

Futu

Future availability
of secondary
raw materials

RaM

Work Package 2

Future Availability of Secondary Raw Materials

Task 2.1:
Scenario Storylines



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2

DRAFT REPORT – VERSION 2

3

NOTICE FOR REVIEWERS

4

Latest Revision: Friday 10th November, 2023 at 16:13

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Contributing

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How to submit comments and corrections

7

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

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What still needs to be done

16

SCENARIO STORYLINES

17

- Contribute to the main points raised by the reviewers of the first draft (see below).
- Add more references, especially for the targets, regulations, and projections.
- Waste stream groups to check the sections related to their waste streams.
- Add more figures and tables.
- FORMATTING
 - Implement the glossary package
 - Split up the methodology and storylines into separate .tex files

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QUANTIFICATION

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- Contribute to the data collection in the future technology list here [Q](#).

26

Main points for discussion

27

- How to transfer general targets?



28

general CRM/SRM ?=>? waste streams ?=>? product groups

29

We would need a set of constraints for each of the recovery flows and processes, as well as the individual waste flows (by code) in each WS, to backcast this.

31

- Consideration of possible future resource constraints in the scenarios.

32

We suggest covering this in sensitivity analysis and multi-objective-optimisation.

33

- Economic considerations (prices, subsidies, PPP vs. GPD etc.).
- Geopolitical Considerations (supply risk, trade, etc.).
- Scenarios relationship with the United Nations Framework Classification (UNFC).
- E-mobility.

35

Do we hold it level across the scenarios, as planned? Or, do we make changes, since the 'Autolobby' & 'Deutschland GmBh.' have recently killed the ICE ban...

36

39 Some quick links to the WIP chapters and appendices

40

- Quantification: chapter 4
- Appendices: chapter 6
- WP2 folder on the FutuRaM Sharepoint 

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Front Matter

45

CHAPTER CONTENTS

46	I	Report Details	v
47	II	Notice	vi
48	III	Preface	vii
49	IV	Report Contents	viii
50	V	List of Tables	xii
51	VI	List of Figures	xiv
52	VII	Executive Summary	xv
53	VIII	Overview of the scenario storylines	xvii
54	IX	Abbreviations	xxiii
55	X	Terminology (abbreviated)	xxv
56	XI	Description of FutuRaM work package task 2.1	xxvi
57		XI.1 Associated milestones	xxvi
58		XI.2 Associated subtasks	xxvii



I. REPORT DETAILS

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Table 1.1: Version history

VER. NO.	DATE	REASONS FOR RELEASE	RESPONSIBLE
1.0	2023-09-11	First draft for review	Stewart Charles McDowall
2.0	2023-11-11	Second draft for review	Stewart Charles McDowall
X	X	X	X
X	X	X	X

60 II. NOTICE

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71 kind with regard to this material.



72 III. PREFACE

73 The FutuRaM project aims to quantify the current and future availability of secondary raw materials
74 (SRM), focusing on critical raw materials (CRMs) [1]. This study is concerned with six waste streams in the
75 EU member states, as well as Iceland, Norway, Switzerland, and the United Kingdom (EU27+4). In this
76 report, the EU27+4 will henceforth be referred to as the EU, unless specified otherwise.

77 **THE WASTE STREAMS COVERED IN FUTURAM ARE:**

- 78  Waste batteries (BAT)
- 79  Construction and demolition waste (CDW)
- 80  End-of-life vehicles (ELV)
- 81  Mining waste (MIN)
- 82  Slags and ashes (SLASH)
- 83  Waste electrical and electronic equipment (WEEE)

84 Work package two (WP2) is conducting foresight studies for materials that are either classified as
85 critical to the EU economy or are significant due to factors such as their large volumes, commercial
86 importance, and environmental impacts [1, 2, 3, 4]. WP2 is tasked with developing a set of coherent
87 scenarios for material use and waste/recovery over time across various sectors in the EU. This report
88 describes the three distinct scenarios and the process by which they were developed.

89 **THE THREE SCENARIOS THAT HAVE BEEN DEVELOPED IN FUTURAM ARE:**

- 90  I. Business-as-usual (BAU)
- 91  II. Recovery (REC)
- 92  III. Circularity (CIR)



93 IV. REPORT CONTENTS

95	1 Front Matter	iv
96	I Report Details	v
97	II Notice	vi
98	III Preface	vii
99	IV Report Contents	viii
100	V List of Tables	xii
101	VI List of Figures	xiv
102	VII Executive Summary	xv
103	VIII Overview of the scenario storylines	xvii
104	IX Abbreviations	xxiii
105	X Terminology (abbreviated)	xxv
106	XI Description of FutuRaM work package task 2.1	xxvi
107	XI.1 Associated milestones	xxvi
108	XI.2 Associated subtasks	xxvii
109	2 Methodology	1
110	2.1 The conceptual framework for scenario development	2
111	2.2 Scenario storyline development process	4
112	2.2.1 Step 1: Define the scope and objectives	5
113	2.2.2 Step 2: Determine methodology	11
114	2.2.3 Step 3: Marker-scenario mapping	17
115	2.2.4 Step 4: Identification of key drivers of change	19
116	2.2.5 Step 5: Develop storyline themes	29
117	2.2.6 Step 6: Qualitative narrative development	29
118	2.2.7 Step 7: Definition of scenario parameters	30
119	2.2.8 Step 8: Quantitative modelling	30
120	2.2.9 Step 9: Implementation	30

121	2.2.10 Step 10: Review process	30
122	3 Scenario storylines	32
123	3.1 Scenario I: Business-as-usual	33
124	3.1.1 Storyline narrative	33
125	3.1.2 Waste stream specific scenario impacts	35
126	3.2 Scenario II: Recovery	40
127	3.2.1 Storyline narrative	40
128	3.2.2 Waste stream specific scenario impacts	42
129	3.3 Scenario III: Circularity	48
130	3.3.1 Storyline narrative	48
131	3.3.2 Scenario needs and impacts	49
132	3.3.3 Waste stream specific scenario impacts	51
133	4 Quantification	57
134	4.1 Introduction	59
135	4.2 Summary	61
136	4.3 External elements	62
137	4.3.1 Introduction	62
138	4.3.2 Summary	64
139	4.3.3 Demographic factors: <i>Population, age, urbanisation</i>	67
140	4.3.4 Economic factors: <i>GDP growth</i>	79
141	4.3.5 The Renewable Energy Transition	86
142	4.3.6 Conclusion	103
143	4.4 Internal elements – Technological Change	104
144	4.4.1 Introduction	105
145	4.4.2 Summary	106
146	4.4.3 Future product and waste composition: <i>Description</i>	107
147	4.4.4 Future product and waste composition: <i>Scenarios</i>	109

148	4.4.5 Future recovery technology: <i>Description</i>	113
149	4.4.6 Future recovery technology: <i>Scenarios</i>	115
150	4.4.7 Future recovery system: <i>Description</i>	119
151	4.4.8 Future recovery system: <i>Scenarios</i>	121
152	4.5 Internal elements — The Circular Economy	126
153	4.5.1 Introduction	127
154	4.5.2 Summary	128
155	4.5.3 The EU Circular Economy Indicators: <i>Description</i>	129
156	4.5.4 The EU Circular Economy Indicators: <i>Scenarios</i>	136
157	4.5.5 Refuse and Reuse: <i>Description</i>	140
158	4.5.6 Refuse and Reuse: <i>Scenarios</i>	142
159	4.5.7 Repairability and ‘Right to Repair’: <i>Description</i>	146
160	4.5.8 Repairability and ‘Right to Repair’: <i>Scenarios</i>	155
161	4.5.9 Remanufacturing: <i>Description</i>	159
162	4.5.10 Remanufacturing: <i>Scenarios</i>	161
163	4.5.11 The Sharing Economy: <i>Description</i>	165
164	4.5.12 The Sharing Economy: <i>Scenarios</i>	169
165	4.6 Conclusion	174
166	5 References	175
167	5.1 Legislation and Government Documents	176
168	5.2 Reports	178
169	5.3 Datasets	180
170	5.4 Books	180
171	5.5 Book Chapters	181
172	5.6 Articles	181
173	5.7 Online Sources	185
174	5.8 Miscellaneous	186

