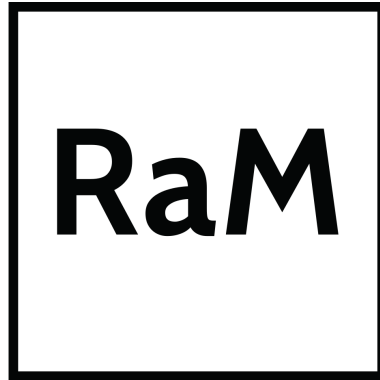


Futu RaM

Future availability
of secondary
raw materials



Work Package 2

Future recovery of secondary raw materials

Scenario Development

DRAFT REPORT

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July 13, 2023

THIS IS A DRAFT REPORT

please submit comments and corrections to s.c.mcdowall@cml.leidenuniv.nl:

- in a txt file with the line numbers or as a pdf with comments (send me one or contribute to the shared one in the FutuRaM WP2 sharepoint)
- or directly as a pull request to the \LaTeX source files on the WP2 github repository

TO DO:

- add more references to the text and their details in 'references.bib'
- waste stream groups to check the sections related to their waste streams

1 I. Preface

2 The FutuRaM project seeks to quantify the current and future availability of secondary raw
3 materials (SRM) with a focus on critical raw materials (CRMs) for six waste streams. The waste
4 streams are:

- 5 • waste electrical and electronic equipment (WEEE)
- 6 • waste batteries (BAT)
- 7 • end-of-life vehicles (ELV)
- 8 • mining waste (MIN)
- 9 • slags and ashes (SLASH)
- 10 • construction and demolition waste (CDW)

11 Work package 2 (WP2) is conducting foresight studies for materials critical to the EU econ-
12 omy, or materials that have significant impacts on EU sustainability because of their large vol-
13 umes. WP2 is developing a set of coherent scenarios for material use and waste/recovery over
14 time in various sectors in the EU. This report describes the three scenarios and the process by
15 which they were developed. The scenarios are:

- 16 • Business as usual (BAU)
- 17 • Recovery (REC)
- 18 • Circularity (CIR)

19 II. Executive Summary

20 This report presents the first phase of the scenario development process — the storyline nar-
21 rative phase. Three distinct future scenarios have been drafted up to the year 2050, Busi-
22 ness as usual, Recovery and Circularity. The scenarios are designed to be internally consistent
23 and to provide a overview of the potential future landscape of waste management and SRM
24 recovery within the EU. The scenario development process employs a methodology that in-
25 tegrates both forecasting and backcasting techniques to construct a comprehensive, future-
26 facing knowledge base that can aid fact-based decision-making.

27 **Scenario 1: Business as Usual (BAU)**

28 The BAU scenario extends the current situation into the future with limited deviation from ex-
29 isting patterns. Utilising backcasting and forecasting techniques, it assesses a potential future
30 where there might be minor advancements in resource efficiency, recovery technology, and
31 energy transition, but where primary extraction of raw materials remains the primary practice.

32 **Scenario 2: Recovery (REC)**

33 The Recovery scenario envisions a future that employs sophisticated technology to dramati-
34 cally enhance SRM recovery from waste streams. It presents a future where the EU success-
35 fully meets its recycling and recovery targets through an effective waste management system
36 and circular design principles. The scenario envisions an increased recovery rate of SRMs, ex-
37 tensive use of digitalisation and automation in recycling processes, and the implementation
38 of new waste regulations in alignment with EU targets.

39 **Scenario 3: Circularity (CIR)**

40 The Circularity scenario encapsulates the fullest possible realisation of a circular economy,
41 extending beyond end-of-life recovery of materials to minimising waste at all stages of pro-
42 duction and consumption. It envisions a future where the EU's targets for recycling, recovery,
43 and circularity are met through extensive stakeholder collaboration, the emergence of new
44 business models, and increased use of renewable energy and circular economy technologies.

45 In subsequent phases of the scenario development process, future product composition

46 and recovery technology will be examined, scenario elements will be quantified, and all sce-
47 nario data will be integrated and coupled with the quantitative models for waste generation
48 and SRM recovery.

49 Through the development of these scenarios, the FutuRaM project aims to provide a nu-
50 anced understanding of the potential future waste management and resource recovery land-
51 scape within the EU. This approach offers insights into key drivers, uncertainties, and the po-
52 tential impacts of policy interventions and technological advancements. By aligning SRM re-
53 covery projects more closely with the United Nations Framework Classification for Resources
54 (UNFC), the project aims to enable the commercial exploitation of SRMs and CRMs by manu-
55 facturers, recyclers, and investors. Ultimately, the comprehensive knowledge base developed
56 through this process is designed to support and inform the decision-making processes of pol-
57 icymakers and governmental authorities.

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117 VI. Summary of scenario storylines

118 Scenario I: Business as usual (BAU)

119 See section 2.1 for the full scenario description and waste-stream-specific scenario impact
120 narratives.

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

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

- 128 • A forecasting model is used to predict the future based on the current situation and the
129 development of existing trends.
- 130 • EU targets including those for recycling and recovery are not met, and the current linear
131 model largely persists.
- 132 • Material demand keeps pace with GDP growth, perpetuating a trend of increasing con-
133 sumption. Primary mining and extraction persist as the leading sources of raw materials,
134 underlining the dependency on traditional extraction methods.
- 135 • Recycling and recovery rates continue to lag, leading to an accumulation of SRM waste
136 that signals missed opportunities for resource reuse.
- 137 • The environmental repercussions of mining and extraction, such as land degradation
138 and water pollution, continue to be a pressing concern, reflecting the ecological toll of
139 this linear model.
- 140 • The EU's dependency on imports of SRMs escalates, heightening the risk of supply dis-

141 ructions. Investment in new SRM recovery technologies remains minimal, stifling inno-
142 vation and advancements in this field.

143 • The industrial focus remains on cost-effective material production and use, disregarding
144 the long-term sustainability aspect.

145 • Material scarcity and price fluctuations pose potential risks to the EU industry, highlight-
146 ing the vulnerability of this business model.

147 • Without any significant updates to environmental regulations, the negative impacts on
148 ecosystems and biodiversity intensify.

149 • Working conditions in mining and extraction industries see no substantial improvements,
150 highlighting continued issues of social inequality.

151 • The EU's reliance on fossil fuels continues, with the energy transition progressing at a
152 slow pace.

153 • The EU's dependency on imports of SRMs escalates, heightening the risk of supply dis-
154 ruptions.

155 **Scenario II: Recovery**

156 See section 2.2 for the full scenario description and the waste-stream-specific scenario impact
157 narratives.

158 In the recovery scenario, the central emphasis is on harnessing sophisticated technologies
159 to salvage SRMs from waste streams at the end of their lifecycle. While there are noticeable
160 strides towards the incorporation of 'circular design' principles and re-X strategies (which focus
161 on reducing, reusing, recycling, repairing, and refurbishing), a vestige of wasteful consumerism,
162 akin to the one observed in the BAU scenario, still lingers. However, this is somewhat mitigated
163 by the implementation of a comprehensive material recovery system.

164 Key characteristics of this technology promoted recovery scenario include:

- 165 • This scenario uses a combination of the forecasting and backcasting methods to envi-
166 sion the future.
- 167 • The backcasting method is used for scenario factors that are covered by governmental
168 targets, starting with the desired outcome and working backwards to the present.
- 169 • The forecasting method is used for scenario factors that are not covered by governmen-
170 tal targets, starting with the current situation and extending to the future.
- 171 • EU targets for recycling and recovery are met, due to the EU's waste management sys-
172 tem becoming more expansive, efficient and effective.
- 173 • Technological innovation drives increased recovery rates of SRMs, enabling the more
174 efficient use of waste.
- 175 • Digitalisation and automation are more extensively used in recycling processes, leading
176 to enhanced productivity and accuracy.
- 177 • There is greater exploration and exploitation of alternative sources such as urban mining,
178 waste streams, and tailings, presenting novel opportunities for resource acquisition.
- 179 • New waste regulations and guidelines for SRM recovery are implemented, enforcing
180 better management and extraction of SRMs.
- 181 • Investment in research and development for SRM recovery technologies experiences
182 an upswing, promoting continuous innovation in this field.
- 183 • Closer collaboration and information sharing between industry and government insti-
184 tutions streamline processes and expedite decision-making.
- 185 • New jobs are created in the recycling and recovery sector, offering economic benefits
186 and improving overall employment rates.
- 187 • SRM production and use become more efficient and cost-effective, fostering economic
188 sustainability.
- 189 • Environmental impacts from mining and extraction is reduced, signaling a more sus-
190 tainable approach to resource acquisition.

191 **Scenario III: Circularity**

192 See section 2.3 for the full scenario description and the waste-stream-specific scenario impact
193 narratives.

194 In this scenario, we move in the direction of the maximum achievable state of material
195 efficiency as government policy, private innovation and social changes are rapidly driving the
196 transition toward a circular economy. The emphasis here rests heavily on re-X strategies that
197 are implemented in the design phase of products (e.g., repairability and re-manufacturability)
198 and that are actualised by changes in consumer behaviour (e.g reduction, refusal, engagement
199 in the 'sharing-economy' and curtailment of the 'throw-away' mindset). Further, being enabled
200 by the widespread adoption of 'circular design' principles and improvements in information
201 transparency (e.g., waste tracking and digital product passports) the system for the treatment
202 of post-consumer waste can divert a significant amount of their inflows (to, for example, re-
203 use and re-manufacture) with the residual fraction being readily segregated into purer, more
204 efficiently recoverable, material streams. This scenario envisions a future where government
205 policies are in synergy with private sector innovation and societal changes, driving a wholesale
206 transition towards a circular economy. Unlike the recovery scenario, where the focus is on
207 the end-of-life recovery of materials, this scenario emphasises minimising waste at all stages,
208 starting from the design phase itself.

209 **The circular economy scenario is characterised by the following:**

- 210 • This scenario uses a combination of the forecasting and backcasting methods to envi-
211 sion the future.
- 212 • The backcasting method is used for scenario factors that are covered by governmental
213 targets, starting with the desired outcome and working backwards to the present.
- 214 • The forecasting method is used for scenario factors that are not covered by governmen-
215 tal targets, starting with the current situation and extending to the future.
- 216 • EU targets for recycling and recovery are met, as are those for circularity, due advances
217 in waste management, ecodesign and re-X strategies.

- 218 • A circular economy is implemented, prioritising waste reduction, resource efficiency,
219 and a shift from the 'take-make-dispose' model.
- 220 • A notable increase in SRM recycling and recovery rates, indicating an efficient use of
221 resources.
- 222 • A larger emphasis on designing products for reuse and recycling, making waste a valu-
223 able resource rather than a problem.
- 224 • More extensive use of renewable energy and clean technologies in SRM production and
225 use, supporting a low-carbon economy.
- 226 • Collaboration between stakeholders, including industry, government, and consumers,
227 improves, enhancing the implementation of circular practices.
- 228 • New business models like leasing and take-back schemes emerge, altering traditional
229 consumption patterns.
- 230 • Digitalisation and data use are heightened to improve efficiency and traceability, aiding
231 in effective resource management.
- 232 • Investment in research and development for circular economy technologies increases,
233 driving innovation and adoption.
- 234 • Awareness and education around sustainable consumption and production practices are
235 amplified, leading to behavioural changes in society.
- 236 • Environmental impacts from mining and extraction reduce, and reliance on imports de-
237 creases, suggesting greater self-sufficiency and sustainability.
- 238 • The creation of new jobs within the recycling, recovery and re-X sectors boosts the econ-
239 omy and alleviates social inequality.
- 240 • Stricter waste regulations and product design guidelines are introduced, accelerating the
241 transition towards circularity.

