general price level of goods and services over time          |
| Employment rates                              | Percentage of the working-age population that is employed                    |
| Exchange rates                                | Value of one currency relative to another currency                           |
| Interest rates                                | Cost of borrowing money or the return on investment                          |
| Gasoline price                                | Cost of gasoline for vehicles  |
| Electricity price                             | Cost of electricity for consumers or businesses                              |
| Raw material prices                           | Prices of primary materials used in production processes                     |
| CO2 market                                    | Trading system for carbon emissions permits or credits                       |
| Education level                               | Level of education attained by individuals or the overall population         |
| Volunteering                                  | Engagement in unpaid activities for the benefit of others                    |
| Transparency                                  | Openness, accountability, and information accessibility                      |
| Compliance with rules                         | Adherence to regulations, guidelines, or standards                           |
| Cultural values / Consciousness               | Beliefs, attitudes, and awareness of individuals and society                 |
| Accessibility                                 | Ease of access to goods, services, or infrastructure                         |
| Land rights                                   | Legal rights to ownership, use, or access to land                            |
| Work-life balance                             | Equilibrium between work and personal life                                   |
| Urbanisation                                  | Increase in the population living in urban areas                             |
| Water supply constraints                      | Limitations on the availability or access to freshwater resources            |
| Increased intrinsic drive for env. protection | Growing internal motivation to protect and conserve the environment          |
| NIMBY to projects                             | Not-In-My-Backyard opposition to the location of certain projects            |
| Climate change impacts (flooding, etc.)       | Consequences of climate change, such as increased flooding or extreme events |
| Climate change mitigation efforts             | Actions taken to reduce greenhouse gas emissions and combat climate change   |
| Redundancy                                    | Availability of backup systems or alternative options                        |
| Material efficiency                           | Effective use and management of materials to minimize waste and loss         |
| Energy efficiency of buildings                | Performance and efficiency of energy consumption in buildings                |

Continued on next page

Table 13.5 – Continued from previous page

| METHOD  | DESCRIPTION   |
|---|---|
| Change of products in the scope WEEE directive          | Inclusion or exclusion of certain products within the scope of the WEEE directive |
| GDP/PPP   | Gross Domestic Product (GDP) adjusted for purchasing power parity (PPP)           |
| Improved repairability                                  | Enhanced ability to repair and maintain products or equipment                     |
| Target enforcement                                      | Implementation and enforcement of specific targets or goals                       |
| Data protection   | Safeguarding personal data and ensuring privacy                                   |
| Infrastructure  | Physical structures and facilities necessary for the functioning of society       |
| Intellectual property issues                            | Legal rights and protections for intellectual creations and innovations           |
| Population  | Total number of people in a given area or region                                  |
| Resource shortage                                       | Insufficient availability or scarcity of natural resources                        |
| Treatment cost  | Cost of waste treatment, disposal, or recycling processes                         |
| Digital product passports                               | Digital documentation providing information about a product's lifecycle           |
| Obsolescence  | State of being outdated or no longer in use or demand                             |
| Digitalization  | Integration and adoption of digital technologies and processes                    |
| SRM prices  | Prices of secondary raw materials or recycled materials                           |
| Product prices  | Prices of goods or products in the market   |
| Recyclability mandates                                  | Requirements or regulations promoting the recyclability of products               |
| Conflict in supply chain                                | Disputes or conflicts within the supply chain of raw materials or products        |
| Obligatory recycling standards for treatment facilities | Mandatory standards for recycling processes in treatment facilities               |
| Improved durability                                     | Enhanced longevity and resistance of products or materials                        |
| Composition change                                      | Alteration or modification of the composition of materials or products            |
| Subsidies   | Financial support or incentives provided by governments or organizations          |
| Availability of recovery technologies                   | Existence and accessibility of technologies for material recovery                 |
| Taxation (raw materials, landfill)                      | Imposition of taxes on raw materials or landfill activities                       |
| Obligatory removal of CRMs from waste                   | Required removal or extraction of critical raw materials from waste streams       |
| Corruption  | Dishonest or unethical behaviour, typically involving misuse of power             |
| Supply chain due diligence laws                         | Regulations or laws requiring companies to assess and manage supply chain risks   |