175	6 Appendices	187
176	6.1 Terminology	188
177	6.2 List of relevant policy actions	194
178	6.3 Scenario development methods	197
179	6.4 Marker scenario mapping	202
180	6.5 Drivers and factors identified in the initial collection phase	211
181	6.6 Drivers and factors identified in the screening phase	217
182	6.7 Drivers and factors after categorisation	221
183	6.8 Drivers and factors for quantification	225

V. LIST OF TABLES

186	Front Matter	iv
187	1.1 Version history	v
188	1.2 List of abbreviations	xxiii
189	1.3 List of terminology (abbreviated)	xxv
190	1.4 WP2.1—Milestone list	xxvi
191	1.5 WP2.1—Subtask list	xxvii
192	Methodology	1
193	2.1 Selected objectives of the FutuRaM project	6
194	2.2 FutuRaM WP2 aims and objectives	7
195	2.3 Types of scenario	16
196	2.4 List of drivers and factors identified in the screening phase	25
197	Scenario storylines	32
198	Quantification	58
199	4.1 List of external scenario elements	63
200	4.2 Population projections for the EU27+4	76
201	4.3 Raw materials essential to the renewable energy sector	90
202	4.4 Normalized renewable energy supply in the EU using the year 2010 as a base reference .	98
203	4.5 Definitions and Objectives of the GEC Model 2023 Scenarios	99
204	Appendices	187
205	6.1 Terminology	189
206	6.2 List of relevant policy actions	195
207	6.3 Scenario development methods	198

208	6.4 Overview of marker scenarios	203
209	6.5 Drivers and factors identified in the initial collection phase	212
210	6.6 List of drivers and factors identified in the screening phase	218
211	6.7 List of drivers and factors identified in the screening phase	222
212	6.8 List of scenario elements categorised for quantification	226



VI. LIST OF FIGURES

Front Matter

iv

Methodology

1

2.1 Scenario storyline development process 4

2.2 An illustration of the process used for identifying key drivers of change 20

2.3 An excerpt of a spreadsheet used as part of the screening process 23

Scenario storylines

32

Quantification

58

4.1 Population projections for the EU27+3 and the UK 68

4.2 Factors incorporated in the long-term model [58] 82

4.3 EU electricity mix forecast until 2050 86

4.4 Change in demand for selected elements 100

4.5 Change in demand for battery relevant elements 101

4.6 Global mineral demand (total) under various scenarios 101

Appendices

187



229 VII. EXECUTIVE SUMMARY

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

234 The scenario development process employs a methodology that integrates both forecasting and
235 backcasting techniques to build a comprehensive, future-facing knowledge base that can aid fact-based
236 decision-making [5, 6, 7, 8, 9, 10, 11].

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

240 The FutuRaM project aims to offer a nuanced understanding of the potential future waste manage-
241 ment and resource recovery landscape within the EU. This approach provides insights into key drivers,
242 uncertainties, and the possible impacts of policy and technological advancements. Additionally, by align-
243 ing SRM recovery efforts with the United Nations Framework Classification for Resources (UNFC) [12],
244 the project aims to facilitate the commercial exploitation of SRMs and CRMs by manufacturers, recyclers,
245 and investors. With the comprehensive knowledge base that we are developing, FutuRaM aims to
246 support informed decision-making by policymakers and government, as well as industry and community
247 stakeholders.

248 FUTURAM'S THREE FUTURE SCENARIOS



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

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

256



257

Scenario II: Recovery (REC)

258 The Recovery scenario imagines a future leveraging advanced technology to significantly enhance SRM
259 recovery from waste streams. It outlines a future where the EU successfully meets its recycling and
260 recovery targets through an effective waste management system and circular design principles [13, 14].
261 This scenario sees an increased recovery rate of SRMs, extensive use of digitalisation and automation in
262 recycling processes, and new or strengthened waste regulations in line with EU targets.

263



264

Scenario III: Circularity (CIR)

265 The Circularity scenario captures the ideal of a fully realised circular economy, going beyond end-of-life
266 recovery to minimise waste at every production and consumption stage. It predicts a future where the
267 EU's targets for recycling, recovery, and circularity are met through extensive stakeholder collaboration,
268 new business models, and increased use of renewable energy and circular economy technologies [15, 16,
269 17].

270

271

VIII. OVERVIEW OF THE SCENARIO STORYLINES

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



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

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

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

- 283 • A forecasting model is used to predict the future based on the current situation and the
284 development of existing trends.
- 285 • EU targets including those for eco-design, recycling and recovery are not met, and the
286 current linear model largely persists.
- 287 • Material demand remains coupled with economic growth, perpetuating a trend of increasing
288 consumption.
- 289 • Primary mining and extraction persist as the leading sources of raw materials, underlining
290 the dependency on traditional extraction methods.
- 291 • Recycling and recovery rates continue to lag, leading to increased production of SRM-
292 containing waste that signals missed opportunities for resource reuse.
- 293 • The EU's dependency on imports of SRMs escalates, heightening the risk of supply disruptions [18].
- 294 • Investment in new SRM recovery technologies remains minimal, stifling innovation and
295 advancements in this field.
- 296 • The industrial focus remains on cost-effective material production and use, disregarding the
297 long-term sustainability aspect.
- 298 • Material scarcity and price fluctuations pose potential risks to the EU industry, highlighting
299 the vulnerability of this business model [19].
- 300 • Without any significant updates to environmental regulations, the negative impacts on
301 ecosystems and biodiversity intensify.

- 303 • Mining activity in the EU remains limited and concentrated in only a few member states.
304 Current exploration projects (e.g., for Lithium in PT, FR, UK and rare earths in SE) are not
305 realised.
- 306 • The transitions to renewable energy and e-mobility continue at their current pace.

307

308

Scenario II: Recovery (BAU)

309



310 See section 3.2 for the full scenario description and the waste-stream-specific scenario impact
311 narratives.

312 In the recovery scenario, the central emphasis is on harnessing sophisticated technologies to salvage
313 SRMs from waste streams at the end of their lifecycle. While there are noticeable strides towards the
314 incorporation of 'circular design' principles and re-X strategies (which focus on reducing, reusing, recycling,
315 repairing, and refurbishing), material demand increases similarly to the BAU scenario. This is, however,
316 mitigated to some extent by the implementation of a comprehensive material recovery system.

317 **Key features of this technology-promoted recovery scenario include:**

- 318 • This scenario uses a combination of forecasting and backcasting methods to envision the
319 future.
- 320 • The backcasting method is used for scenario factors that are covered by governmental
321 targets, starting with the desired outcome and working backwards to the present.
- 322 • The forecasting method is used for scenario factors that are not covered by governmental
323 targets, starting with the current situation and extending to the future.
- 324 • EU targets for recycling and recovery are met, due to the EU's waste management system
325 becoming more expansive, efficient and effective.
- 326 • Technological innovation drives increased recovery rates of SRMs, enabling the more effi-
327 cient use of waste.
- 328 • Digitalisation and automation are more extensively used in recycling processes, leading to
329 enhanced productivity and efficiency.
- 330 • Business models like leasing and take-back schemes emerge, altering traditional consump-
331 tion patterns (here, the focus is on take-back for recycling).
- 332 • Ecodesign mandates are implemented, again, here, with a focus on end-of-life recovery.
- 333 • There is greater exploration and exploitation of alternative sources such as urban mining,
334 waste streams, and tailings, presenting novel opportunities for resource acquisition.
- 335 • New waste regulations and guidelines for SRM recovery are implemented, enforcing better
336 management and extraction of SRMs.
- 337 • Investment in research and development for SRM recovery technologies experiences an
338 upswing, promoting continuous innovation in this field.
- 339 • Closer collaboration and information sharing between industry and government institu-

tions (e.g., waste tracking and digital product passports) streamline processes and expedite decision-making.

- New jobs are created in the recycling and recovery sector, offering economic benefits and improving overall employment rates.
 - SRM production and use become more efficient and cost-effective, fostering economic sustainability.

346



347

Scenario III: Circularity

348



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

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

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

362 This scenario envisions a future where government policies are in synergy with private sector in-
363 novation and societal changes, driving a wholesale transition towards a circular economy. Unlike the
364 recovery scenario, where the focus is on the end-of-life recovery of materials, this scenario emphasises
365 minimising waste at all stages, starting from the design phase itself.