VII. Acronyms

Table O.1: List of acronyms

Acronym	Definition
SRM	Secondary Raw Material
CRM	Critical Raw Material
WEEE	Waste Electrical and Electronic Equipment
BATT	Waste Batteries
ELV	End-of-Life Vehicles
MIN	Mining Waste
SLASH	Slags and Ashes
CDW	Construction and Demolition Waste
LCA	Life Cycle Assessment
S-LCA	Social Life Cycle Assessment
UNFC	United Nations Framework Classification for Resources
AI	Artificial Intelligence
EU	European Union
EEE	Electrical and Electronic Equipment
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
GDP	Gross Domestic Product
BAU	Business as Usual
R&D	Research and Development
EoL	End-of-Life
EoU	End-of-Use
CE	Circular Economy
EoW	End-of-Waste
EPR	Extended Producer Responsibility
WFD	Waste Framework Directive

243

VIII. Terminology (abbreviated)

244

The following table provides an abbreviated list of terminology used in this report.

245

See section 5.1 for a complete list.

Table 0.2: List of terminology (abbreviated)

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

IX. Description of FutuRaM work package task 2.1

Associated milestones

Table O.3: Milestone list

Milestone	Milestone name	WP	Due date	Resp. partner	Means of verification
MS11	Mapping of published scenarios and Story-line/scenario description	2	Dec. 2023	ULEI	Dataset on available scenarios is fed into D1.1 and qualitative descriptions of 3 futures for the six waste streams are circulated

Associated subtasks

Table O.4: Subtask list

WP	Task	Sub Task	Name	Waste Group	Description of sub-task	Start	End	Contributors	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, Chalmers, GTK, LMU, RECHARGE, SGU, TUB, Leiden Uni, VITO, Empa, UCL	x
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, Chalmers, GTK, LMU, RECHARGE, SGU, TUB, Leiden Uni, VITO, Empa, UCL	x
2	2.1	2.3	Scenario storylines	Cross Cutting	Flesh out the storylines of the 3 main scenarios	M05	M08	UNITAR, Chalmers, TUB, Leiden Uni	x
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, Chalmers, SGU, Leiden Uni, VITO, UCL	DRAFTED

250 **Chapter 1**

251 **Methodology**

1.1 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 the future.
- 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.
- 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.

- 276 • Be used as a tool for learning and exploration, encouraging dialogue and collaboration
277 among stakeholders.
- 278 • Inform policy and decision-making processes, providing insights into the potential con-
279 sequences of different choices and interventions.
- 280 • Be communicated effectively to a wide range of audiences, ensuring accessibility and
281 clarity of information.
- 282 • Contribute to the advancement of knowledge and understanding in the field of waste
283 management, resource recovery, and circular economy.

284 By adhering to these principles, the FutuRaM project aims to develop robust, informative,
285 and policy-relevant scenarios that support sustainable decision-making and contribute to the
286 transition towards a more circular and resource-efficient economy. The methodology ensures
287 that the scenarios capture the complexity and interconnectedness of the waste streams, tak-
288 ing into account various factors such as legislation, technology, geopolitics, and societal values.
289 Ultimately, the goal is to provide decision makers with valuable insights and tools to navigate
290 the challenges and opportunities associated with secondary raw materials in a rapidly chang-
291 ing world.

292 1.2 Scenario storyline development process

293 Building scenarios involves several steps and methodologies, which can vary depending on
294 the specific context and objectives. The following section provides an overview of the sce-
295 nario development process used in FutuRaM. Figure 1.1 provides a visual representation of the
296 process.

297 1.2.1 Step 1: Define the scope and objectives

298 Scope and objectives of the scenario development process

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

301 **Aim:**

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

307 **Scope:**

308 FutuRaM will establish a methodology, reporting structure, and guidance to improve the
309 raw materials knowledge base up to 2050. FutuRaM will focus on six waste streams: batteries;
310 electrical and electronic equipment; vehicles; mining; slags and ashes; and construction and
311 demolition. It will integrate SRM and CRM data to model their current stocks and flows, and
312 consider economic, technological, geopolitical, regulatory, social and environmental factors
313 to further develop, demonstrate and align SRM recovery projects with the United Nations
314 Framework Classification for Resources (UNFC), a tool that enables a better understanding of
315 the viability of raw material projects. This will enable the commercial exploitation of SRMs
316 and CRMs by manufacturers, recyclers, and investors, and the knowledge base developed in
317 the project will support policy makers and governmental authorities.

318 Selected objectives of the FutuRaM project are presented in Table 1.1.

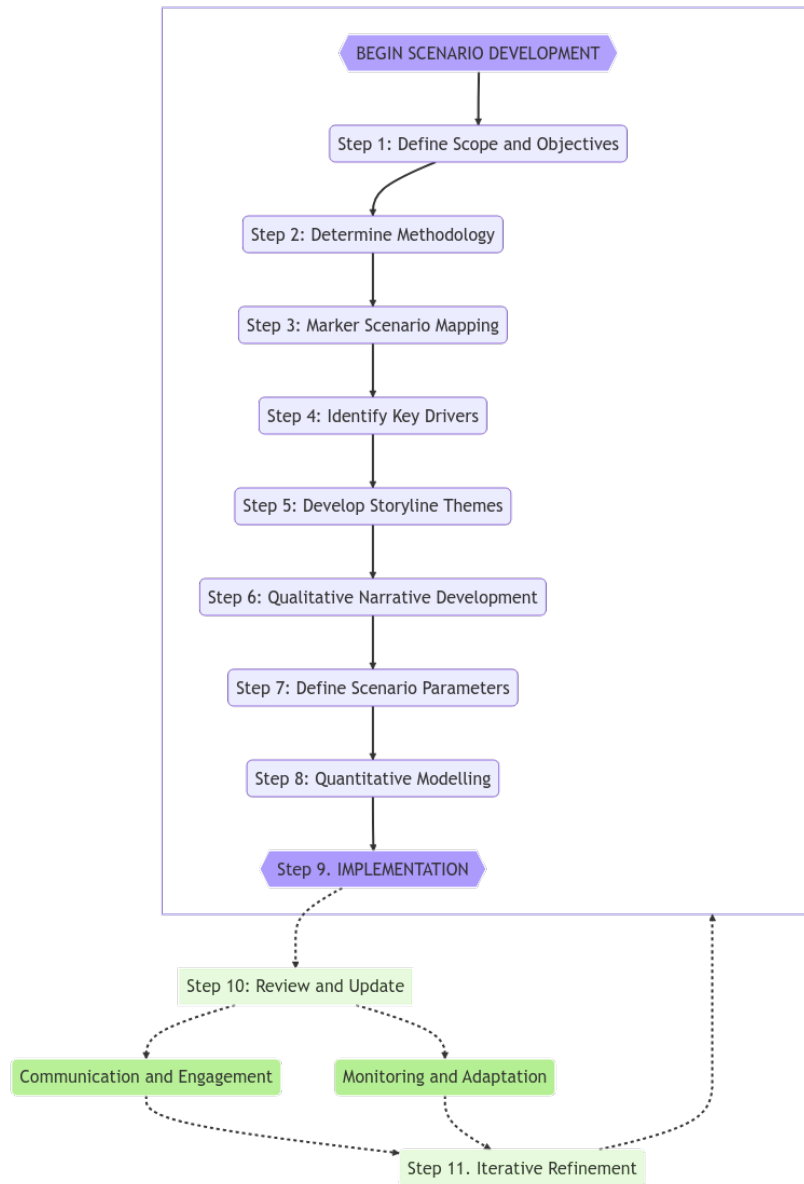


Figure 1.1: Scenario storyline development process

Table 1.1: Selected objectives of FutuRaM

Need	Action
A successful transition to a climate-neutral, circular and digitised EU economy relies heavily on a secure supply of raw materials. In order to strengthen EU autonomy and reduce over-dependency, we must boost domestic sourcing, both for primary and SRMs	FutuRaM will quantify the future availability of SRMs for three future scenarios for the EU material economy, from following current consumption trends, to moderate or rapid transitioning toward a climate-neutral, circular, and digitised EU economy (WP2). The material demand and the SRMs 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. While some of these studies have partially included CRMs demand and focused on the potential supply risks for achieving climate targets, these prospective scenarios have not been effectively harmonised across industrial sectors, and generally lack information on SRMs and the recovery industry in general. Transitions toward sustainable societies are likely to involve major changes and increased complexity in the material economy. Further research into current and future SRMs and CRMs present in the urban mine is thus urgent to prepare industry for their eventual recovery. In addition, scenarios that include other Circular goals such as lifetime extension need to be better assessed in terms of material cycles	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 United Kingdom (EU27+4) and quantify their eventual end-of-life fate. FutuRaM will extend existing model approaches by a set of distinct scenarios which cover circular economy (e.g., lifetime extension through repair and remanufacturing), high SRMs recoverability, and business as usual. These scenarios will incorporate emerging recycling technologies in line with stakeholder dialogues that consider normative boundary conditions such as carbon neutrality by 2050.

Scope definition:

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 centered 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, transportation, as well as policy related to the environment, the economy, society, technology, and geopolitics.

Geographic scope

The scenarios will be developed for the EU-27 plus Iceland, Norway, Switzerland and United Kingdom (EU27+4). The scenarios will consider the current and future waste management practices and resource recovery technologies in these countries. Additionally, the scenarios will consider the current and future policies and targets related to waste management and resource efficiency in these countries. To some extent, the scenarios will also consider the current and future trade relationships between these countries and other countries around the world.

Temporal scope

The scenarios will be developed for the time horizon of 2025–2050. This time horizon is aligned with the long term targets of the EU, including the EU Green Deal, the EU Circular Economy Action Plan, and the EU Industrial Strategy. The discrete stages in the forecasts are planned to be: 2025, 2030, 2035, 2040, 2045 and 2050. The temporal resolution of the scenarios will be determined during the quantification phase of the scenario development

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

350 **Aims and objectives definition**

351 The specific objectives of the FutuRaM scenario building process are presented in Table 1.2.

Table 1.2: 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	Develop a set of plausible scenarios that encompass these waste stream 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. Integration of the scenario with the system model will allow assessment of the impacts of these strategies on not only the availability of SRM and CRMs, but also on the environment, the economy, and society.

Consideration of EU legislation and policy targets

The scenarios developed in FutuRaM include the targets that the EU is setting for specific elements/materials/waste streams, following, in particular, the ambitions of the EU Green Deal [3] and the proposed critical raw materials (CRM) legislation [2]. Additionally, the consumer-product-centric waste streams BATT, ELV, and WEEE have specific EU legislation that will be considered in the scenarios.

General policies and legislation

The EU Green Deal is a set of policy initiatives by the European Commission with the overarching aim of making Europe climate neutral in 2050. This policy portfolio is a response to the Paris Agreement and the United Nations Sustainable Development Goals and it covers a wide range of economic sectors with an emphasis on investments toward building up local, 'sustainable' industries. The scope of FutuRaM is aligned with the EU Green Deal's goal of ensuring the sustainable sourcing and use of raw materials, reducing dependency on imports, and promoting resource security.