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Table 13.5 – Continued from previous page

| METHOD                          | DESCRIPTION  |
|---------------------------------|--|
| Improved recyclability          | Increased ability of products or materials to be recycled or reused        |
| Ecodesign                       | Designing products with consideration for their environmental impact       |
| Trade barriers                  | Barriers or restrictions to international trade or commerce                |
| Industrialization of Europe     | Development and growth of industrial activities in European countries      |
| Reduced consumerism             | Shift towards decreased consumption and a more sustainable lifestyle       |
| Accessibility/Infrastructure    | Availability and adequacy of infrastructure to support accessibility       |
| New mines in rich EU countries? | Establishment of new mines in economically prosperous European countries   |
| Miniaturization                 | Process of making products or components smaller and more compact          |
| Sharing economy                 | Economic system based on sharing resources and services                    |
| Repairability mandates          | Requirements or regulations promoting the repairability of products        |
| Renewable energy targets        | Set goals or objectives for increasing the use of renewable energy sources |

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## 13.6. DRIVERS AND FACTORS IDENTIFIED IN THE SCREENING PHASE

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4468 The following table lists the scenario elements that were identified in the screening phase of driver/factor collection.

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Table 13.6: List of drivers and factors identified in the screening phase

| DOMAIN          | DRIVER/FACTOR                                      | DEFINITION   | BAU | REC | CIR |
|-----------------|--|--|-----|-----|-----|
| Economic        | CO2 market price                                   | Price of carbon dioxide (CO2) emissions in carbon markets  | I   | I   | I   |
| Economic        | Economic growth                                    | Rate of economic growth  | I   | I   | I   |
| Economic        | Energy prices                                      | Prices of energy resources   | I   | I   | I   |
| Economic        | Market saturation                                  | Level of saturation reached in the market for certain products or services   | I   | I   | II  |
| Economic        | Raw material vs SRM prices                         | Price comparison between raw materials and Secondary Raw Materials (SRMs)  | I   | I   | I   |
| Economic        | Re-industrialisation of EU                         | Process of revitalizing industrial activities in the European Union  | I   | I   | I   |
| Environmental   | Climate change impacts (flooding, etc.)            | Impacts of climate change such as flooding and other related events  | I   | I   | I   |
| Environmental   | Climate change mitigation efforts                  | Efforts made to mitigate the effects of climate change   | I   | I   | I   |
| Environmental   | Increased drive for env. protection                | Growing motivation and drive to protect the environment  | I   | III | III |
| Environmental   | Resource shortage                                  | Shortage of natural resources  | I   | I   | I   |
| Legal/Political | Ecodesign/re-X mandates                            | Establishment of ecodesign requirements for specific product groups to improve circularity, energy performance, and other environmental sustainability aspects | I   | II  | III |
| Legal/Political | Governance: corruption vs compliance               | Contrasting levels of corruption and compliance within governance systems  | I   | I   | I   |
| Legal/Political | International trade and co-operation (vs. autarky) | Level of international trade and cooperation versus self-sufficiency   | I   | I   | I   |
| Legal/Political | Product information transparency                   | Provision of transparent product information to consumers, manufacturers, importers, repairers, recyclers, or national authorities                             | I   | III | III |
| Legal/Political | Progress toward renewable energy targets           | Progress made in achieving renewable energy targets  | I   | I   | I   |
| Legal/Political | Stricter environmental regulations                 | Implementation of more stringent rules and regulations for environmental protection  | I   | III | III |
| Legal/Political | Subsidies/taxation to promote circularity          | Provision of subsidies or implementation of taxation policies to incentivize circularity   | I   | I   | I   |
| Legal/Political | Supply chain due diligence laws                    | Implementation and enforcement of laws requiring companies to address negative human rights and environmental impacts in their value chains                    | I   | II  | III |
| Social          | Hoarding   | The act of stockpiling and keeping excessive amounts of products   | III | II  | II  |
| Social          | NIMBY to projects                                  | Opposition of local communities to the location of new projects, such as mining, in their vicinity   | I   | I   | I   |
| Social          | Participation in re-X activities                   | "Involvement in activities related to the ""re-"" concepts, including refusing, reducing, repairing, and reusing products"                                     | I   | II  | III |
| Social          | Population   | Size and growth of the population  | I   | I   | I   |