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

- 367 • This scenario uses a combination of forecasting and backcasting methods to envision the
368 future.
- 369 • The backcasting method is used for scenario factors that are covered by governmental
370 targets, starting with the desired outcome and working backwards to the present.
- 371 • The forecasting method is used for scenario factors that are not covered by governmental
372 targets, starting with the current situation and extending to the future.
- 373 • EU targets for recycling and recovery are met, as are those for circularity, due to advances in
374 waste management, ecodesign and re-X strategies.
- 375 • A circular economy is implemented, prioritising waste reduction, resource efficiency, and a
376 shift from the 'take-make-dispose' model.
- 377 • A notable increase in SRM recycling and recovery rates, indicating an efficient use of re-
378 sources.
- 379 • A larger emphasis on designing products for reuse and recycling, making waste a valuable

- 380 resource rather than a problem.
- 381 • More extensive use of renewable energy and clean technologies in SRM production and
382 use, supporting a low-carbon economy.
- 383 • Collaboration between stakeholders — including industry, government, and consumers —
384 improves, enhancing the implementation of circular practices.
- 385 • New business models like leasing and take-back schemes emerge, altering traditional con-
386 sumption patterns [20].
- 387 • Digitalisation and data use are heightened to improve efficiency and traceability, aiding in
388 effective resource management.
- 389 • Investment in research and development for circular economy technologies increases,
390 driving innovation and adoption.
- 391 • Awareness and education around sustainable consumption and production practices are
392 amplified, leading to behavioural changes in society.
- 393 • Reliance on imports decreases, suggesting greater self-sufficiency and sustainability.
- 394 • The creation of new jobs within the recycling, recovery and re-X sectors boosts the econ-
395 omy and alleviates social inequality.
- 396 • Stricter waste regulations and product design guidelines are introduced, accelerating the
397 transition towards circularity.

IX. ABBREVIATIONS

Table 1.2: List of abbreviations

ACRONYM	DEFINITION
AI	Artificial Intelligence
BAU	Business as Usual
BATT	Waste Batteries
BRGM	French Geological Survey (Bureau de Recherches Géologiques et Minières)
CDW	Construction and Demolition Waste
CE	Circular Economy
CRM	Critical Raw Material
CU	Chalmers University
EEE	Electrical and Electronic Equipment
ELV	End-of-Life Vehicles
Empa	Swiss Federal Laboratories for Materials Science and Technology
EoL	End-of-Life
EoU	End-of-Use
EoW	End-of-Waste
EU	European Union
EU27+4	EU + Iceland, Norway, Switzerland and the United Kingdom
EPR	Extended Producer Responsibility
GDP	Gross Domestic Product
GEC	Global Energy and Climate [Model]
GTK	Geological Survey of Finland
LCA	Life Cycle Assessment
LCC	Life Cycle Cost Assessment
LMU	Ludwig Maximilian University of Munich
LU	Leiden University
MIN	Mining Waste
R&D	Research and Development
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals

Continued on next page

Table 1.2 – Continued from previous page

ACRONYM	DEFINITION
RECHARGE	EU rechargeable battery industry association
SGU	Geological Survey of Sweden
SLASH	Slags and Ashes
S-LCA	Social Life Cycle Assessment
SLCA	Sustainability Life Cycle Assessment
SRM	Secondary Raw Material
TRL	Technology Readiness Level
TUB	Technische Universität Berlin
UCL	University College London
UNITAR	United Nations Institute for Training and Research
UNFC	United Nations Framework Classification for Resources
VITO	Flemish Institute for Technological Research
WEEE	Waste Electrical and Electronic Equipment
WEEE Forum	Waste Electrical and Electronic Equipment Forum
WFD	Waste Framework Directive

401

X. TERMINOLOGY (ABBREVIATED)

402

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

403

See section 6.1 for a complete list.

Table 1.3: List of terminology (abbreviated)

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





XI. DESCRIPTION OF FUTURAM WORK PACKAGE TASK 2.1

405

XI.1. Associated milestones

Table 1.4: WP2.1 – Milestone list

M#	MILESTONE NAME	WP	DUE DATE	RESP. PARTNER	MEANS OF VERIFICATION
MS11	Mapping of published scenarios and Storyline/scenario description	2	Dec. 2023	ULEI	Datasets on available scenarios are fed into D1.1 and qualitative descriptions of 3 futures for the six waste streams are circulated

Back to ToC

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XI.2. Associated subtasks

Table 1.5: WP2.1 – Subtask list

WP	TASK	SUB-TASK	NAME	WS	DESCRIPTION	START	END	PARTNERS	STATUS
2	2.1	2.1	Scenario mapping	Cross-cutting	Map various studies from the academic, policy, and grey literature for future scenarios and assess the applicability within FutuRaM	M01	M05	WEEE Forum, UNITAR, BRGM, CU, GTK, LMU, RECHARGE, SGU, TUB, LU, VITO, Empa, UCL	✓
2	2.1	2.2	Scenario methods	Cross-cutting	Compile various methodologies for scenario development and assess their applicability for developing scenarios on material recovery and circular economy for Europe	M02	M05	WEEE Forum, UNITAR, BRGM, CU, GTK, LMU, RECHARGE, SGU, TUB, LU, VITO, Empa, UCL	✓
2	2.1	2.3	Scenario storylines	Cross-cutting	Flesh out the storylines of the 3 main scenarios	M05	M08	UNITAR, CU, TUB, LU	✓
2	2.1	2.4	Qualitative scenario development	Cross-cutting	Use the chosen methods and qualitative methods to develop the three main scenarios to be used in FutuRaM (e.g. BAU, increased material recovery, and full circular economy)	M07	M11	UNITAR, CU, SGU, LU, VITO, UCL	✓(V2)

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Methodology

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CHAPTER CONTENTS

415	2.1	The conceptual framework for scenario development	2
416	2.2	Scenario storyline development process	4
417	2.2.1	Step 1: Define the scope and objectives	5
418	2.2.2	Step 2: Determine methodology	11
419	2.2.3	Step 3: Marker-scenario mapping	17
420	2.2.4	Step 4: Identification of key drivers of change	19
421	2.2.5	Step 5: Develop storyline themes	29
422	2.2.6	Step 6: Qualitative narrative development	29
423	2.2.7	Step 7: Definition of scenario parameters	30
424	2.2.8	Step 8: Quantitative modelling	30
425	2.2.9	Step 9: Implementation	30
426	2.2.10	Step 10: Review process	30



427 2.1. THE CONCEPTUAL FRAMEWORK FOR 428 SCENARIO DEVELOPMENT

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

430 **The scenarios should:**

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

461 By adhering to these principles, the FutuRaM project aims to develop robust, informative, and policy-

462

463

relevant scenarios that support sustainable decision-making and contribute to the transition towards a more circular and resource-efficient economy.



464

2.2. SCENARIO STORYLINE DEVELOPMENT PROCESS

465

Building scenarios involves several steps and various methodologies, these will differ depending on the specific context and objectives of the exercise [5, 6, 7, 8, 9, 21, 22, 23, 24].