The EU Circular Economy Action Plan is a policy framework developed by the European Commission to promote the circular economy in the European Union. It sets out a comprehensive set of measures and targets to improve resource efficiency, reduce waste, and foster sustainable production and consumption. The Action Plan includes initiatives related to product design, waste management, recycling, and resource efficiency, among others. The Action Plan is a key element of the European Green Deal and it is closely linked to the EU Industrial Strategy.

The plan:

- Aims to promote the transition to a more circular economy in the EU
- Sets out a range of measures to promote the sustainable use of resources, reduce waste, and increase recycling
- Includes proposals for new legislation, such as an EU-wide framework for the circular economy, and revisions to existing legislation, such as the WEEE Directive

- 379 • Emphasizes the importance of product design for the circular economy, and proposes
380 measures to promote eco-design and repairability
- 381 • Includes initiatives to promote the use of secondary raw materials, such as the estab-
382 lishment of a European Raw Materials Alliance
- 383 • Aims to reduce greenhouse gas emissions and improve resource efficiency in the EU
- 384 • Calls for increased cooperation and dialogue among stakeholders in the circular econ-
385 omy.

386 **The Critical Raw Materials Act** is a proposed EU regulation that aims to ensure a secure
387 and sustainable supply of raw materials to the EU. The Act identifies a list of strategic raw ma-
388 terials, which are crucial to technologies important to Europe's green and digital ambitions and
389 for defence and space applications, that are subject to potential supply risks. The regulation
390 will cover the entire raw materials value chain, from primary extraction to manufacture to its
391 potential recovery as a secondary raw material.

392 By 2030, one single ex-EU country shall produce not more than 65% of the EU's annual
393 consumption of each strategic raw material. Clear benchmarks have been set for domestic
394 capacities of the EU in 2030:

- 395 • Extract at least 10% of the EU's annual consumption
- 396 • Process at least 40% of the EU's annual consumption
- 397 • Recycle at least 15% of the EU's annual consumption

398 These benchmarks have been included in the scenarios developed in FutuRaM. Specifi-
399 cally, in the Recovery scenario, where the emphasis is on the recovery of materials from waste
400 streams and the Circularity scenario where the emphasis is on the implementation of 're-X'
401 strategies, such as recycling, remanufacturing, and reuse. These benchmarks are considered
402 too optimistic to be included in the Business-as-usual scenario.

403 Waste stream-specific legislation and policy targets

404 With respect to the waste streams that are analysed in FutuRaM, the following waste stream-
405 specific developments aligned with EU targets have been considered:

- 406 • BATT: Proposed revision of the Batteries Directive (2020/0353(COD))
 - 407 – Establishes rules for the collection, treatment, and recycling of batteries and accu-
408 mulators in the EU
 - 409 – Requires Member States to set up collection and recycling systems for waste bat-
410 teries and accumulators
 - 411 – Sets specific recycling targets for different types of batteries and accumulators
 - 412 – Prohibits the
413 use of certain hazardous substances in the manufacturing of batteries and accu-
414 mulators
 - 415 – Requires labeling and information for consumers on the proper disposal of batter-
416 ies and accumulators
 - 417 – Requires producers to take responsibility for the costs of collecting, treating, and
418 recycling waste batteries and accumulators
 - 419 – Aims to reduce the environmental impact of batteries and accumulators through-
420 out their life cycle.
- 421 • ELV: Proposed revision currently under review now and to be completed during 2023:
 - 422 – Sets out rules for the collection, treatment, and recycling of end-of-life vehicles
423 (ELV) in the EU
 - 424 – Requires Member States to set up collection systems for ELV and ensure that they
425 are treated and recycled in an environmentally sound manner
 - 426 – Sets collection and recycling targets for ELV: 85% of the weight of each vehicle
427 must be reused or recycled, and 95% of the weight of each vehicle must be reused,
428 recycled, or recovered

- 429 • WEEE Directive (about to be evaluated with a review likely in 2024):
 - 430 – Sets out rules for the collection, treatment, and recycling of waste electrical and
 - 431 electronic equipment (WEEE) in the EU
 - 432 – Requires Member States to establish collection systems for WEEE and ensure that
 - 433 it is treated and recycled in an environmentally sound manner
 - 434 – Sets collection and recycling targets for different types of WEEE
 - 435 – Requires producers to take responsibility for the costs of treating and recycling
 - 436 WEEE
 - 437 – Requires the use of the waste hierarchy for WEEE management
 - 438 – Aims to prevent the generation of WEEE and promote its reuse and recycling
 - 439 – Requires the labeling of electrical and electronic equipment to facilitate its proper
 - 440 disposal.
- 441 • CDW: No activity currently planned.
- 442 • MIN: Focus is currently on human health and environmental impact rather than waste.
- 443 • SLASH: No activity currently planned.

444 **Extent of policy and legislation inclusion in the scenarios**

445 The targets that result from the planned and ongoing review processes are non-negotiable
446 and legally binding, and thus should be incorporated in our scenarios. These targets, how-
447 ever, are only applicable to post-consumer products, namely WEEE, BAT and ELV. This en-
448 visioned future in which legally binding targets for collection, reuse and/or material recycling
449 are achieved can be implemented as the Recovery scenario. If there are no targets set for a
450 specific consumer product category, then approach targets similar to the WEEE directive and
451 in line with the EU Green Deal. For the Circularity scenario, FutuRaM will also consider the
452 effects of proposed ecodesign requirements for sustainable products (e.g., longer lifetimes,
453 increased reusability, repairability, recyclability).

454 However, for waste that does not consist of discarded consumer products, but instead
455 results from industrial production activities, in particular for MinW, and for SLASH, we must

456 still produce specific scenarios related to mining, metallurgy, and waste and fuel combustion.
457 The scenarios will account for increasing resource use effectiveness and production process
458 efficiency, thus indicating lower volumes and quality of generated production residues (both
459 by-products and waste such as red mud, waste rock, slags, etc.) per unit of product (expressed
460 either as product mass or product value), whether that product is a metal (e.g., a copper cath-
461 ode), metal alloy (e.g., aluminium alloy n° 5183) or metal product (e.g., cold rolled stainless
462 steel sheet). Ashes are highly diverse, and each specific type will have a specific storyline that
463 is congruent within each scenario.

464 In conclusion, WEEE, ELV, and BATT waste material recovery will follow the targets in the
465 EU. For SLASH and MIN, we will evaluate recent trends in waste generation and extract plausi-
466 ble ranges of generation toward 2050. For CDW, embedded WEEE will follow EU targets, and
467 bulk waste will incorporate storylines and scenarios that are congruent with those of SLASH
468 and MIN. Various drivers will be assigned to move between these ranges and will be key to
469 the specific, harmonized storyline for the scenario. Finally, the targets and storylines will be
470 aligned with assumptions on technology development.

471 **Consideration of geopolitical developments**

472 The storylines also attempt to consider geopolitical considerations and thus supply chain re-
473 siliency for satisfying the product demand in the scenarios. The growth in material demand for
474 the energy and mobility transitions can be satisfied either by an increase of mining and met-
475 allurgy activities within the EU or by growing imports from raw material producing countries
476 outside the EU. That is, if we go for increased domestic EU production to minimize geopolit-
477 ical supply risk, it may indicate more EU production residue generation even under increased
478 production efficiency and resource effectiveness. The increase of domestic industrial activity,
479 as a response to an envisioned increased internal demand, supposes an equivalent rise of so-
480 cietal approval for mining and refining activities on EU territory. If the increased demand is,
481 however, satisfied by imports from non-EU countries, which we know have domestic resource
482 consumption also growing significantly due to the energy and mobility transition, our conclu-
483 sion would be that we just shift the mining and refining activities from EU countries towards
484 resource-rich non-EU countries. This shift would also imply an increased risk for geopolitical

instability and/or security of supply of critical raw materials to the EU.

1.2.2 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.

The table in section 5.2 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.

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.

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.

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. The addition of extra dimensions increases the possible number of scenarios. By assessing the consistency and plausibility of these combinations with a matrix-based method, it was possible to reduce the number of scenarios. Ultimately, the supply chain security dimension was eliminated due to the consortium's inability to speculate on geopolitical developments and the added incertitude it would introduce to the scenarios.

Delphi method The Delphi method was used in the scenario building process to gather

534 and aggregate the opinions of experts or stakeholders. Internal consultation with consortium
535 members who were experts in their respective waste streams or other aspects of the recovery
536 system was conducted. The method involved steps such as the selection of experts, gener-
537 ation of initial questionnaires, iterative rounds of responses, and convergence and consensus
538 building.

539 **Choice of scenario type**

540 The general types of scenario are summarised in Table 1.3.

Table 1.3: Types of scenario (adapted from [1])

Scenario category	Scenario type	Quantitative/qualitative	Time-frame	System structure	Focus on internal or external factors
Predictive <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
Explorative <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
Normative <i>how can a target be reached?</i>	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

541 The scenarios developed in the FutuRaM project are a combination of predictive and nor-
542 mative:

543 • **BAU:**

544 *What will happen if current trends continue?*

545 This scenario is predictive in nature, based on the assumption that the current trends
546 and developments in waste management and resource recovery systems will continue
547 into the future.

548 • **Recovery:**

549 *What will it take to achieve the EU's targets for material use and recovery?*

550 *Focus on technology*

551 This scenario is normative, focusing on manipulating the technology and infrastructure
552 of the recovery system to achieve the EU's targets and mandates.

553 • **Circularity:**

554 *What will it take to achieve the EU's targets for material use and recovery?*

555 *Focus on re-X strategies*

556 This scenario is a combination of normative and explorative, considering the targets and
557 mandates of the EU's circular economy action plan and exploring re-X strategies in the
558 recovery system.

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

562 1.2.3 Step 3: Marker scenario mapping

563 Justification and methodology

564 This preliminary step in the scenario development process involves conducting a literature
565 study to identify existing scenarios that are relevant to the FutuRaM project. This step is crucial

as it serves several important purposes and provides valuable insights for the overall scenario development process. It helps the scenario development team to build on existing knowledge, identify relevant scenarios, gain insights and inspiration, fill knowledge gaps, and enhance credibility and comparability.

Building on existing knowledge:

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

Identifying relevant scenarios:

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

Gaining insights and inspiration:

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

Filling knowledge gaps:

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

process.

Enhancing credibility and comparability:

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

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

section 5.3 presents an overview of the marker scenarios considered in the FutuRaM project. The table is not intended to be exhaustive but rather to provide an overview of the different scenarios that have been developed in the field of waste management, resource recovery, and circular economy.

1.2.4 Step 4: Identification of key drivers of change

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

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

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

The key drivers identified in this step will be used to develop the storyline themes and

scenario parameters in the next step.

Figure 1.2 illustrates the process of identifying key drivers of change.

Methodology and results of this stage in FutuRaMs scenario development:

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. The selection, screening, and categorization 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.

1. Preliminary collection:

This step involved gathering a pool of potential elements that could be included in the storylines and scenarios. These elements were derived from expert input from waste streams and the scenario development team including taking also knowledge from the literature review and existing scenarios identified in Step 2 — Marker scenario mapping.

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 affect an system. A PESTEL analysis can help identify opportunities and threats linked to each of these factors, understand the broader context and shape scenarios accordingly.