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Table 13.6 – Continued from previous page

| DOMAIN    | DRIVER/FACTOR                       | DEFINITION   | BAU | REC | CIR |
|-----------|-------------------------------------|--|-----|-----|-----|
| Social    | Urbanisation                        | Rate of urban population growth  | I   | I   | I   |
| Technical | Digitisation                        | Adoption and integration of digital technologies   | I   | I   | I   |
| Technical | Integration of SRM system across EU | Integration of a Secondary Raw Materials (SRM) system across the European Union                          | I   | III | III |
| Technical | Product technology                  | Changes in product function or composition that lead to changes in waste stream composition and quantity | I   | III | III |
| Technical | Recovery technology                 | Technologies and processes for recovering materials from waste   | I   | III | III |

## 13.7. DRIVERS AND FACTORS AFTER CATEGORISATION

4470 The 21 elements that were identified in this stage are listed in Table 13.7.

4471 Note that CIR and REC are very similar for many scenario elements, the main difference being the way  
4472 in which the targets are achieved. That is, for CIR, re-X strategies are promoted, whereas, for REC, the focus  
4473 is on technological advancements in the recovery system.  
4474

4475 This distinction will have a significant impact on how the scenarios are quantitatively modelled and on  
4476 the subsequent outcomes of these models.  
4477

Table 13.7: List of drivers and factors identified in the screening phase

| DOMAIN | DRIVER/FACTOR   | DEFINITION   | INTERNAL | BAU | REC | CIR |
|--------|---|--|----------|-----|-----|-----|
| TECH   | Recovery technology   | Implementation and advancements in waste recovery technologies                   | TRUE     | I   | III | III |
| TECH   | Product technology  | Changes in product function or composition                                       | TRUE     | I   | III | III |
| TECH   | Integration of SRM system across EU                             | Integration of a secondary raw material recovery system across EU countries      | TRUE     | I   | III | III |
| ENV    | Increased drive for environmental protection                    | Growing concern and motivation for environmental conservation                    | TRUE     | I   | III | III |
| ECO    | Progress toward renewable energy targets                        | Advancements and achievements in renewable energy generation                     | TRUE     | III | III | III |
| ECO    | Subsidies and taxation to promote circularity                   | Financial incentives or taxes to encourage circular economy                      | TRUE     | I   | II  | III |
| SOC    | Participation in re-X activities                                | Engagement in refuse-reduce-repair-reuse activities                              | TRUE     | I   | I   | III |
| POL    | Stricter environmental regulations                              | Tightening of environmental laws and regulations                                 | TRUE     | II  | III | III |
| POL    | Stricter waste management regulations                           | Strengthening of waste management laws and regulations                           | TRUE     | II  | III | III |
| POL    | Supply chain due diligence laws: implementation and enforcement | Obligations for identifying and mitigating negative impacts in supply chains     | TRUE     | I   | III | III |
| POL    | Compliance with waste targets                                   | Meeting specific waste management and recycling targets                          | TRUE     | I   | III | III |
| ENV    | Resource shortages  | Limited availability of natural resources  | FALSE    | n/a | n/a | n/a |
| ECO    | Raw material vs SRM prices                                      | Price dynamics and competition between raw materials and secondary raw materials | FALSE    | n/a | n/a | n/a |
| ENV    | Climate change impactsmitigation                                | Effects and actions related to climate change                                    | FALSE    | n/a | n/a | n/a |
| ECO    | International trade and co-operation (vs. autarky)              | Collaborative trade agreements and global cooperation                            | FALSE    | n/a | n/a | n/a |
| ECO    | Energy prices   | Costs and fluctuations in energy prices  | FALSE    | n/a | n/a | n/a |
| ECO    | Economic growth   | Overall economic expansion and development                                       | FALSE    | n/a | n/a | n/a |
| ECO    | Re-industrialisation of EU                                      | Shift towards increased industrial activities in the EU                          | FALSE    | n/a | n/a | n/a |
| SOC    | NIMBY to projects   | Opposition to local projects and developments                                    | FALSE    | n/a | n/a | n/a |