466

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

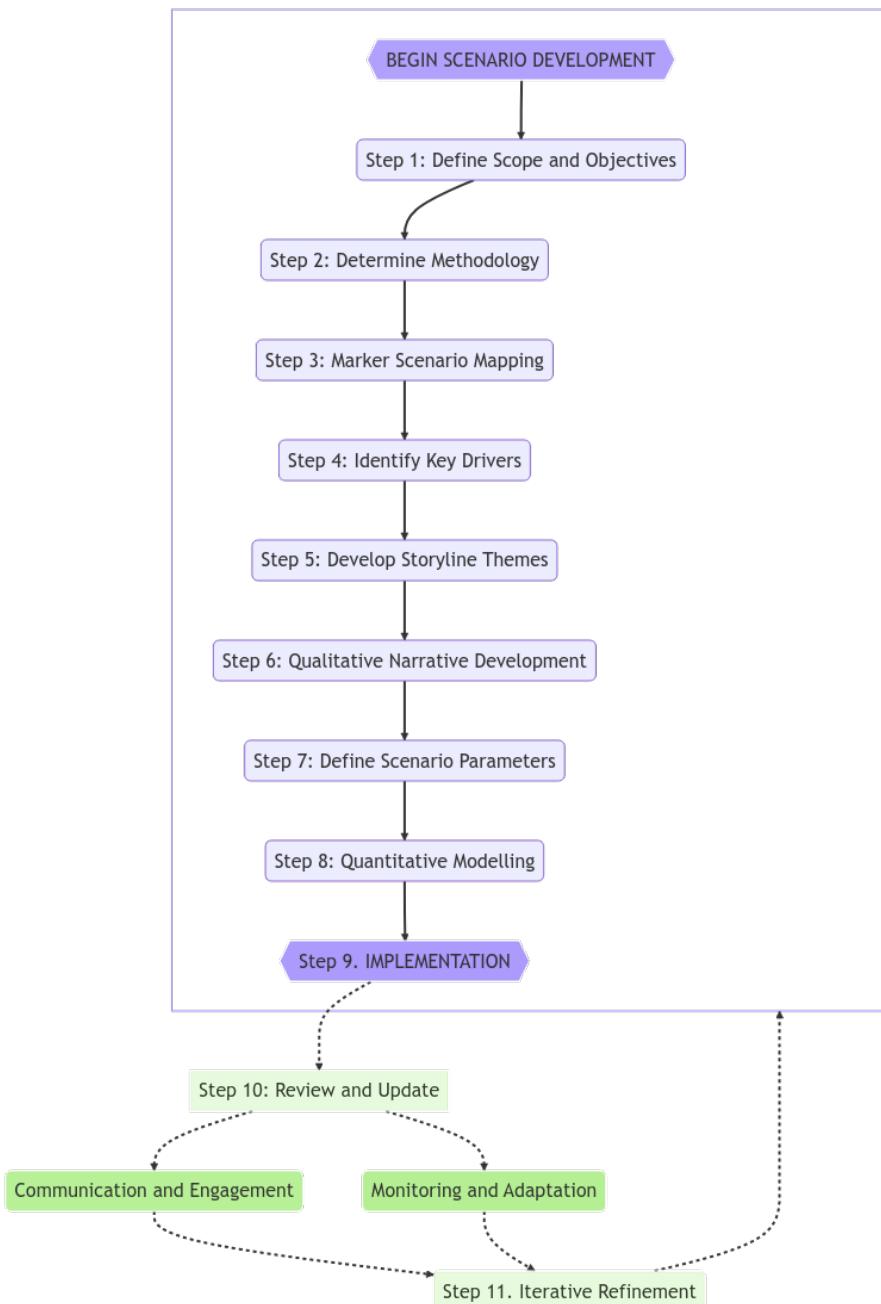


Figure 2.1: Scenario storyline development process

2.2.1. Step 1: Define the scope and objectives

Scope and objectives of the scenario development process

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

Aim of FutuRaM:

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

Scope of FutuRaM:

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

It will integrate SRM and CRM data to model their current stocks and flows and consider economic, technological, geopolitical, regulatory, social and environmental factors to further develop, demonstrate and align SRM recovery projects with the United Nations Framework Classification for Resources (UNFC) [12].

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

Selected objectives of the FutuRaM project in general are presented in Table 2.1.

WP2 – 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

Table 2.1: Selected objectives of the FutuRaM project

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

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

507 **Geographic scope**

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

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Additionally, the scenarios will consider the current and future policies and targets
related to waste management and resource efficiency in these countries. To some ex-
tent, the scenarios will also consider the current and future trade relationships between
these countries and other countries around the world.

515 **Temporal scope**

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518
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.

519
520
The discrete stages in the forecasts are planned to be: 2025, 2030, 2035, 2040,
2045 and 2050.

521
The temporal resolution of the scenarios will be determined during the quantification

phase of the scenario development process.

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

Furthermore, the scenarios will be developed with the understanding that the further into the future we look, the more uncertain the predictions become [8, 25, 26].

WP2 — Aims and objectives definition

Table 2.2: FutuRaM WP2 aims and objectives

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

Consideration of EU legislation and policy targets

The scenarios developed in FutuRaM consider targets that the EU is setting for specific elements, materials, and waste streams. The targets incorporated into FuTuRaM's scenarios are aligned with the ambitions of the EU's Green Deal [27] and its Critical Raw Materials (CRM) act [2].

Additionally, the consumer-product-centric waste streams BATT, ELV, and WEEE have specific EU legislation that is directly applicable to them and will be considered in detail in the scenarios [28, 29, 30, 31, 32, 33].

GENERAL POLICIES AND LEGISLATION

The EU Green Deal [27] is a set of policy initiatives by the European Commission with the overarching aim of making the EU climate-neutral in 2050.

This policy portfolio is a response to the Paris Agreement and the United Nations Sustainable Development Goals. It covers a wide range of economic sectors with an

542 emphasis on investments towards building local, 'sustainable' industries.

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

548 **The EU Circular Economy Action Plan [15]** is a policy framework developed by the
549 European Commission to promote the circular economy in the European Union.

550 It sets out a comprehensive set of measures and targets to improve resource effi-
551 ciency, reduce waste, and foster sustainable production and consumption. The Action
552 Plan includes initiatives related to product design, waste management, recycling, and
553 resource efficiency, among others. The Action Plan is a key element of the European
554 Green Deal and is closely linked to the EU Industrial Strategy.

555 **The Circular Economy Action Plan:**

- 556 • Aims to promote the transition to a more circular economy in the EU.
- 557 • Sets out a range of measures to promote the sustainable use of resources,
558 reduce waste, and increase recycling.
- 559 • Includes proposals for new legislation, such as an EU-wide framework for
560 the circular economy, and revisions to existing legislation, such as the WEEE
561 Directive.
- 562 • Emphasises the importance of product design for the circular economy and
563 proposes measures to promote eco-design and repairability.
- 564 • Includes initiatives to promote the use of secondary raw materials, such as
565 the establishment of a European Raw Materials Alliance.
- 566 • Aims to reduce greenhouse gas emissions and improve resource efficiency
567 in the EU.
- 568 • Calls for increased cooperation and dialogue among stakeholders in the cir-
569 cular economy.

570 **The Critical Raw Materials Act (CRM Act) [2]** is an EU regulation that aims to ensure
571 a secure and sustainable supply of raw materials to the EU.

572 The Act identifies a list of strategic raw materials, which are crucial to technologies
573 important to Europe's green and digital ambitions and for defence and space applica-
574 tions, that are subject to potential supply risks. The regulation will cover the entire raw

575 materials value chain, from primary extraction to manufacturing to potential recovery
576 as a secondary raw material.

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

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

- 581
- Extract at least 10% of the EU's annual consumption

582

 - Process at least 40% of the EU's annual consumption

583

 - Recycle at least 15% of the EU's annual consumption

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

589 Many of these targets, benchmarks and mandates — despite being included in
590 legislation — are considered too optimistic to be included in the Business-as-usual
591 scenario (BAU) as they often make expectations whose attainment is likely highly
592 unrealistic without radical reform of the waste management system. For example, the
593 targets in the Battery Act suggest near-complete recovery for several elements [33].

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

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

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

605 However, for waste that does not consist of discarded consumer products, but
606 instead results from industrial production activities, in particular for MIN and SLASH, we

607 must still produce specific scenarios related to mining, metallurgy, and waste and fuel
608 combustion. The production of new mining wastes will depend on new local mining
609 activity.

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

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

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

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

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

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

631 ***Consideration of geopolitical developments***

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

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

639 The most volatile aspect of the 'criticality calculation' is the risk profile of the produc-

ing country. For many material-exporting nations, this is not something that can be reliably forecast, especially not over the next 30 years. Thus, it will be assumed that the growth in material demand for (among other needs) the energy and mobility transitions can be satisfied either by an increase in mining and metallurgy activities within the EU or by growing imports from raw material-producing countries outside the EU.

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

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

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

However, '...most experts predict that reshoring or nearshoring will be of limited importance. With time, though, resilience may improve through international cooperation, diversification and the accelerated uptake of digital technologies.' [34]

Note: supply constrictions will be considered in the model's sensitivity analysis and the codebase will be designed to allow for the optimisation of the SRM recovery system based on any supply-demand value statements.

2.2.2. Step 2: Determine methodology

Methodology types and selection criteria

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

Relevance:

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

Applicability:

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

Feasibility:

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

Transparency:

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

Flexibility:

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

Accessibility:

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

Effectiveness:

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

Efficiency:

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

Acceptability:

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

Further details are given in this section, and the table in section 6.3 provides an overview of the methods and tools considered, along with a brief description of each and its relevance to the specific context and objectives of the FutuRaM scenario development process.