The acronym PESTEL stands for:

- **Political:** 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.
- **Economic:** 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.
- **Sociocultural:** These factors include societal trends and characteristics that could affect your business. They include demographic trends (like age, gender, and eth-

nicity), cultural trends, lifestyle preferences, consumer attitudes, and broader societal expectations.

- **Technological:** 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.
- **Environmental:** 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.
- **Legal:** 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.

The 68 elements identified in the initial screening stage are listed in section 5.4.

2. Screening:

In the screening step, the collected elements are evaluated and assessed based on specific criteria. This evaluation helps determine the relevance, reliability, and significance of each element for the development of storylines and scenarios. Many elements were aggregated, especially if they were deemed to follow similar trends to others. Elements that did not meet the predefined criteria or were deemed irrelevant or unreliable were be excluded from further consideration.

The 28 elements that were identified in this stage are listed in section 5.5.

In Figure 1.3, an excerpt of a spreadsheet illustrates part of the screening process for the FutuRaM scenarios which was informed by the waste streams. In this exercise, the elements were evaluated based on their relevance to the waste streams and their potential impact on the waste management system. The elements were also assessed based on their plausibility and likelihood of occurrence in the future. The elements that were deemed relevant, plausible, and influential were included in the storylines and scenarios.

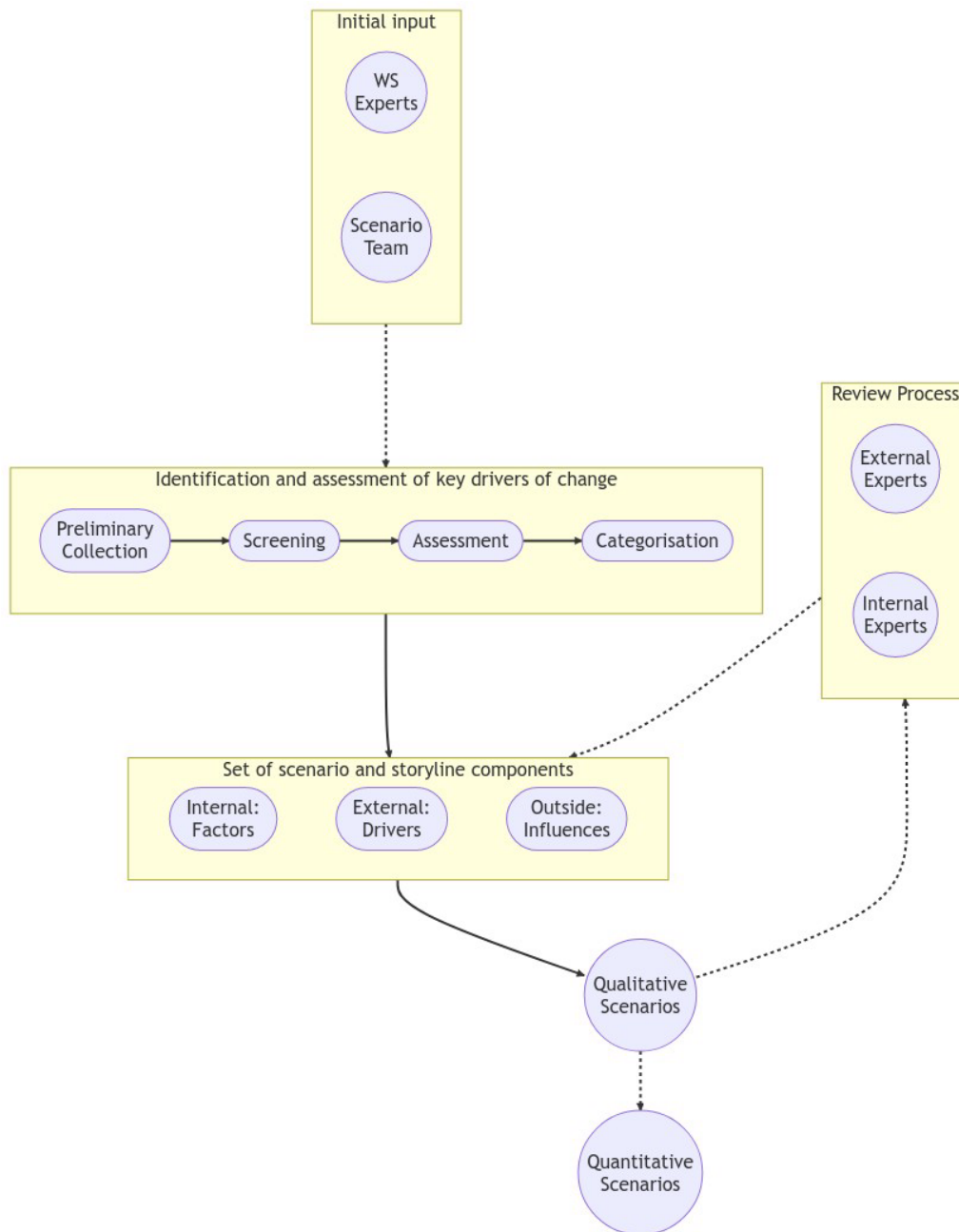


Figure 1.2: An illustration of the process used for identifying key drivers of change

THIS TABLE IS FOR THE ASSESSMENT OF THE RELEVANCE 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-V 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	5.00
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	4.00
Treatment cost				4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
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	3.00
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	4.00
Product prices				3.00	4.00	1.00	4.00	3.00	3.00	5.00	3.00	3.00	3.00	3.00
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	2.00
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	2.00
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	2.00
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	2.00
Availability of recovery technologies				3.00	3.00	0.00	3.00	2.25	1.00	4.00	1.00	1.00	4.00	4.00
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	2.00
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	2.00
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	1.00
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	1.00
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	2.00
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	1.00
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	2.00
Accessibility/Infrastructure			#DIV/0!	3.00	0.00	0.00	0.00	0.75	3.00	4.00	4.00	3.00	3.00	4.00
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	2.00
Minuturisation	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	1.00
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	3.00
Renewable energy targets				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00

Figure 1.3: Excerpt of a spreadsheet used as part of the screening process

673 **3. Assessment**

674 Once the screening process was complete, the remaining elements were aggregated
675 and categorised based on their thematic relevance or characteristics. This categorisa-
676 tion helps organize the elements into meaningful groups or themes that align with the
677 objectives and scope of the scenarios.

678 The 21 elements that were identified in this stage are listed in Table 1.4.

Table 1.4: Key drivers of change identified in the screening stage

Element	Domain	Definition	Internal	BAU	REC	CIR
Recovery technology	TECH	Implementation and advancements in waste recovery technologies	TRUE	1	3	3
Product technology	TECH	Changes in product function or composition	TRUE	1	3	3
Integration of SRM system across EU	TECH	Integration of a sustainable resource management system across EU countries	TRUE	1	3	3
Increased drive for environmental protection	ENV	Growing concern and motivation for environmental conservation	TRUE	1	3	3
Progress toward renewable energy targets	ECO	Advancements and achievements in renewable energy generation	TRUE	1	3	3
Subsidies/taxation to promote circularity	ECO	Financial incentives or taxes to encourage circular economy	TRUE	1	3	3
CO2 market price	ECO	Price and market dynamics of carbon emissions	TRUE	1	3	3
Participation in re-X activities	SOC	Engagement in refuse-reduce-repair-reuse activities	TRUE	1	1	3

Continued on next page

Table 1.4 — Continued from previous page

Element	Domain	Definition	Internal	BAU	REC	CIR
Stricter environmental regulations	POL	Tightening of environmental laws and regulations	TRUE	1	3	3
Stricter waste management regulations	POL	Strengthening of waste management laws and regulations	TRUE	1	3	3
Supply chain due diligence laws: implementation and enforcement	POL	Obligations for identifying and mitigating negative impacts in supply chains	TRUE	0	3	3
Compliance with waste targets	POL	Meeting specific waste management and recycling targets	TRUE	0	3	3
Resource shortages	ENV	Limited availability of natural resources	FALSE	n/a	n/a	n/a
Raw material vs SRM prices	ECO	Price dynamics and competition between raw materials and secondary raw materials	FALSE	n/a	n/a	n/a
Climate change impacts/mitigation	ENV	Effects and actions related to climate change	FALSE	n/a	n/a	n/a
International trade and co-operation (vs. autarky)	ECO	Collaborative trade agreements and global cooperation	FALSE	n/a	n/a	n/a
Energy prices	ECO	Costs and fluctuations in energy prices	FALSE	n/a	n/a	n/a
Economic growth	ECO	Overall economic expansion and development	FALSE	n/a	n/a	n/a

Continued on next page

Table 1.4 — Continued from previous page

Element	Domain	Definition	Internal	BAU	REC	CIR
Re-industrialisation of EU	ECO	Shift towards increased industrial activities in the EU	FALSE	n/a	n/a	n/a
NIMBY to projects	SOC	Opposition to local projects and developments	FALSE	n/a	n/a	n/a
Population and Urbanisation	SOC	Growth and urban development of population	FALSE	n/a	n/a	n/a

679 4. Categorisation

680 The scenario elements were then assessed based on their potential impact on the waste
681 management system. For each element, an assessment was made as to whether it was
682 within the scope of FutuRaM to include them as variables in the models, and therefore
683 also the scenarios and their storylines. Those deemed to be within the scope are 'inter-
684 nal' and will be intensively researched and modelled. Those deemed to be outside the
685 scope are 'external' and will be included in the storylines, will vary over time, but will not
686 vary across the three scenarios. Those deemed to be outside the scope and also outside
687 the influence of the waste management system are 'outside' and will not be included in
688 the storylines or scenarios.

689 Justification for keeping elements outside of the scenario models:

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

696 Furthermore, the scenarios should prioritize elements that can be considered as 'policy
697 knobs', meaning variables or factors that can be adjusted or controlled to test different set-
698 tings. By including these policy knobs, the scenarios can explore the effects of different policy
699 decisions or interventions on the SRM system's outcomes. This targeted approach ensures
700 that the scenarios generated are relevant to the project's objectives and facilitate meaningful
701 analysis.

702 It is crucial to avoid excessive complexity and convolution in scenario modelling. When
703 there are too many convoluted elements included, the results of the modelling exercise can
704 become, at best, difficult to understand and interpret. At worst, the outcomes may become
705 practically useless due to the overwhelming interactions and uncertainties introduced by the

706 complex elements. Therefore, careful consideration is necessary to strike a balance between
707 incorporating essential factors and maintaining the clarity and usefulness of the scenario mod-
708 elling results.

709 **Examples:**

710 • **Resource shortages:**

711 Resource shortages can be highly unpredictable and subject to various external factors
712 such as geopolitical events, natural disasters, or technological advancements. The pre-
713 cise timing and extent of resource shortages are challenging to forecast accurately, mak-
714 ing it difficult to include them within the model without introducing significant uncer-
715 tainty.

716 • **Raw material vs SRM prices:**

717 The dynamics and competition between raw materials and secondary raw materials can
718 be complex and influenced by various market factors, technological advancements and
719 policy interventions. The precise timing and extent of these dynamics are challenging
720 to forecast accurately, making it difficult to include them within the model without in-
721 troducing significant uncertainty.

722 **Conclusion**

723 The methodology used for the FutuRaM scenario development ensured that the selected el-
724 ements were relevant, plausible, and influential. The use of the PESTEL analysis framework
725 during the preliminary collection phase provided a comprehensive overview of the macro-
726 environmental factors. Furthermore, the screening process and the assessment ensured that
727 the selected elements were coherent, consistent, and aligned with the objectives and scope
728 of the scenario exercise. The final list of scenario elements is well-suited to the purposes of
729 the FutuRaM project and will be used to develop the three FutuRaM scenarios.