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Table 13.7 – Continued from previous page

| DOMAIN | DRIVER/FACTOR               | DEFINITION                                    | INTERNAL | BAU | REC | CIR |
|--------|-----------------------------|---|----------|-----|-----|-----|
| SOC    | Population and urbanisation | Growth and urban development of population    | FALSE    | n/a | n/a | n/a |
| ECO    | CO2 market price            | Price and market dynamics of carbon emissions | FALSE    | n/a | n/a | n/a |

## 13.8. DRIVERS AND FACTORS FOR QUANTIFICATION

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4479 The following Table 13.8 lists the categorised scenario elements that were quantified and incorporated into the modelling.

**Table 13.8: List of scenario elements categorised for quantification. The roman numerals in the columns BAU, REC, and CIR represent the magnitude of the future trend for the element in the scenario. Internal, external, and outside refer to the classification type of the scenario element**

| DOMAIN | ELEMENT  | INTERNAL | EXTERNAL | OUTSIDE | BAU | REC | CIR | PARAMETERS AFFECTED   |
|--------|--|----------|----------|---------|-----|-----|-----|---|
| ECO    | Subsidies and taxation to promote circular strategies  | ✓        |          |         | I   | I   | III | demand, waste generation, lifetimes, sharing, collection,   |
| POL    | Targets and enforcement to promote circular strategies | ✓        |          |         | I   | I   | III | demand, waste generation, lifetimes, sharing, collection  |
| SOC    | Participation in re-X activities                       | ✓        |          |         | I   | I   | III | demand, waste generation, lifetimes, sharing, collection,   |
| ECO    | Subsidies and taxation to promote recovery strategies  | ✓        |          |         | I   | III | I   | recycling rates, recovery capacity, recovery impacts, collection                                      |
| POL    | Targets and enforcement to promote recovery strategies | ✓        |          |         | I   | III | I   | recycling rates, recovery rates, capacity   |
| POL    | Supply chain due diligence laws                        | ✓        |          |         | I   | III | III | composition, export   |
| POL    | Stricter environmental regulations                     | ✓        |          |         | I   | III | III | composition, waste generation, lifetimes, export, recovery rates, recovery capacity, recovery impacts |
| POL    | Stricter waste management regulations                  | ✓        |          |         | I   | III | III | composition, waste generation, lifetimes, export, recovery rates, recovery capacity, recovery impacts |
| TECH   | Product technology                                     | ✓        |          |         | I   | III | III | lifetimes, recovery rates, recovery impacts   |
| TECH   | Recovery technology                                    | ✓        |          |         | I   | III | III | recovery rates, recovery capacity, recovery impacts   |
| TECH   | Integration of SRM recovery system across Europe       | ✓        |          |         | I   | III | III | recycling rates, recovery rates, recovery capacity, recovery impacts                                  |
| ECO    | Progress toward renewable energy targets               |          | ✓        |         | -   | -   | -   | composition, demand, waste generation, recovery impacts   |
| ECO    | Economic growth  |          | ✓        |         | -   | -   | -   | composition, demand, waste generation   |
| SOC    | Population   |          | ✓        |         | -   | -   | -   | demand, waste generation  |
| ECO    | Primary vs. secondary raw material prices              |          | ✓        |         | n/a | n/a | n/a | considered in sensitivity analysis  |