Choice of methodology

The grant proposal for the FutuRaM project outlined that there should be at least three scenarios developed, namely business as usual, recovery, and circularity. This remains

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the case; however, during the scenario development process, additional scenarios or
scenario dimensions were considered, including supply chain security and the energy
transition.

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Considered dimension — Supply chain security:

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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.

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Considered dimension — Energy transition:

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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.

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Method — Multi-criteria analysis and cross-impact analysis

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In order to assess the potential inclusion of these additional scenario dimensions, a multi-criteria analysis and a cross-impact analysis were conducted [35]. The addition of extra dimensions increases the possible number of scenarios significantly. By assessing the consistency and plausibility of these combinations with a matrix-based method, it was possible to reduce the number of scenarios.

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

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

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

736
Method — Delphi

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The Delphi method [36] was used in the initial stages of the scenario-building process

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to gather and aggregate the opinions of experts or stakeholders. Internal consultation
with consortium members who were experts in their respective waste streams or other
aspects of the recovery system was conducted.

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

746 **Choice of Scenario Type**

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The general types of scenarios are summarized in Table 2.3. In the context of futures
studies, various approaches and methodologies are employed to understand the po-
tential trajectories of future developments [6, 7, 8, 21, 22, 23].

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

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

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755
Pros: These scenarios offer insights into potential future outcomes, aiding in long-term
planning.

756
757
Cons: They are contingent on assumptions and may not account for unexpected
events.

758
759
Applicability: Predictive scenarios are valuable when the aim is to forecast future
developments under certain conditions.

760 **Explorative Scenarios (Answering ‘What Can Happen?’):**

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Pros: Explorative scenarios explore a wide range of potential future scenarios, fostering
preparedness for various outcomes.

763
Cons: They do not prioritize the likelihood or desirability of scenarios.

764
765
Applicability: These scenarios are beneficial when considering multiple potential
futures and the need to adapt to diverse outcomes.

766 **Normative Scenarios (Answering ‘How Can a Specific Target Be Reached?’):**

767 **Pros:** Normative scenarios focus on achieving predefined objectives and offer guidance
768 on strategies to attain them.

769 **Cons:** They are inherently normative, starting with specific goals in mind.

770 **Applicability:** Normative scenarios are suitable when the objective is to work towards
771 predefined targets and develop actionable plans to reach them.

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

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

782 In practice, a combination of qualitative and quantitative techniques can be em-
783 ployed to create scenarios tailored to specific needs. For instance, a blend of techniques
784 may be used to generate forecasts, especially when external factors are uncertain.
785 Likewise, strategic scenarios often begin with external scenario generation and proceed
786 to identify available policy options.

Table 2.3: Types of scenario (adapted from [6, 7])

SCENARIO CATEGORY	SCENARIO TYPE	OUTCOME	TIMEFRAME	SYSTEM STRUCTURE	FOCUS ON 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	Preserving	Typically quantitative	Often long	One	Both external and internal
	Transforming	Typically qualitative with quantitative elements	Often very long	Changing, can be several	Not applicable

F

Back to ToC

787
788 The scenarios developed in the FutuRaM project are a combination of predictive
and normative:
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BAU:

790 *What will happen if current trends continue?*

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



Recovery:

795 *What will it take to achieve the EU's targets for material use and recovery? Focus on
796 technology*

797 This scenario is normative, focusing on manipulating the technology and infra-
798 structure of the recovery system to achieve the EU's targets and mandates.



Circularity:

800 *What will it take to achieve the EU's targets for material use and recovery? Focus on
801 re-X strategies*

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

805 The methodology and scenario types were selected based on their relevance, appli-
806 cability, feasibility, transparency, flexibility, accessibility, effectiveness, efficiency, and
807 acceptability to the scenario development process.

2.2.3. Step 3: Marker-scenario mapping

Justification and methodology

810 This preliminary step in the scenario development process involves conducting a litera-
811 ture study to identify existing scenarios that are relevant to the FutuRaM project. This
812 step is crucial as it serves several important purposes and provides valuable insights for
813 the overall scenario development process. It helps the scenario development team to
814 build on existing knowledge, identify relevant scenarios, gain insights and inspiration,
815 fill knowledge gaps, and enhance credibility and comparability.

Building on existing knowledge:

816 Conducting a literature study allows the FutuRaM project team to tap into existing
817 knowledge and expertise in the fields of waste management, resource recovery, and
818

819 circular economy. It provides a foundation of existing scenarios that have been developed by other researchers, organizations, or institutions. By building on this existing
820 knowledge, the FutuRaM project can leverage the insights, methodologies, and findings
821 from previous scenario studies, saving time and resources.
822

823 **Identifying relevant scenarios:**

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

830 **Gaining insights and inspiration:**

831 Reviewing existing scenarios provides the FutuRaM project team with valuable insights
832 and inspiration for the development of their own scenarios. It allows them to understand
833 the different approaches, assumptions, and methodologies used in previous scenario
834 studies. This knowledge can inform the design and structure of the FutuRaM scenarios,
835 helping to ensure a rigorous and well-founded approach.

836 **Filling knowledge gaps:**

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

843 **Enhancing credibility and comparability:**

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

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

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Table 6.4 in section 6.4 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 fields of waste management, resource recovery, and circular economy.

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2.2.4. Step 4: Identification of key drivers of change

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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.

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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.

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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.

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

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

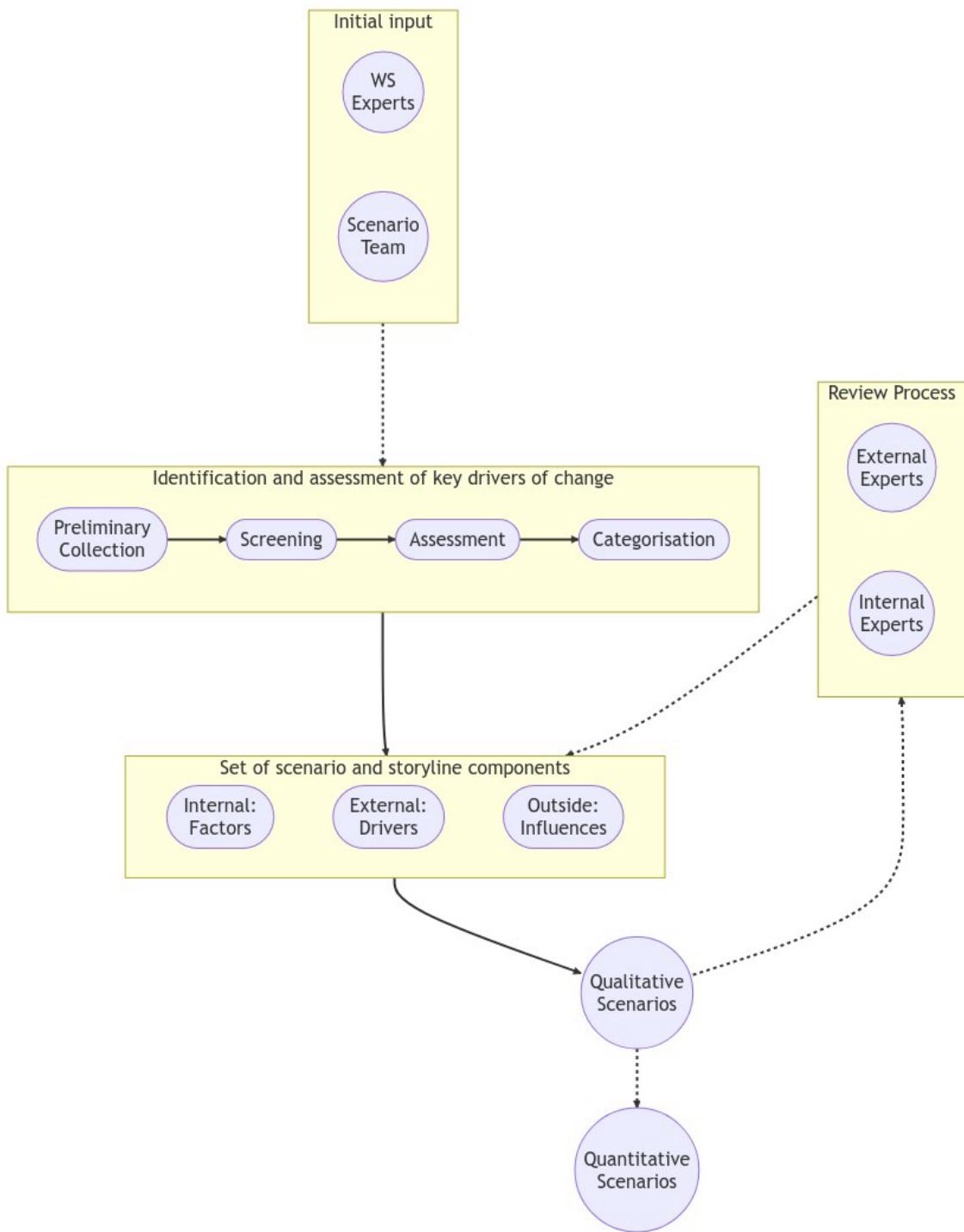


Figure 2.2: An illustration of the process used for identifying key drivers of change

872 ***Methodology and results of this stage in FutuRaM's scenario development:***
873

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

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

879 **1. Preliminary collection:**

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

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

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

888 A PESTEL analysis can help identify opportunities and threats linked to each of
889 these factors, understand the broader context, and shape scenarios accordingly [37,
890 38].