730 1.2.5 Step 5: Develop storyline themes

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

735 1.2.6 Step 6: Qualitative narrative development

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

741 1.2.7 Step 7: Definition of scenario parameters

742 The scenario parameters are the set of quantitative values or functions that will be used to
743 define the scenario inputs for the model. These parameters will be defined in the next stages
744 of the project.

745 1.2.8 Step 8: Quantitative modelling

746 The scenario quantification will be performed in the next stages of the project.

747 1.2.9 Step 9: Implementation

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

749 1.2.10 Step 10: Review process

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

752 The first stage of the review process is to open the scenario development process to the
753 wider FutuRaM consortium. This will be done by sharing the scenario development process
754 and the results of the assessment and categorization step with the consortium and inviting
755 feedback and suggestions. The feedback will be used to refine the elements and their cate-
756 gorization and to identify any elements that may have been missed in the initial assessment.

757 The second stage will involve opening the scenario development process to external stake-
758 holders and subject matter experts.

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

761 **Chapter 2**

762 **Scenario storylines**

2.1 Scenario 1: Business as usual

2.1.1 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. 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 marginal 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 towards a more sustainable SRM system.

Primary extraction of raw materials remains the dominant source for raw materials consumed in the EU, continuing the linear 'take-make-dispose' model of resource consumption. Recycling and recovery rates remain stubbornly low, resulting in significant SRM waste. Meanwhile, material demand continues to rise in tandem with GDP growth, further exacerbating the resource pressure.

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

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

Moreover, environmental regulations remain largely static, inadequately addressing emerging challenges or incentivising sustainable practices. The lack of regulatory progress may further exacerbate environmental damage and biodiversity loss. Working conditions in mining and extraction industries persist as challenging, with no significant improvements in labour rights or safety standards.

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

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 recycling and recovery are not met, and the current linear model largely persists.
- 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.
- Recycling and recovery rates continue to lag, leading to an accumulation of SRM waste that signals missed opportunities for resource reuse.

- 816 • The environmental repercussions of mining and extraction, such as land degradation
817 and water pollution, continue to be a pressing concern, reflecting the ecological toll of
818 this linear model.
- 819 • The EU's dependency on imports of SRMs escalates, heightening the risk of supply dis-
820 ruptions. Investment in new SRM recovery technologies remains minimal, stifling inno-
821 vation and advancements in this field.
- 822 • The industrial focus remains on cost-effective material production and use, disregarding
823 the long-term sustainability aspect.
- 824 • Material scarcity and price fluctuations pose potential risks to the EU industry, highlight-
825 ing the vulnerability of this business model.
- 826 • Without any significant updates to environmental regulations, the negative impacts on
827 ecosystems and biodiversity intensify.
- 828 • Working conditions in mining and extraction industries see no substantial improvements,
829 highlighting continued issues of social inequality.
- 830 • Investment in new SRM recovery technologies remains minimal, stifling innovation and
831 advancements in this field.
- 832 • The EU's reliance on fossil fuels continues, with the energy transition progressing at a
833 slow pace.
- 834 • The EU's dependency on imports of SRMs escalates, heightening the risk of supply dis-
835 ruptions.

836 2.1.2 Waste stream specific scenario impacts

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

- 840 • A growing volume of battery waste due to the increased use of electric vehicles and
841 renewable energy storage systems.

- 842 • Lack of technological innovation and regulatory incentives lead to low recovery rates.
- 843 • Collection systems for battery waste remain sporadic and unstandardised.
- 844 • Little collaboration between industry and government in the field of battery recovery.
- 845 • Primary extraction remains the dominant source for battery materials.
- 846 • Share of LIB will increase (EV, LMT, Industrial LIB uptake)
- 847 • LIB Battery Chemistries will change
- 848 • No big changes for EEE-BATT and Portable-BATT
- 849 • Use of critical resources continue but are already decreasing (BATT chemistry already
- 850 changing towards less CRM content)
- 851 • Large scale reuse of batteries is minimal
- 852 • Collection rates do not fulfil the EU targets
- 853 • Recycling efficiencies do not fulfil the EU targets
- 854 • Recovery rates do not fulfil the EU targets

855 **ELV (End-of-Life Vehicles)** The BAU scenario maintains the current approach to end-of-
856 life vehicles, with minimal improvements in the recovery and recycling process. The absence
857 of effective technologies and regulatory incentives results in low recovery rates of valuable
858 materials from ELVs.

- 859 • Legislation banning new ICEVs from 2035
- 860 • Current recovery technologies are unable to significantly improve the extraction of valu-
861 able materials from ELVs.
- 862 • Consumer demand continues to drive high production of new vehicles.
- 863 • ELV collection systems remain uncoordinated and inefficient.
- 864 • Minimal collaboration between government and industry for ELV recovery.

- 865 • A significant proportion of vehicle components continue to end up as waste.
- 866 • Gradual and slow improvement of recycling chain technology efficiency
- 867 • No new legislation to improve recovery and support circular strategies in comparison to
- 868 2023

869 **WEEE (Waste Electrical and Electronic Equipment)** In the BAU scenario, the treatment
870 of WEEE does not significantly change. The lack of technological progress and effective reg-
871 ulation results in low recovery rates of valuable materials from WEEE.

- 872 • Limited improvements in the recovery of valuable materials from WEEE.
- 873 • High consumer demand for new electronics continues to drive high WEEE generation.
- 874 • Inefficient collection systems result in significant amounts of WEEE ending up in land-
- 875 fills.
- 876 • Little collaboration between government and industry for WEEE recovery.
- 877 • The majority of WEEE continues to be treated as waste, with low recycling rates.
- 878 • No ground breaking technologies and practices to improve recovery and circularity.
- 879 • Reuse of products and components is not widely utilised
- 880 • Changes in legislation (e.g., circular economy and product design targets, targets for col-
881 lection and recycling) are not strictly implemented.
- 882 • The BAU and the Recovery scenarios are similar from the put-on-market perspective
883 (e.g., production and consumption remain the same), but it's the recovery stage that
884 makes the difference.

885 **Mining waste (MIN)** The BAU scenario sees the continuation of current practices in mining
886 waste management. The absence of advanced recovery technologies and regulatory incen-
887 tives leads to low recovery rates of valuable materials from mining waste.

- 888 • Limited technological advancements lead to static recovery rates of valuable materials
889 from mining waste.
- 890 • Continued reliance on primary extraction as the dominant source of raw materials.
- 891 • Minimal collaboration between government and industry for mining waste recovery.
- 892 • Low levels of traceability and management of mining waste.
- 893 • Mining waste remains a significant environmental challenge.

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

895 In the BAU scenario, the management of Construction and Demolition Waste (CDW) re-
896 mains largely unchanged. Lack of progress in recovery technologies and regulatory incentives
897 lead to low recovery rates of valuable materials from CDW.

- 898 • Limited improvements in the recovery of valuable materials from CDW.
- 899 • Continued high generation of CDW due to the demand in the construction sector.
- 900 • Inefficient collection systems result in significant amounts of CDW ending up in landfills.
- 901 • Minimal collaboration between government and industry for CDW recovery.
- 902 • The majority of CDW continues to be treated as waste, with low recycling rates.
- 903 • Plausible target: 70% recovery rate of CDW by 2050.
- 904 • Example of treatment technological development: waste concrete is primarily down-
905 cycled as backfill via stationary crushing processes.

906 **SLASH (Slags and Ashes)** In the BAU scenario, SLASH continue to be treated as waste.
907 The absence of recovery technologies and regulatory incentives leads to low recovery rates of
908 valuable materials from SLASH.

- 909 • Increased generation of SLASH because SRMs are not recovered and end up in inciner-
910 ation and smelter residues.

- 911 • Low quality of SLASH due to:
 - 912 – poor sorting and separation of waste streams
 - 913 – high contamination
 - 914 – large proportion coming from mixed waste incineration
- 915 • Lack of technological advancements result in low recovery rates of valuable materials
- 916 from SLASH.
- 917 • Continued high generation of SLASH due to the reliance on traditional energy sources.
- 918 • Minimal incentives for the recovery and reuse of materials from SLASH.
- 919 • Low levels of traceability and management of SLASH.
- 920 • SLASH continues to be a significant environmental challenge due to the high volume
- 921 generated.

922 2.2 Scenario 2: Recovery

923 2.2.1 Storyline narrative

924 In the recovery scenario, the central emphasis is on harnessing sophisticated technologies
925 to salvage SRMs from waste streams at the end of their lifecycle. While there are noticeable
926 strides towards the incorporation of ‘circular design’ principles and re-X strategies (which focus
927 on reducing, reusing, recycling, repairing, and refurbishing), a vestige of wasteful consumerism,
928 akin to the one observed in the BAU scenario, still lingers. However, this is somewhat mitigated
929 by the implementation of a comprehensive material recovery system.

930 In this scenario, the central actor is the waste treatment sector, with the spotlight falling on
931 the enhancement of recovery technology. The implementation and optimisation of cutting-
932 edge technologies, such as Artificial Intelligence (AI), automation, and advanced robotics, play
933 a significant role in revolutionising waste treatment processes. These technologies streamline

934 waste sorting, improve the quality of recovered materials, and increase the overall efficiency
935 of the recovery process.

936 This scenario calls for an emphasis on policy development and standardisation to fos-
937 ter EU-wide development, integration, and compliance. Here, the role of governments and
938 policy-makers becomes crucial in setting ambitious recovery targets, developing conducive
939 regulatory frameworks, and enforcing compliance. This multi-pronged approach also involves
940 strengthening cross-border cooperation, harmonising waste management standards, and pro-
941 moting knowledge and technology transfer among EU member states.

942 To realise more ambitious environmental impact reduction targets, significant progress
943 needs to be made in both technological and policy aspects. Enhancing technological capabili-
944 ties will improve recovery rates, while robust policy measures will ensure these advancements
945 are integrated into the wider economy in a regulated manner. The future of this scenario de-
946 pends on the successful fusion of advanced technology, regulatory harmonisation, and a com-
947 mitment to continuous improvement in waste management and SRM recovery.

948 Key characteristics of this technology promoted recovery scenario include:

- 949 • This scenario uses a combination of the forecasting and backcasting methods to envi-
950 sion the future.
- 951 • The backcasting method is used for scenario factors that are covered by governmental
952 targets, starting with the desired outcome and working backwards to the present.
- 953 • The forecasting method is used for scenario factors that are not covered by governmen-
954 tal targets, starting with the current situation and extending to the future.
- 955 • EU targets for recycling and recovery are met, due to the EU's waste management sys-
956 tem becoming more expansive, efficient and effective.
- 957 • Technological innovation drives increased recovery rates of SRMs, enabling the more
958 efficient use of waste.
- 959 • Digitalisation and automation are more extensively used in recycling processes, leading
960 to enhanced productivity and accuracy.