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| DOMAIN | ELEMENT  | INTERNAL | EXTERNAL | OUTSIDE | BAU | REC | CIR | PARAMETERS AFFECTED                                      |
|--------|--|----------|----------|---------|-----|-----|-----|--|
| ECO    | Energy prices                                      |          | ✓        |         | n/a | n/a | n/a | considered in sensitivity analysis                       |
| ECO    | Carbon price                                       |          | ✓        |         | n/a | n/a | n/a | considered in sensitivity analysis                       |
| ENV    | Resource supply constraints                        |          | ✓        |         | n/a | n/a | n/a | considered in sensitivity analysis:                      |
| ECO    | International trade and co-operation (vs. autarky) |          |          | ✓       | n/a | n/a | n/a | not model input (resource supply constraints is a proxy) |
| ECO    | Re-industrialisation of EU                         |          |          | ✓       | n/a | n/a | n/a | not model input  |
| SOC    | Resistance to recovery projects (NIMBY)            |          |          | ✓       | n/a | n/a | n/a | not model input (considered in UNFC assessments)         |

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## 13.9. WORK BREAKDOWN STRUCTURE FOR WP2

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Table 13.9 lists tasks and subtasks for work package two, along with the responsible partner and the planned start and end dates for each task. This table was sourced from the FuTuRaM project management plan [153].

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Table 13.10 shows the Gaant chart for the entire FuTuRaM project. This chart was sourced from the FuTuRaM grant agreement, page 37 [151].