891 **The acronym PESTEL stands for:**

892 **Political:** These factors refer to the impact of government policies, regulations,
893 and political stability. This includes issues like tax policy, labour laws, envi-
894 ronmental regulations, trade restrictions and reforms, tariffs, and political
895 stability.

896 **Economic:** These factors relate to the broader economic environment, including
897 factors like economic growth, exchange rates, inflation rates, interest rates,
898 disposable income of consumers and businesses, and the general health of
899 the economy.

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

904 **Technological:** These factors refer to the impact of emerging technologies, re-
905 search and development activities, automation, the rate of technological
906 change, and the adoption of technology within your market.

907 **Environmental:** These factors refer to ecological aspects that can affect a sys-
908 tem. This includes environmental regulations, consumer attitudes towards
909 sustainability, climate change, and other natural events.

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

913 The 68 elements identified in the initial screening stage are listed in section 6.5.

914 2. Screening:

915 In the screening step, the collected elements are evaluated and assessed based on
916 specific criteria. This was conducted through a literature study and internal consul-
917 tation of scientists in the project. This evaluation helps determine the relevance,
918 reliability, and significance of each element for the development of storylines and
919 scenarios. Many elements were aggregated, especially if they were deemed to
920 follow similar trends to others (e.g., recyclability mandates and improved recy-
921 clability in project design). Elements that did not meet the predefined criteria or
922 were deemed irrelevant, 'un-modellable' or unreliable were excluded from further
923 consideration (e.g., corruption, data protection, and supply chain conflict).

924 The 28 elements that were identified in this stage are listed in section 6.6.

925 In Figure 2.3, an excerpt of a spreadsheet illustrates part of the screening process for
926 the FutuRaM scenarios, which was informed by the waste streams. In this exercise,
927 the elements were evaluated based on their relevance to the waste streams and
928 their potential impact on the waste management system. The elements were also
929 assessed based on their plausibility and likelihood of occurrence in the future. The
930 elements that were deemed relevant, plausible, and influential were included in
931 the storylines and scenarios.

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

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

932 **3. Assessment:**

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

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



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

DOMAIN	DRIVER/FACTOR	DEFINITION	INTER	BAU	REC	CIR
TECH	Recovery technology	Implementation and advancements in waste recovery technologies	TRUE	I	III	III
TECH	Product technology	Changes in product function or composition	TRUE	I	III	III
TECH	Integration of SRM system across EU	Integration of a secondary raw material recovery system across EU countries	TRUE	I	III	III
ENV	Increased drive for environmental protection	Growing concern and motivation for environmental conservation	TRUE	I	III	III
ECO	Progress toward renewable energy targets	Advancements and achievements in renewable energy generation	TRUE	III	III	III
ECO	Subsidies and taxation to promote circularity	Financial incentives or taxes to encourage circular economy	TRUE	I	II	III
SOC	Participation in re-X activities	Engagement in refuse-reduce-repair-reuse activities	TRUE	I	I	III
POL	Stricter environmental regulations	Tightening of environmental laws and regulations	TRUE	II	III	III
POL	Stricter waste management regulations	Strengthening of waste management laws and regulations	TRUE	II	III	III

Continued on next page

Table 2.4 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTER	BAL	REC	CIR
POL	Supply chain due diligence laws: implementation and enforcement	Obligations for identifying and mitigating negative impacts in supply chains	TRUE	I	III	III
POL	Compliance with waste targets	Meeting specific waste management and recycling targets	TRUE	I	III	III
ENV	Resource shortages	Limited availability of natural resources	FALSE	na	na	na
ECO	Raw material vs SRM prices	Price dynamics and competition between raw materials and secondary raw materials	FALSE	na	na	na
ENV	Climate change impactsmitigation	Effects and actions related to climate change	FALSE	na	na	na
ECO	International trade and co-operation (vs. autarky)	Collaborative trade agreements and global cooperation	FALSE	na	na	na
ECO	Energy prices	Costs and fluctuations in energy prices	FALSE	na	na	na
ECO	Economic growth	Overall economic expansion and development	FALSE	na	na	na
ECO	Re-industrialisation of EU	Shift towards increased industrial activities in the EU	FALSE	na	na	na

Continued on next page

Table 2.4 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTER	BAL	REC	CIR
SOC	NIMBY to projects	Opposition to local projects and developments	FALSE	na	na	na
SOC	Population and urbanisation	Growth and urban development of population	FALSE	na	na	na
ECO	CO2 market price	Price and market dynamics of carbon emissions	FALSE	na	na	na

F

Back to ToC

944 4. Categorisation

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

949 Those deemed to be within the scope are ‘internal’ and will be intensively re-
950 searched and modelled (e.g., composition and design changes).

951 Those deemed to be outside the scope are ‘external’ and will be included in the
952 storylines, will vary over time, but will not vary across the three scenarios (e.g.,
953 population and GPD).

954 Those deemed to be outside the scope and also outside the influence of the waste
955 management system are ‘outside’ and will not be included in the storylines or
956 scenarios, though, in some cases, may be considered in the sensitivity analysis
957 (e.g., supply constraints).

958 ***Justification for keeping certain elements outside of the scenario 959 models:***

960 The purpose of the FutuRaM project is not to provide all-encompassing scenarios
961 that attempt to capture every possible future development. Such scenarios are
962 inherently inaccurate and can give a false sense of certainty to the model’s out-
963 comes. Instead, the focus of FutuRaM is specifically on the Sustainable Resource
964 Management (SRM) system and its implications for the future. Therefore, the
965 scenarios developed within FutuRaM should selectively incorporate elements that
966 have a direct impact on the SRM system.

967 Furthermore, the scenarios should prioritize elements that can be considered as
968 ‘policy knobs’, meaning variables or factors that can be adjusted or controlled to
969 test different settings. By including these, the scenarios can explore the effects of
970 different policy decisions or interventions on the SRM system’s outcomes. This
971 targeted approach ensures that the scenarios generated are relevant to the project’s
972 objectives and facilitate meaningful analysis.

973 It is crucial to avoid excessive complexity and convolution in scenario modelling.
974 When there are too many convoluted elements included, the results of the mod-
975 elling exercise can become, at best, difficult to understand and interpret. At worst,
976 the outcomes may become practically useless due to the overwhelming interac-
977 tions and uncertainties introduced by the complex elements. Therefore, careful
978 consideration is necessary to strike a balance between incorporating essential fac-
979 tors and maintaining the clarity and usefulness of the scenario modelling results.

980

Examples:

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Resource shortages: Resource shortages can be highly unpredictable and subject to various external factors such as geopolitical events, natural disasters, or technological advancements. The precise timing and extent of resource shortages are challenging to forecast accurately, making it difficult to include them within the model without introducing significant uncertainty. This is especially true for the long-term time horizon of the FutuRaM scenario set. This factor will, however, be considered in the sensitivity analysis of the model and additionally, the codebase will be designed to allow for the optimization of the SRM recovery system based on any supply-demand value statements.

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Raw material vs SRM prices: The dynamics and competition between raw materials and secondary raw materials can be complex and influenced by various market factors, technological advancements and policy interventions. As with resource shortages, these dynamics are challenging to forecast accurately, making it difficult to include them within the model without introducing significant uncertainty. It will, however, be possible to couple the model with a market model to explore the effects of different price dynamics on the SRM system's outcomes. This could be considered in a multi-objective optimization procedure performed as an extension to the model.