- 961 • There is greater exploration and exploitation of alternative sources such as urban mining,
962 waste streams, and tailings, presenting novel opportunities for resource acquisition.
- 963 • New waste regulations and guidelines for SRM recovery are implemented, enforcing
964 better management and extraction of SRMs.
- 965 • Investment in research and development for SRM recovery technologies experiences
966 an upswing, promoting continuous innovation in this field.
- 967 • Closer collaboration and information sharing between industry and government insti-
968 tutions streamline processes and expedite decision-making.
- 969 • New jobs are created in the recycling and recovery sector, offering economic benefits
970 and improving overall employment rates.
- 971 • SRM production and use become more efficient and cost-effective, fostering economic
972 sustainability.
- 973 • Environmental impact from mining and extraction is reduced, signaling a more sustain-
974 able approach to resource acquisition.
- 975 • The EU's dependence on primary extraction is reduced, with SRM recovery becoming a
976 more significant source of raw materials.

977 **2.2.2 Waste stream specific scenario impacts**

978 **BATT (Battery waste)**

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

- 983 • Increase in end-of-life batteries due to the growth of electric vehicles and renewable
984 energy storage.

- 985 • Advanced recovery technologies facilitate efficient extraction of valuable materials from
986 battery waste.
- 987 • Standardised collection systems enhance the quantity and quality of battery waste avail-
988 able for recovery.
- 989 • Industry and government collaboration leads to investments in research and develop-
990 ment of battery recovery technologies.
- 991 • Despite progress in battery design and recycling, primary extraction remains a significant
992 source for battery materials.
- 993 • Battery passport will have a strong impact on collection, material recovery rates and
994 recycling rates.
- 995 • Collection
 - 996 – Portable batteries collection increase according to the WEEE-WS
 - 997 – Improved collection of LMT
 - 998 – Improved regulation and collection of Industrial batteries
- 999 • Material recovery
 - 1000 – Improved recycling technologies
 - 1001 – Battery Pass will improve material recovery
 - 1002 – Higher recovery rate for lithium
 - 1003 – Increase in recycling by average weight
 - 1004 – Recycling of plastics
- 1005 • Ambitious goals of recycling/recovery rates compete with re-use, so re-use remains low.
- 1006 • Improved public awareness means that fewer batteries end up in the municipal waste
1007 stream and there is less hoarding.
- 1008 • Design for recycling (DFR):
 - 1009 – Material and composition selection for recycling.

- 1010 – Higher requirements on disassemblability.
- 1011 – Information available to promote efficient recovery.

1012 **ELV (End-of-Life Vehicles)**

1013 The recovery scenario envisions a more effective and technology-driven end-of-life vehi-
 1014 cle treatment process. Advancements in recovery technologies allow for an improved extrac-
 1015 tion of valuable materials from vehicles at their end of life, although consumerism still drives
 1016 high demand for new vehicles.

- 1017 • Innovations in recovery technologies allow for a higher recovery rate of valuable mate-
 1018 rials from ELVs.
- 1019 • Despite advancements in vehicle design, the total number of vehicles produced remains
 1020 high due to consumer demand.
- 1021 • Improved systems for ELV collection are established, ensuring efficient management of
 1022 ELV waste.
- 1023 • Increased collaboration between the government and industry leads to investments in
 1024 ELV recovery technologies.
- 1025 • The focus on recovery still means a significant amount of vehicle components end up
 1026 as waste.
- 1027 • Focus on managing end-of-life of vehicles
- 1028 • Prioritise increased recovery of secondary materials
- 1029 • EU recovery targets are reached (currently implemented/proposed targets, but also in-
 1030 creased and new targets)
- 1031 • Common/bulk materials (Fe, Non-Fe, plastics etc.,) and precious metals (Au, Ag, Pd, Pt)
 1032 reach high mass recycling rates and high element recycling rates. Other CRMs currently
 1033 not recovered reach a moderate level of recovery.
- 1034 • For instance,

- 1035 – More advanced dismantling and processing steps (e.g., components and materials)
- 1036 – More specialised recovery of certain components and materials (e.g., electric mo-
- 1037 tors including permanent magnets and embedded REE)
- 1038 – More public and private interest in developing recycling chains
- 1039 – Increase in collection rate due to increase in participation from public and busi-
- 1040 nesses, i.e., target-based incentives with strong regulations and monitoring
- 1041 • Design for recycling (DFR):
- 1042 – Material and composition selection.
- 1043 – Higher requirements on ‘disassemblability’.
- 1044 – Information available to enable recovery.

1045 **WEEE (Waste Electrical and Electronic Equipment)**

1046 Under the recovery scenario, WEEE becomes a significant resource for secondary raw ma-
 1047 terials. Technological advancements in the sector improve the efficiency of WEEE treatment,
 1048 although the consumerism-driven demand for new electronics remains high.

- 1049 • Advanced technologies enable higher recovery rates of valuable materials from WEEE.
- 1050 • Despite advancements in design for recyclability, WEEE generation remains high due to
- 1051 the consumer demand for new electronics.
- 1052 • Standardised collection systems for WEEE are implemented, improving the supply of
- 1053 materials for recovery.
- 1054 • Increased industry-government collaboration leads to further development in WEEE
- 1055 recovery technologies.
- 1056 • Consumer behaviour remains a significant hurdle for more efficient WEEE management.
- 1057 • Higher recycling rate — make full use of the disposed parts. For instance:
- 1058 – more automation of the dismantling and processing steps (e.g., AI)

- 1059 – recycling technologies improvements (e.g., small components recovery is also hap-
- 1060 pening)
- 1061 – more functional collection infrastructure
- 1062 – financial support provided to recyclers/operators
- 1063 – bans on WEEE exports push for increased domestic recycling
- 1064 • SRM/CRM recovery targets introduction — linked to production phase requirements (e.g.,
- 1065 x% of SRM used in place of virgin ones).
- 1066 • ‘Design for recovery’ principle — Ecodesign mandates changes in weight and composi-
- 1067 tion of EEE so complexity and the type of materials used
- 1068 • Higher public awareness and participation on WEEE issue and management.
- 1069 • Higher compliance from the public, the producers and the businesses.
- 1070 • Strong regulations and monitoring are in place with higher collection and recycling tar-
- 1071 gets which are set and implemented and fines are set to those who fail to achieve the
- 1072 targets.
- 1073 • Focus given more to the EoL management of WEEE.

1074 **Mining waste (MIN)**

1075 Under the recovery scenario, technological advancements enable the extraction of resid-

1076 ual valuable materials from mining waste, transforming it into a valuable resource. However,

1077 the continued reliance on primary mining due to consumer demand generates significant

1078 amounts of mining waste.

- 1079 • Technological advancements facilitate the extraction of valuable materials from mining
- 1080 waste.
- 1081 • Despite progress in recovery technologies, primary extraction remains the dominant
- 1082 source of raw materials due to high consumer demand.
- 1083 • Government and industry collaboration support the development of technologies for
- 1084 the recovery of materials from mining waste.

- 1085 • Increased traceability and management of mining waste through digitalisation.
- 1086 • Mining waste remains a significant environmental challenge.

1087 **CDW (Construction and Demolition Waste)**

1088 Under the recovery scenario, Construction and Demolition Waste (CDW) becomes an im-
1089 portant resource for secondary raw materials. Improved recovery technologies allow for the
1090 extraction of valuable materials from CDW. Despite some progress in eco-design and material
1091 efficiency, the construction industry continues to generate significant amounts of waste.

- 1092 • Advanced recovery technologies allow for higher recovery rates of valuable materials
1093 from CDW.
- 1094 • Despite improvements in design and material efficiency, CDW generation remains high
1095 due to the construction demand.
- 1096 • Standardised collection systems for CDW enhance the efficiency of waste manage-
1097 ment.
- 1098 • Increased collaboration between government and industry leads to investments in CDW
1099 recovery technologies.
- 1100 • The recovery focus still means a significant proportion of construction materials end up
1101 as waste.
- 1102 • Eliminating the disposal of any avoidable CDW, through the implementation and ex-
1103 pansion of incentives, and regulatory measures.
- 1104 • The focus of this scenario is to significantly reduce the amount of CDW that ends up in
1105 treatment plants without any useful applications, e.g., landfilling, incineration, and land
1106 spreading.
- 1107 • This scenario is characterized by a high recovery rate, achieved via:
 - 1108 – increased investment and enhanced regulatory system in waste management
 - 1109 – leading to more waste recovery infrastructure

- 1110 – widespread application of selective demolition and on-site waste sorting
- 1111 – the implementation of waste-to-energy facilities.

1112 **SLASH (Slags and Ashes)**

1113 In the recovery scenario, SLASH are recognized as a potential resource for secondary raw
1114 materials. Advances in recovery technologies enable the extraction of valuable metals from
1115 SLASH. However, the total volume of SLASH generated remains significant due to the con-
1116 tinued reliance on traditional energy sources.

- 1117 • Advanced recovery technologies allow for the extraction of valuable metals and miner-
1118 als from SLASH.
- 1119 • Despite improvements in energy production, SLASH generation remains significant due
1120 to the continued reliance on traditional energy sources.
- 1121 • New regulations incentivize the recovery and reuse of materials from SLASH.
- 1122 • Digital solutions enhance the traceability and management of SLASH.
- 1123 • SLASH remains a significant environmental challenge due to the volume generated.
- 1124 • Transferring down-cycling to recycling or even upcycling.
- 1125 • Recycling technology improvements (e.g., cement additives using biomass ash is under
1126 investigation)
- 1127 • More functional collection infrastructure.
- 1128 • Financial support provided to recyclers/operators.
- 1129 • Introduction of SRM/CRM recovery targets. For example, recovery of P from biomass
1130 ash for fertilizer. Recovery of Zn and Pb from Zn and Pb smelter slag.
- 1131 • Higher awareness and participation of relevant sectors on SLASH issue and manage-
1132 ment.
- 1133 • Strong regulations and monitoring are in place with higher collection and recycling tar-
1134 gets.

2.3 Scenario 3: Circularity

2.3.1 Storyline narrative

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

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

In the circularity scenario, the widespread adoption of 'circular design' principles becomes a cornerstone of production. In a circular design approach, products are designed and produced in a way that considers their entire lifecycle, including eventual disassembly and reuse. This means that every component of the product can either be biologically broken down without

any harm to the environment or technically reprocessed into new products, creating a closed loop of materials.

Additionally, this scenario envisions an improvement in transparency, with measures such as waste tracking and digital product passports becoming standard. Waste tracking allows for efficient management of waste flows, aiding in effective resource planning, while digital product passports provide information about a product's composition and how it can be properly disassembled, reused, or recycled.

This system is supported by the active engagement of all stakeholders in the value chain, from designers and manufacturers to consumers and waste managers. It is driven not only by technological advancements but also by systemic changes in policy and behaviour. A key aspect of this scenario is the shift from ownership to service-based models, where businesses retain ownership of their products and consumers pay for the service the product provides, encouraging businesses to design for longevity, repairability, and recyclability.

Thus, the circularity scenario underscores a comprehensive and systemic approach towards resource management, where every stage of the product lifecycle, from design to disposal, is optimised for sustainability and efficiency. It's not only about improving waste treatment but also about preventing waste generation in the first place. This scenario represents a holistic shift in economic and social systems, enabling a sustainable future where resources are never wasted, but instead, continually flow in a circular loop.