| WP | Task | SubTask | SubTask Name  | Waste Group | Step (Optional) | Description SubTask/Step  | Partners   |         |      |          |     |     |          |     |      |            | Start | End  |     |     |     |
|----|------|---------|---|-------------|-----------------|---|------------|---------|------|----------|-----|-----|----------|-----|------|------------|-------|------|-----|-----|-----|
|    |      |         |   |             |                 |   | WEEE Forum | UNI PAR | BRGM | Chalmers | GTK | IMU | RECHARGE | SGU | TU B | Leiden Uni | ViTO  | EmPa | UCL |     |     |
| 2  | 2.1  | 2.1.1   | Scenario mapping  | ALL         |                 | Map various studies from the academic, policy, and gray literature for future scenarios and assess the applicability within FutuRaM   | X          | X       | X    | X        | X   | X   | X        | X   | X    | X          | X     | M01  | M05 |     |     |
| 2  | 2.1  | 2.1.2   | Scenario methods  | ALL         |                 | Compile various methodologies for scenario development and assess their applicability for developing scenarios on material recovery and circular economy for Europe   | X          | X       | X    | X        | X   | X   | X        | X   | X    | X          | X     | M02  | M05 |     |     |
| 2  | 2.1  | 2.1.3   | Scenario storylines   | ALL         |                 | Flesh out the storylines of the 3 main scenarios  | X          |         | X    |          |     |     |          | X   | X    |            |       |      | M05 | M08 |     |
| 2  | 2.1  | 2.1.4   | Qualitative scenario development                                      | ALL         |                 | Use the chosen methods and qualitative methods to develop the three main scenarios to be used in FutuRaM (e.g. BAU, increased material recovery, and full circular economy)   |            | X       |      | X        |     |     | X        |     | X    | X          |       | X    | M07 | M11 |     |
| 2  | 2.2  | 2.2.1   | Emerging technology assessment for future material use                | ALL         |                 | Compile information on emerging technologies for sectors associated with waste streams, including changing material use   | X          | X       | X    | X        | X   | X   | X        | X   | X    | X          | X     |      | M03 | M10 |     |
| 2  | 2.2  | 2.2.2   | Emerging technology assessment for recovery                           | ALL         |                 | Compile information on emerging technologies for sectors associated with waste streams, including changing material use   | X          | X       | X    | X        | X   | X   | X        | X   | X    | X          | X     |      | M07 | M11 |     |
| 2  | 2.2  | 2.2.3   | Technology quantification   | ALL         |                 | Develop methods for a quantified assessment of technology implementation (e.g. market share)  |            | X       |      | X        |     |     |          |     |      |            |       |      |     | M11 | M16 |
| 2  | 2.2  | 2.2.4   | Technology intergration   | ALL         |                 | Quantitatively integrate future technologies into the scenarios   |            | X       |      | X        |     |     |          |     |      |            |       |      |     | M16 | M20 |
| 2  | 2.2  | 2.2.5   | Technology integration  | ALL         |                 | Quantitatively integrate future technologies into the scenarios with Tasks 4.1 and 4.2<br>Compile (and possibly harmonize) present and future material use based on emerging technology assessment (Subtask 2.2.1)  |            |         |      |          |     |     |          |     |      |            |       |      | M14 | M20 |     |
| 2  | 2.3  | 2.3.1   | Future product/resource material composition                          | ALL         |                 | Identify methods for imputing missing composition data  | X          | X       | X    |          |     |     |          | X   | X    | X          | X     | X    |     | M06 | M18 |
| 2  | 2.3  | 2.3.2   | Methods for data gaps in future compositions                          | ALL         |                 | Create database of material compositions for future products/waste streams for each scenario in combination with WP3  | X          |         |      |          |     |     |          | X   | X    |            |       |      |     | M14 | M20 |
| 2  | 2.3  | 2.3.3   | Create database of future waste stream compositions                   | ALL         |                 | Compile preliminary results from Tasks 4.1 and 4.2 and WP3, and harmonize initial waste stream results, feeding back to these tasks   |            | X       | X    | X        |     |     |          | X   | X    | X          | X     | X    |     | M18 | M20 |
| 2  | 2.4  | 2.4.1   | Harmonization of future material waste stream material recovery       | ALL         |                 | Evaluate the use of S-LCA, tecnoeconomic assessments, cost-benefit analysis, multi-criteria analysis using information from both the waste stream models and the UNFC case studies                                  |            |         |      |          |     |     |          | X   | X    |            |       |      | M18 | M21 |     |
| 2  | 2.4  | 2.4.2   | Develop methods for environmental and social and economic assessments | ALL         |                 | Implement methods chosen from subtask 2.4.2 to assess the social, economic, and environmental impacts for each scenario (thus quantify environmental and socioeconomic impacts of SRM recovery under each scenario) |            |         | X    | X        |     | X   |          |     |      | X          |       | X    |     | M18 | M30 |
| 2  | 2.4  | 2.4.3   | Perform social, economic and environmental assessments                | ALL         |                 | Adapt/modify/streamline the methodology for application within the context of the UNFC  |            |         |      | X        |     | X   |          | X   |      | X          | X     | X    |     | M30 | M36 |
| 2  | 2.4  | 2.4.4   | Feedback with UNFC methodology  | ALL         |                 | Compile all the modelling and case study information thus far and prepare for report writing  |            |         |      | X        |     | X   |          | X   |      | X          | X     | X    |     | M24 | M36 |
| 2  | 2.5  | 2.5.1   | Compile information for the report                                    | ALL         |                 | Write the report on the bottlenecks, environmental, and socioeconomic impacts of secondary material recovery  | X          | X       | X    | X        | X   | X   | X        | X   | X    | X          | X     |      | M37 | M43 |     |
| 2  | 2.5  | 2.5.2   | Report writing  | ALL         |                 | Report review by stakeholders and partners  | X          | X       | X    | X        |     | X   | X        | X   | X    | X          | X     |      | M44 | M45 |     |
| 2  | 2.5  | 2.5.3   | Report reviewing  | ALL         |                 | Revise report based on recommendations  | X          | X       |      |          |     |     |          |     |      |            |       |      |     | M46 | M46 |
| 2  | 2.5  | 2.5.4   | Report revising   | ALL         |                 | Deliver final report  |            |         |      |          |     |     |          |     |      |            |       |      | M47 | M47 |     |
| 2  | 2.5  | 2.5.5   | Report delivery   | ALL         |                 |   |            |         |      |          |     |     |          |     |      |            |       |      | M48 | M48 |     |