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2.2.5. Step 5: Develop storyline themes

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

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2.2.6. Step 6: Qualitative narrative development

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



2.2.7. Step 7: Definition of scenario parameters

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

2.2.8. Step 8: Quantitative modelling

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

2.2.9. Step 9: Implementation

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

2.2.10. Step 10: Review process

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

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

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

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

Conclusion of methodology section

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



1039 Furthermore, the screening process and the assessment by internal experts ensured
1040 that the selected elements were coherent, consistent, and aligned with the objectives
1041 and scope of the scenario exercise.

1042 The final list of scenario elements is suited to the goal of the FutuRaM project — to
1043 quantify the future availability of SRMs and to evaluate EU material autonomy — and
1044 will be used to develop the three FutuRaM scenarios into a quantitative model.



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Scenario storylines

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CHAPTER CONTENTS

1051	3.1 Scenario I: Business-as-usual	33
1052	3.1.1 Storyline narrative	33
1053	3.1.2 Waste stream specific scenario impacts	35
1054	3.2 Scenario II: Recovery	40
1055	3.2.1 Storyline narrative	40
1056	3.2.2 Waste stream specific scenario impacts	42
1057	3.3 Scenario III: Circularity	48
1058	3.3.1 Storyline narrative	48
1059	3.3.2 Scenario needs and impacts	49
1060	3.3.3 Waste stream specific scenario impacts	51



3.1. SCENARIO I: BUSINESS-AS-USUAL



3.1.1. 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 [39]. While there may be advances in some areas such as resource efficiency, recovery technology, and the energy transition, substantial modifications remain hindered by economic, social, and political constraints. The primary extraction of raw materials continues to be the primary source to meet the EU's demand.

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

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

Primary extraction of raw materials remains the dominant source for raw materials consumed in the EU, continuing the linear 'take-make-dispose' model of resource consumption. Base metals are well recycled, given their developed markets and economies of scale but rare/special metals are wasted because recycling technologies and economics do not allow for their recovery. Recycling and recovery rates remain stubbornly low, resulting in significant CRM 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 signif-

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icant concern. These operations continue to degrade ecosystems, leading to loss of
biodiversity and contributing to climate change [40]. Simultaneously, the EU becomes
increasingly dependent on imports of SRMs, raising concerns about supply chain secu-
rity and geopolitical risks [40].

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Innovation in SRM recovery technologies is hampered by a lack of investment and
regulatory support. The focus remains predominantly on cost-effective material produc-
tion 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, limiting stable penetration of new recovery technology and threatening
economic stability.

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

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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.

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1109
In the Business-as-usual (linear economy) scenario, the following are key character-
istics:

- 1110 • A forecasting model is used to predict the future based on the current situa-
1111 tion and the development of existing trends.
- 1112 • Many EU targets for recycling and recovery are not met, and the current
1113 linear model largely persists.
- 1114 • Material demand keeps pace with GDP growth, perpetuating a trend of in-
1115 creasing consumption. Primary mining and extraction persist as the leading
1116 sources of raw materials, underlining the dependency on traditional extrac-
1117 tion methods.
- 1118 • Recycling and recovery rates continue to lag, leading to an accumulation of
1119 SRM waste that signals missed opportunities for resource reuse.
- 1120 • The environmental repercussions of mining and extraction, such as land
1121 degradation and water pollution, continue to be a pressing concern, reflect-
1122 ing the ecological toll of this linear model.
- 1123 • The EU's dependency on imports of SRMs escalates, heightening the risk of
1124 supply disruptions. While supply disruption can serve to stimulate invest-
1125 ment in new SRM recovery, volatility stifles innovation and advancements in

1126 this field.

- 1127
- 1128 • The industrial focus remains on cost-effective material production and use,
disregarding the long-term sustainability aspect.
-

1130 3.1.2. Waste stream specific scenario impacts

1131 BATT (Battery waste)

1132 Sources: [13, 14, 32, 33]

1133 In the business-as-usual (BAU) scenario, the management of end-of-life batteries
1134 remains largely unchanged. The lack of technological innovation and regulatory
1135 incentives leads to a continued low recovery rate of valuable materials from battery
1136 waste.

- 1137 • A growing volume of battery waste due to the increased use of electronic
1138 transport and renewable energy storage systems.
- 1139 • Lack of technological innovation and regulatory incentives lead to low recov-
1140 ery rates for certain battery types and certain elements.
- 1141 • Collection systems for battery waste remain sporadic and unstandardised.
- 1142 • Primary extraction remains the dominant source of battery materials.
- 1143 • Share of LIB will increase (EV, LMT, Industrial LIB uptake)
- 1144 • LIB Battery Chemistries will change and new LIB technologies will enter the
1145 market. Though, not with a focus on recycling and recovery.
- 1146 • Larger portable batteries: shift towards Li-ion batteries
- 1147 • Small format batteries in EEE: no significant change in battery chemistry.
- 1148 • Use of critical resources continues but is already decreasing (BATT chemistry
1149 already changing towards less CRM content)
- 1150 • Large-scale reuse of batteries is minimal
- 1151 • Collection rates do not fulfil the EU targets
- 1152 • Recycling efficiencies do not fulfil the EU targets
- 1153 • Recovery rates do not fulfil the EU targets



ELV (*End-of-Life Vehicles*)

Sources: [14, 31, 41, 42]

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

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



WEEE (*Waste Electrical and Electronic Equipment*)

Sources: [29, 30, 43, 44, 45, 46]

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

- Limited improvements in the recovery of valuable materials from WEEE.
- High consumer demand for new electronics continues to drive high WEEE generation.
- Ineffective collection systems and lack of public interest result in significant amounts of WEEE ending up in landfills.
- No significant growth in collaboration between government and industry for WEEE recovery.
- The majority of WEEE continues to be treated with common domestic waste, with low recycling rates.



- 1183 • No groundbreaking technologies and practices to improve recovery and
1184 circularity.
- 1185 • Reuse of products and components is not widely utilised
- 1186 • Changes in legislation (e.g., circular economy and product design targets,
1187 targets for collection and recycling) are not strictly implemented.
- 1188 • The BAU and the REC scenarios are similar from the put-on-market perspec-
1189 tive (e.g., production and consumption remain the same), but it's the recov-
1190 ery stage that makes the difference.



MIN (*Mining Waste*)

Sources:

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

- 1196 • Limited technological advancements lead to static recovery rates of valuable
1197 materials from mining waste.
- 1198 • Continued reliance on primary extraction as the dominant source of raw
1199 materials.
- 1200 • Minimal advances in collaboration between government and industry for
1201 mining waste recovery.
- 1202 • Low levels of traceability and management of mining waste.
- 1203 • Mining waste remains a significant environmental challenge.
- 1204 • Mining waste recovery projects remain too expensive.
- 1205 • Little incentive for the private sector and public sector, except for monitor-
1206 ing environmental risks of existing deposits.



CDW (*Construction and Demolition Waste*)

Sources: [47]

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

- 1208 • Focus on new construction to meet demand, no changes in CDW genera-



tion rate.

- No increase or refurbishment or renovation activities relative to new construction rates.
- Continue meeting the 2020 EU target from the Waste Directive [47] of 70% CDW recovery (including preparation for re-use, recycling and other material recovery, including backfilling)
- Recovery of metals remains on already high levels (90%) [48].
- Recovery of minerals remains on already high levels (70%) by using them as aggregates in road construction and backfilling [48].
- Recycling of wind turbines stays around 85% (mainly metals), permanent magnets continue to be recycled as part of the metal fractions.[CITATION]
- Base metals are recovered as they have been, though there are limited improvements in recovery technologies and regulatory incentives.
- Repowering trends for wind turbines persist.
- Excluding wind turbines, there is no particular focus on the recovery of CRMs from CDW, where they constitute only a small fraction of the total mass (e.g., embedded in scrap steel).



SLASH (*Slags and Ashes*)

Sources:

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

- Increased generation of SLASH because SRMs are not recovered and end up in incineration and smelter residues.
- Low quality of SLASH due to:
 - poor sorting and separation of waste streams (e.g., consumer electronics and batteries, end up in general waste streams and are incinerated)
 - high ‘contamination’ from the above-described failures of segregation.
 - large proportion coming from mixed waste incineration
- Lack of technological advancements results in low recovery rates of valuable materials from SLASH.