2.3.2 Waste stream specific scenario impacts

BATT (Battery waste)

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 renew-

- 1189 able energy storage.
- 1190 • New regulations incentivise battery manufacturers to design for recycling.
- 1191 • Battery recycling technologies improve, enabling higher recovery rates of valuable met-
- 1192 als.
- 1193 • Standardised collection systems for battery waste are established, improving the effi-
- 1194 ciency of the recycling process.
- 1195 • Service-based business models like leasing ensure manufacturers retain ownership of
- 1196 the batteries, promoting circularity.
- 1197 • Greater transparency through digital product passports aids in effective battery waste
- 1198 management.
- 1199 • Battery passport and publicly accessible Information from new Battery Regulation (SoH,
- 1200 SoC, Predicted lifetime/warranty, etc.) given by the economic operator that places the
- 1201 battery on the market enables high re-use rates.
- 1202 • Increased repairability/modularity.
- 1203 • Reduced demand from 'sharing economy' and more 'sustainable' transport choices.
- 1204 • New emerging technologies more suited for reuse/repair.
- 1205 • Ambitious targets set by business and public policy.

1206 **ELV (End-of-Life Vehicles)**

1207 For End-of-Life Vehicles (ELVs), the circular economy model revolutionises the way vehi-

1208 cles are designed, used, and discarded. Emphasising extended vehicle life through repair and

1209 remanufacturing, this scenario also optimises the recovery of materials from vehicles at the

1210 end of their life.

- 1211 • Vehicle design shifts towards repairability, upgradability, and recyclability, increasing the
- 1212 lifespan of vehicles.

- 1213 • Standardised systems for ELV collection are established, ensuring efficient waste man-
1214 agement.
- 1215 • Innovative technologies enable higher recovery rates of metals and other valuable ma-
1216 terials from ELVs.
- 1217 • Service-based models like vehicle leasing and sharing reduce the total number of vehi-
1218 cles produced.
- 1219 • Digital product passports provide information about vehicle components, aiding in ef-
1220 fective recycling or reuse.
- 1221 • Focus on managing use-phase of vehicles.
- 1222 • Circular strategies take place before material recovery so that material recovery is “de-
1223 layed”.
- 1224 • Information available to enable these strategies.
- 1225 • Three main types of circular strategies can be considered, but it is not specified now
1226 whether they complement or replace each other.
 - 1227 – Light-weighting
 - 1228 – Downsizing: Increase in share of smaller car
 - 1229 – Decrease weight: Material substitution with lighter materials (e.g., high strength
1230 steel, aluminum, plastic, carbon fibre, titanium, primary emphasis on vehicles body
1231 and chassis).
 - 1232 – Decrease weight: Decrease material content per vehicles
- 1233 • Ambitious targets set by business and public policy.
- 1234 • Remanufacturing/Repair/Reuse.
 - 1235 – Increase in average lifetime: Due to an increase in durability.
 - 1236 – Increase in average lifetime: Due to an increase in the availability of repair compo-
1237 nents.
 - 1238 – Increase in average lifetime: Better after-service.

- 1239 – Modular and common design: Leads to an increase in the availability of repair com-
1240 ponents in the second-hand market.
- 1241 – Ambitious targets set by business and public policy.
- 1242 • More intense use.
- 1243 – Increase in average occupancy and average vehicle-kilometres per trip.
- 1244 – Decrease in average lifetime (in terms of years): As the utilisation factor increases.
- 1245 • Increase in circular strategies due to an increase in participation from the public and
1246 businesses, i.e., target-based incentives with strong regulations and monitoring.

1247 **WEEE (Waste Electrical and Electronic Equipment)**

1248 In the circularity scenario, WEEE becomes a valuable resource instead of a disposal chal-
1249 lenge. Thanks to product design changes and the application of advanced recovery technolo-
1250 gies, a significant percentage of the materials in WEEE is reclaimed and fed back into the pro-
1251 duction cycle.

- 1252 • Electronic products are designed for longevity, repairability, upgradability, and recycla-
1253 bility.
- 1254 • Advanced technologies enable higher recovery rates of precious metals from WEEE.
- 1255 • Collection systems for WEEE are improved, ensuring a steady supply of materials for
1256 recycling.
- 1257 • Digitalisation and data use enhance traceability and efficiency in WEEE management.
- 1258 • Service-based models for electronics promote the use of products as a service rather
1259 than ownership, reducing WEEE generation.
- 1260 • Increased durability and lifespans.
- 1261 • Increased repairability.
- 1262 • More sharing and product-service systems, corresponding to a reduction in the lifetime
1263 (for some equipment).

- 1264 • More reuse practices (expanded second-hand market).
- 1265 • Less hoarding.
- 1266 • Higher formal collection and recycling rate.
- 1267 • Focus given more to the production and use phase rather than the EoL (End-of-Life).
- 1268 • 'Design for circularity' principle: Ecodesign mandates repairability, durability, no obso-
- 1269 lence, modularity, software upgrades possible, and diverse brands that use the same
- 1270 charger (e.g., Apple).
- 1271 • Strong regulations and monitoring are in place with higher reuse and circular targets,
- 1272 which are set and implemented, and fines are imposed on the Member States (MS)
- 1273 that fail to achieve the targets.
- 1274 • Support and development of circular strategies infrastructure (e.g., easy information ac-
- 1275 cess for repairability, repairing shops, accessibility to spare components on the market,
- 1276 etc.).

1277 **Mining waste (MIN)**

1278 In this scenario, the impact on mining waste is two-fold. Firstly, the need for primary min-
1279 ing is reduced due to efficient resource use and high recovery rates of materials. Secondly,
1280 mining waste itself is treated as a valuable resource, with advanced technologies being used
1281 to extract residual valuable materials.

- 1282 • Decrease in primary mining reduces the generation of mining waste.
- 1283 • Advanced technologies are employed to extract valuable materials from mining waste.
- 1284 • Policies and regulations incentivise the reuse of mining waste in various applications.
- 1285 • Digital solutions improve tracking and management of mining waste.
- 1286 • Collaboration between stakeholders promotes circular practices in the mining industry.

1287 **CDW (Construction and Demolition Waste)**

1288 Construction and Demolition Waste (CDW) is another sector that sees significant improve-
1289 ment in the circularity scenario. Emphasising design for disassembly and the use of recyclable
1290 materials, this scenario drastically reduces the generation of CDW and promotes the recovery
1291 of valuable materials from the waste stream.

- 1292 • Buildings are designed for disassembly, increasing the lifespan of materials and reducing
1293 CDW.
- 1294 • Recycling technologies for CDW improve, allowing higher recovery rates of materials.
- 1295 • Policies and regulations incentivise the use of recycled materials in construction.
- 1296 • Standardised systems for CDW collection and separation are established.
- 1297 • Digital tools like building information modelling (BIM) improve resource management
1298 in construction.
- 1299 • This scenario envisions a almost closed-loop system where CDW is considered a re-
1300 source, with an emphasis on minimising waste generation and maximising resource ef-
1301 ficiency in recovery.
- 1302 • Waste reduction is prioritized through the implementation of eco-designs, including de-
1303 signing out waste (DOW), lightweight design (LWD), and design for dismantling (DFD).
- 1304 • Reuse and repair standards and networks are established to boost the reuse of end-of-
1305 life building components and equipment.
- 1306 • If reuse is no longer possible, waste is recycled through high-efficiency recycling facilities
1307 rather than down-cycled or used for energy recovery.
- 1308 • This scenario is characterized by meeting all material needs through recovery (including
1309 mineral wastes from other industries) with high material efficiency achieved through the
1310 development of new business models, advanced designs and recycling technologies,
1311 strict waste management regulations, and innovative products and services.

- 1312 • Plausible target: Achieving a 100% recovery rate of avoidable CDW by 2050, with a
1313 recycling rate accounting for 30% and component reuse accounting for 20%. Raw ma-
1314 terial consumption should be reduced by 50% compared to the 2020 level.
- 1315 • Example of treatment technological development: Waste concrete is primarily recy-
1316 cled through an innovative mobile dry process. Biodiesel-based thermal treatment is
1317 applied to further pyrolyze the fine aggregate to recover cement. Lightweight design is
1318 implemented to reduce concrete use.

1319 **SLASH (Slags and Ashes)**

1320 In the circularity scenario, the approach to SLASH dramatically changes. Instead of being
1321 treated as waste, SLASH is seen as a valuable secondary raw material. Advances in technology
1322 allow for the extraction of valuable metals and minerals from SLASH, which then re-enter the
1323 material cycle.

- 1324 • A shift in perception treats SLASH as a valuable resource instead of waste.
- 1325 • Advanced technologies enable the extraction of valuable metals and minerals from
1326 SLASH.
- 1327 • New regulations incentivise the use of SLASH in various applications, such as in the con-
1328 struction industry.
- 1329 • Digital solutions enhance the tracking and management of SLASH.
- 1330 • Collaboration between industries utilises SLASH in new and innovative ways.
- 1331 • Reduce the generation of SLASH by increasing the efficiency of the manufacturing side.
1332 For example, developing higher efficient production of metals and reducing by-products
1333 such as smelter slag. For ash from the incineration of solid biomass, maximizing the use
1334 of biomass by setting proper temperature, time, and furnace conditions to reduce ash
1335 contents and improve the efficiency of power and heat generation. For ash, develop-
1336 ing other renewable technologies from bioenergy to reduce the incineration of solid
1337 biomass, e.g., biogas.

- 1338 • Reduce the generation of SLASH by increasing the proportion of higher calorific waste
1339 and decreasing lower calorific waste, e.g., MSW (Municipal Solid Waste).
- 1340 • Developing domestic feedstock supply for bioenergy or metal production to reduce the
1341 cost of transportation and others.
- 1342 • Higher formal collection and recycling rate compared to BAU, but lower compared to
1343 the Recovery scenario.

1344 Chapter 3

1345 Quantification

To be completed in the next stages of the project.

1347 **Chapter 4**

1348 **References**

- 1349 [1] Lena Boerjeson et al. "Towards a user's guide to scenarios - a report on scenario types
1350 and scenario techniques". In: (2005). ISSN: 1652-5442.
- 1351 [2] EU. *European Critical Raw Materials Act*. 2023. URL: [https://single-market-economy.
1352 ec.europa.eu/publications/european-critical-raw-materials-act_en](https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en).
- 1353 [3] EU. *The European Green Deal*. 2019. URL: [https://eur-lex.europa.eu/legal-
1354 content/EN/TXT/?uri=CELEX%3A52019DC0640](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640).

1355 **Chapter 5**

1356 **Appendices**

1357 5.1 Terminology

1358 The following is a suggested terminology for use in our discussions and reports related to sce-
1359 narios.

1360 This glossary is modelled on that used by Skea et. al. (2021), Outlooks, explorations and
1361 normative scenarios: Approaches to global energy futures compared. Some additional defi-
1362 nitions were sourced from University of Arizona — Scenario Planning for Climate Adaption.