Table 13.9: Work breakdown structure for work package two

| Title   | Leader/M |  | Year 1 |   | Associate | Year 2 with document |   | Year 3 |    | Area (2021) |    | Year 4 |     | ISB |    | 20/05/2021 |    |    |    |    |    |    |    |      |    |    |          |
|---|----------|--|--------|---|-----------|----------------------|---|--------|----|-------------|----|--------|-----|-----|----|------------|----|----|----|----|----|----|----|------|----|----|----------|
|   |          |  | 1      | 3 |           | 5                    | 7 | 9      | 11 | 13          | 15 | 17     | 19  | 21  | 23 | 25         | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41   | 43 | 45 | 47       |
| <b>1 Conceptual and Methodological Development</b>                          | Empa     |  |        |   |           | M6                   |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    | D1.1 |    |    |          |
| 1.1 Develop, harmonize and integrate framework, concepts, methods and tools | Empa     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    | D1.2 |    |    |          |
| 1.2 Proposal on SRMs statistics to the EC                                   | Empa     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    | D1.3 |    |    |          |
| 1.3 Draft reporting standard in line with the UNFC                          | UNITAR   |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| <b>2 Foresight for Future Secondary Raw Materials</b>                       | ULEI     |  |        |   |           |                      |   |        |    |             |    |        | M11 |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 2.1 Develop scenario storyline  | ULEI     |  |        |   |           |                      |   |        |    |             |    |        |     | M17 |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 2.2 Integrate future technologies into the scenarios                        | Chalm    |  |        |   |           |                      |   |        |    |             |    |        |     | M17 |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 2.3 Forecast material composition and products for each scenario            | TUB      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 2.4 Quantify environmental and socioeconomic impacts of the scenarios       | ULEI     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 2.5 Env. and socio-econ. impacts and bottlenecks of future scenarios        | ULEI     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D.2.1    |
| <b>3 Secondary Raw Material Composition</b>                                 | TUB      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 3.1 Agree composition data templates for SRM potential                      | TUB      |  |        |   |           |                      |   |        |    |             |    |        | M7  |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 3.2 Collect, update, and consolidate composition data for SRMs              | TUB      |  |        |   |           |                      |   |        |    |             |    |        |     | M12 |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 3.3 Extend waste stream composition assessment to SRMs                      | TUB      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D3.1     |
| <b>4 Stock and Waste Flow Characterization</b>                              | UNITAR   |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 4.1 Quantify stocks and flows of ProSUM streams                             | UNITAR   |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 4.2 Quantify stocks and flows of CDW, MinW, SLASH                           | ULEI     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 4.3 Quantify SRM stocks and flows   | UNITAR   |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D4.1     |
| <b>5 SRM availability assessment in line with the UNFC ...</b>              | LMU      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 5.1 Map current practice, gaps and future needs for SRMs                    | LMU      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 5.2 Use case studies to test (...) in line with the UNFC                    | LMU      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D5.1     |
| <b>6 Development of data information system for EU</b>                      | BRGM     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 6.1 Data model, registries and harvesting for SRM-KB                        | BRGM     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 6.2 API : Injection web services and diffusion web services                 | BRGM     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M21      |
| 6.3 Web site: developing the SRM-KB in EU                                   | BRGM     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D6.1     |
| <b>7 Exploitation, Communication &amp; Dissemination</b>                    | SPI      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 7.1 Communication, dissemination and exploitation plan                      | SPI      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M15      |
| 7.2 Stakeholder mapping, consultation and engagement                        | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D7.4     |
| 7.3 Developing a business plan for the KERs                                 | SPI      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D7.3     |
| 7.4 Communication & dissemination tools and activities                      | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M22      |
| 7.5 Dissemination   | SPI      |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M10,D7.5 |
| 7.6 Clustering activities   | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M9       |
| <b>8 Project Management</b>   | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | M14      |
| 8.1 Consortium & Admin Management   | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.2 Scientific Management   | UNITAR   |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.3 Reporting and Legal & Financial Management                              | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.4 Risk Management   | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.5 Data Management Plan  | Empa     |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.6 Creation and management of the Advisory Board                           | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    |          |
| 8.7 Ethics requirements   | WF       |  |        |   |           |                      |   |        |    |             |    |        |     |     |    |            |    |    |    |    |    |    |    |      |    |    | D8.3     |

Table 13.10: Gantt chart for the entire FutuRaM project

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## **END OF REPORT**

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# FutuRaM

Future availability  
of secondary  
raw materials