Table 5.1: 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	Skea
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	Skea
Outlook	To provide a most likely estimate of future trends as a guide for decision-making	Scenario type	Forecast, projection	Skea
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	Skea
Scenario scale	Description of the spatial extent or temporal extent of a scenario. For us, mostly EU toward 2050.	Scenario component		UniArizona
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		UniArizona
Scenario literature	Journal articles, grey literature, etc., from which data is sourced that can be used to justify decisions in scenario development	Scenario component		

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Table 5.1 — Continued from previous page

Term	Definition	Level/Context	Also called	Source
Scenario logics	Methods for structuring the relationships between different drivers and assumptions in scenarios	Scenario component		Rowland et al. 2014 reported in UniArizona
Time horizon	End date of the scenario's forecast	Scenario attribute		Skea
Snapshot	The position of scenario/s at a particular point of time	Scenario attribute		Skea
Storyline and simulation	Combination of qualitative narrative development and quantitative modelling	Scenario component		Mahmoud et al. 2009, Wollenberg et al. 2000 reported in UniArizona
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	Skea
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		PBL

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Table 5.1 — Continued from previous page

Term	Definition	Level/Context	Also called	Source
IEA and GEC	Global Energy and Climate Model of the International Energy Agency. Used to create their forecasts: Net Zero Emissions (NZE), Announced Pledges Scenario (APS), and Stated Policies Scenario (STEPS)	Marker scenario examples		IEA
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	Walker et al. 2012, reported in UniArizona
Factors	Causes of system change that are internal from the system of analysis. Can be (hopefully) quantified, or at least estimated	Scenario component (internal)		
Factor variables	Discrete elements which are subject to change and have effects on one or more factors	Factor component		
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		
Trends	An inclination in a particular direction	Attribute of drivers or factors	System development	
Likelihood	The likelihood of an occurrence, an outcome, or a result, where this can be estimated probabilistically.	Attribute of drivers or factors	Probability	Rowland et al. 2014, IPCC standard

1363 **5.2 Scenario development methods**

1364 The following table provides an overview of the methods and tools considered, along with a
1365 brief description of each and its relevance to the specific context and objectives of the Futu-
1366 RaM scenario development process.

Table 5.2: 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

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Table 5.2 – Continued from previous page

Method	Description	Key characteristics	Limitations	Application
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
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

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Table 5.2 – Continued from previous page

Method	Description	Key characteristics	Limitations	Application
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

1367 **5.3 Marker scenario mapping**

1368 The following table presents an overview of the marker scenarios considered in the FutuRaM
1369 project. The table is not intended to be exhaustive, but rather to provide an overview of the
1370 different scenarios that have been developed in the field of waste management, resource
1371 recovery, and circular economy.

Table 5.3: Overview of marker scenarios

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	
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	Link
Environmental Impacts of Global Offshore Wind Energy Development until 2040	Academic	C&D	Scenario: 2019–2040	Global	4 (based on IEA)	Link
Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060	Academic	C&D	Scenario: 2020–2060	Global	2 (based on SSP2)	Link
Modelling global material stocks and flows for residential and service sector buildings towards 2050	Academic	C&D	Scenario: 2020–2060	Global	1 (SSP2)	Link
The evolution and future perspectives of energy intensity in the global building sector 1971–2060	Academic	C&D	Scenario: 2020–2060	Global	1 (SSP2)	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Tracking Construction Material over Space and Time Prospective and Geo-referenced modelling of Building Stocks and Construction Material Flows	Academic	C&D	Scenario to 2060	Global	6 scenarios concerning per-capita floor area, building stock turnover, and construction material.	Link
Global construction materials database and stock analysis of residential buildings between 1970–2050	Academic	C&D	Scenario to 2060	Global	1 (SSP2)	Link
A comprehensive set of global scenarios of housing, mobility, and material efficiency for material cycles and energy systems modelling	Academic	C&D	Scenario to 2060	Global	Low energy demand, SSP1, SSP2	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Global scenarios of resource and emission savings from material efficiency in residential buildings and cars	Academic	C&D, ELV	Scenarios to 2050	Global	SSP1, SSP2	Link
Matching global cobalt demand under different scenarios for co-production and mining attractiveness	Academic	Cobalt, batteries	2050	Global	5	Link
Copper at the crossroads: Assessment of the interactions between lowcarbon energy transition and supply limitations	Academic	Copper	2050	Global	2: 2°C and 4°C	Link
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)	Link
The rise of electric vehicles—2020 status and future expectations	Academic	ELV, Batteries	up to 2050	Global	various	Link
Scenarios for the Return of Lithium-ion Batteries out of Electric Cars for Recycling	Academic	ELV, Batteries	Scenario to 2050	Global	2	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
The dynamic equilibrium mechanism of regional lithium flow for transportation electrification	Academic	ELV, Batteries	Scenario to 2050	Global	1 (projection)	Link
Future material demand for automotive lithium-based batteries	Academic	ELV, Batteries	Scenario to 2050	Global	4 (based on IEA)	Link
Analysis of the Li-ion battery industry in light of the global transition to electric passenger light duty vehicles until 2050	Academic	ELV, Batteries	Scenario to 2050	Global	Combination of SSPs and RCPs	Link
Circular economy strategies for electric vehicle batteries reduce reliance on raw materials	Academic	ELV, Batteries	Scenario to 2050	Global	Reference + 4 technologies	Link
Summary and critical review of the International Energy Agency's special report: The role of critical minerals in clean energy transitions	Academic	Energy	Global	IEA 2021		Link
Review of critical metal dynamics to 2050 for 48 elements	Academic	Energy	Scenario to 2050	Global	1 compiled from various renewable technologies	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Major metals demand, supply, and environmental impacts to 2100: A critical review	Academic	Energy	Scenario to 2100	Global	1 review of 197 studies	Link
Requirements for Minerals and Metals for 100% Renewable Scenarios	Academic	Energy	Scenario to 2050	Global	1.5 degree scenario	Link
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	Link
Modelling the demand and access of mineral resources in a changing world	Academic	Energy, construction	2060	Global	RTS, BD2S IEA	Link
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	Link
A slag prediction model in an electric arc furnace process for special steel production	Academic	Slags	None	Global	0	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Decarbonising the iron and steel sector for a 2°C target using inherent waste streams	Academic	Slags	Scenario to 2050	Global	1 (2 degree climate goal)	Link
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)	Link
Resource Demand Scenarios for the Major Metals	Academic	Various	Scenario to 2050	Global	4 (UN GEO-4)	Link
Raw material depletion and scenario assessment in European Union — A circular economy approach	Academic	Various	None	EU	0	Link
Material bottlenecks in the future development of green technologies	Academic	Various	Scenario to 2050	Global	1 BAU	Link
Reuse assessment of WEEE: Systematic review of emerging themes and research directions	Academic	WEEE	None	Global	0	Link
A systematic literature review on the circular economy initiatives in the European Union	Academic	Circularity	None	EU	Circular strategies	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Material Flow Accounting: Measuring Global Material Use for Sustainable Development	Academic	Various	Scenario to 2100	Global	1 BAU	Link
Circular Economy Action Plan	Action plan	Various	Scenario to 2050	EU	35 actions to climate neutrality	Link
Construction and demolition waste: challenges and opportunities in a circular economy	Report	C&D	None	EU	0	Link
IEA world energy model	Report	Energy	Scenario to 2050	Global	4	Link
Bloomberg scenarios	Report	Energy	Scenario to 2050	Global	3	Link
The Role of Critical Minerals in Clean Energy Transitions	Report	Energy	None	Global	0	Link
Transitions to 2050 decide now act for climate	Report	Energy	Scenario to 2050	France	4 to reach 2.1C by 2100	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
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	Link
Inventaires des besoins en matière, énergie, eau et sols des technologies de la transition énergétique	Report	Energy	Scenario to 2050	France	1	Link
Minerals in the future of Europe	Report	MinW	Scenario to 2050	EU	3 (2050 net-zero, digital, circular)	Link
Minerals, Critical Minerals and the US Economy	Report	MinW	None	US	0	Link
Minéraux stratégiques — État des lieux et propositions pour une vision partagée	Report	MinW	None	FR	0	Link
The Critical Raw Materials (CRM) initiative — Underpinning the strategic approach to the EU's raw materials policy	Report	MinW	None	EU	0	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
Towards the Circular Economy: Accelerating the scale-up across global supply chains	Report	Circularity	None	Global	0	Link
The Circular Economy in Europe	Report	Circularity	None	EU	0	Link
Global material flows and resource productivity: Forty years of evidence	Report	Circularity	None	Global	0	Link
The circular economy concept: contextualisation and multiple perspectives	Report	Circularity	None	Global	0	Link
Global material flows database	Database	Various	None	Global	0	Link
International Resource Panel	Organization	Various	None	Global	0	Link
World Business Council for Sustainable Development	Organization	Various	None	Global	0	Link
Ellen MacArthur Foundation	Organization	Various	None	Global	0	Link
European Environment Agency	Organization	Various	None	EU	0	Link
International Energy Agency	Organization	Energy	None	Global	0	Link
United Nations Environment Programme	Organization	Various	None	Global	0	Link
United Nations Industrial Development Organization	Organization	Various	None	Global	0	Link

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Table 5.3 — Continued from previous page

Literature	Type	Waste stream	Temporal Coverage	Location	Number of scenarios	Link
World Bank	Organization	Various	None	Global	0	Link
World Economic Forum	Organization	Various	None	Global	0	Link

1372 **5.4 Drivers and factors identified in the initial collection phase**

1373 The following table lists the elements that were identified in the initial phase of driver/factor
1374 collection.

Table 5.4: 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

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Table 5.4 – Continued from previous page

Driver/factor	Definition
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 5.4 – Continued from previous page

Driver/factor	Definition
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

5.5 Drivers and factors identified in the screening phase

The following table lists the scenario elements that were identified in the screening phase of driver/factor collection.

Table 5.5: List of drivers and factors identified in the screening phase

Domain	Driver/factor	Definition	BAU	REC	CIR
Technical	Recovery technology	Technologies and processes for recovering materials from waste	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
Economic	Market saturation	Level of saturation reached in the market for certain products or services			
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
Legal/Political	Stricter environmental regulations	Implementation of more stringent rules and regulations for environmental protection	I	III	III
Legal/Political	Product information transparency	Provision of transparent product information to consumers, manufacturers, importers, repairers, recyclers, or national authorities	I	III	III
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	Supply chain due diligence laws: implementation/enforcement	Implementation and enforcement of laws requiring companies to address negative human rights and environmental impacts in their value chains	I	II	III
Legal/Political	Governance: corruption vs compliance	Contrasting levels of corruption and compliance within governance systems			
Legal/Political	Progress toward renewable energy targets	Progress made in achieving renewable energy targets		II	III
Legal/Political	Subsidies/taxation to promote circularity	Provision of subsidies or implementation of taxation policies to incentivize circularity		I	II
Legal/Political	International trade and co-operation (vs. autarky)	Level of international trade and cooperation versus self-sufficiency			
Economic	CO2 market price	Price of carbon dioxide (CO2) emissions in carbon markets			
Economic	Energy prices	Prices of energy resources			
Economic	Economic growth	Rate of economic growth	I	I	
Economic	Re-industrialisation of EU	Process of revitalizing industrial activities in the European Union			

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Table 5.5 — Continued from previous page

Domain	Driver/factor	Definition	BAU	REC	CIR
Economic	Raw material vs SRM prices	Price comparison between raw materials and Secondary Raw Materials (SRMs)			
Environmental	Climate change impacts (flooding, etc.)	Impacts of climate change such as flooding and other related events			
Environmental	Climate change mitigation efforts	Efforts made to mitigate the effects of climate change			
Environmental	Increased drive for env. protection	Growing motivation and drive to protect the environment	I	III	III
Environmental	Resource shortage	Shortage of natural resources	II	I	
Social	NIMBY to projects	Opposition of local communities to the location of new projects, such as mining, in their vicinity			
Social	Population	Size and growth of the population			
Social	Urbanisation	Rate of urban population growth			
Social	Hoarding	The act of stockpiling and keeping excessive amounts of products		II	III
Social	Participation in re-X activities	Involvement in activities related to the "re-" concepts, including refusing, reducing, repairing, and reusing products	I	II	III