- 1243 • Continued high generation of SLASH due to the reliance on traditional en-
ergy sources.
 - 1244 • Minimal incentives for the recovery and reuse of materials from SLASH.
 - 1245 • Low levels of traceability and management of SLASH.
 - 1246 • SLASH continues to be a significant environmental challenge due to the
high volume generated.
 - 1247 • Some products from SLASH are recovered in low added value, for example,
as aggregates for roads or additives in cement.
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3.2. SCENARIO II: RECOVERY



3.2.1. Storyline narrative

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

In this scenario, the central actor is the waste treatment sector, with the spotlight falling on the enhancement of recovery technology. The implementation and optimisation of cutting-edge technologies, such as Artificial Intelligence (AI), automation, and advanced robotics, play a significant role in revolutionising waste treatment processes. These technologies streamline waste sorting, improve the quality of recovered materials, and increase the overall efficiency of the recovery process.

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

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

1282 Key characteristics of this technology-promoted recovery scenario include:

- 1283 • This scenario uses a combination of forecasting and backcasting methods to
envision the future.
- 1284
- 1285 • The backcasting method is used for scenario factors that are covered by
governmental targets, starting with the desired outcome and working back-
wards to the present.
- 1286
- 1287
- 1288 • The forecasting method is used for scenario factors that are not covered by
governmental targets, starting with the current situation and extending to
the future.
- 1289
- 1290
- 1291 • EU targets for recycling and recovery are met, due to the EU's waste man-
agement system becoming more expansive, efficient and effective.
- 1292
- 1293 • Technological innovation drives increased recovery rates of SRMs, enabling
the more efficient use of waste.
- 1294
- 1295 • Digitalisation and automation are more extensively used in recycling pro-
cesses, leading to enhanced productivity and accuracy.
- 1296
- 1297 • There is greater exploration and exploitation of alternative sources such as
urban mining, waste streams, and tailings, presenting novel opportunities for
resource acquisition.
- 1298
- 1299
- 1300 • New waste regulations and guidelines for SRM recovery are implemented,
enforcing better management and extraction of SRMs.
- 1301
- 1302 • Investment in research and development for SRM recovery technologies
experiences an upswing, promoting continuous innovation in this field.
- 1303
- 1304 • Closer collaboration and information sharing between industry and govern-
ment institutions streamline processes and expedite decision-making.
- 1305
- 1306 • New jobs are created in the recycling and recovery sector, offering economic
benefits and improving overall employment rates.
- 1307
- 1308 • SRM production and use become more efficient and cost-effective, foster-
ing economic sustainability.
- 1309
- 1310 • Environmental impact from mining and extraction is reduced, signalling a
more sustainable approach to resource acquisition.
- 1311
- 1312 • The EU's dependence on primary extraction is reduced, with SRM recovery
becoming a more significant source of raw materials.
- 1313

3.2.2. Waste stream specific scenario impacts

BATT (Battery waste)

Sources: [13, 14, 32, 33]

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

- Increase in end-of-life batteries due to the growth of electric vehicles and renewable energy storage.
- Advanced recovery technologies facilitate the efficient extraction of valuable materials from battery waste.
- Standardised collection systems enhance the quantity and quality of battery waste available for recovery.
- Industry and government collaboration lead to investments in research and development of battery recovery technologies.
- Battery passports have a strong impact on collection, material recovery rates and recycling rates.
- Collection
 - Portable battery collection increases according to the trend seen in the WEEE waste stream.
 - Improved collection of light means of transport (LMT) batteries.
 - Improved regulation and collection of Industrial batteries.
- Material recovery
 - Improved recycling technologies
 - Battery Pass will improve material recovery
 - Higher recovery rate for lithium
 - Increase in recycling by average weight
 - Recycling of plastics
- Ambitious goals of recycling/recovery rates compete with reuse, so reuse remains low.



- 1346 • Improved public awareness means that fewer batteries end up in the munici-
1347 pal waste stream and there is less hoarding.
- 1348 • Against this: there is competition for the batteries from the reuse vs. recy-
1349 cling market.
- 1350 • Design for recycling (DFR):
 - 1351 – Material and composition selection for recycling [14].
 - 1352 – Higher requirements on disassemblability.
 - 1353 – Information available to promote efficient recovery.



ELV (*End-of-Life Vehicles*)

Sources: [14, 31, 41, 42]

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

- 1360 • Innovations in recovery technologies allow for a higher recovery rate of
1361 CRM-containing materials from ELVs.
- 1362 • The total number of vehicles produced remains high due to consumer de-
1363 mand.
- 1364 • Improved systems for ELV collection are established, ensuring efficient man-
1365 agement of ELV waste.
- 1366 • Increased collaboration between the government and industry leads to in-
1367 vestments in ELV recovery technologies.
- 1368 • Focus on managing end-of-life of vehicles
- 1369 • EU recovery targets are reached (currently implemented/proposed targets,
1370 but also increased and new targets)
- 1371 • Common/bulk materials (Fe, Non-Fe, plastics etc.,) and precious metals (Au,
1372 Ag, Pd, Pt) reach high mass recycling rates and high element recycling rates.
1373 Other CRMs currently not recovered reach a moderate level of recovery.
- 1374 • For instance,
 - 1375 – More advanced dismantling and processing steps (e.g., components
1376 and materials)



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- More specialised recovery of certain components and materials (e.g., electric motors including permanent magnets and embedded REE) as suggested in the proposal for a revised ELV directive.
 - More public and private interest in developing recycling chains
 - Increase in collection rate due to increase in participation from the public and businesses, i.e., target-based incentives with strong regulations and monitoring
- Design for recycling (DFR):
 - Higher requirements on ‘disassemblability’.
 - Information available to enable recovery.



WEEE (Waste Electrical and Electronic Equipment)

1388
Sources: [29, 30, 43, 44, 45, 46]

1389 Under the recovery scenario, WEEE becomes a significant resource for secondary raw
1390 materials. Technological advancements in the sector improve the efficiency of WEEE
1391 treatment, although the consumerism-driven demand for new electronics remains
1392 high.

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- Advanced technologies enable higher recovery rates of valuable materials from WEEE
 - Despite advancements in design for recyclability, WEEE generation remains high due to the consumer demand for new electronics
 - Standardised and segregated collection systems for WEEE are implemented, improving the supply of materials for recovery
 - Increased industry-government collaboration leads to further development in WEEE recovery technologies
 - Consumer behaviour remains a significant hurdle for more efficient WEEE management
 - Higher recycling rate — make full use of the disposed parts. For instance:
 - more automation of the dismantling and processing steps (e.g., AI)
 - recycling technologies improvements (e.g., small components recovery is also happening)
 - more effective collection infrastructure
 - financial support provided to recyclers/operators

- 1409 — bans on WEEE exports push for increased domestic recycling [49]
- 1410 • ‘Design for recovery’ principle — Ecodesign mandates changes in weight and
1411 composition of EEE so complexity and the type of materials used
- 1412 • Higher public awareness and participation on WEEE issue and management
- 1413 • Higher compliance from the public, the producers and the businesses
- 1414 • Strong regulations and monitoring are in place with higher collection and
1415 recycling targets which are set and implemented and fines are set for those
1416 who fail to achieve the targets
- 1417 • Focus is given more to the EoL management of WEEE



MIN (Mining Waste)

Sources:

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

- 1422 • Technological advancements facilitate the extraction of valuable materials
1423 from mining waste.
- 1424 • Despite progress in recovery technologies, primary extraction remains the
1425 dominant source of raw materials due to high consumer demand.
- 1426 • Government and industry collaboration support the development of tech-
1427 nologies for the recovery of materials from mining waste.
- 1428 • Increased traceability and management of mining waste through digitalisa-
1429 tion.
- 1430 • Mining waste remains a significant environmental challenge.



CDW (Construction and Demolition Waste)

Sources: [47]

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



- 1439 • Focus on new construction to meet demand, no changes in CDW genera-
1440 tion rate.
- 1441 • No increase or refurbishment or renovation activities.
- 1442 • Enhancement of the quality of recycling to recover materials at higher value.
- 1443 • Increased investment and enhanced regulatory system in waste manage-
1444 ment, contributing to increased recovery.
- 1445 • Creation of new waste recovery infrastructure that improves recovery.
- 1446 • Widespread application of selective demolition and strict on-site waste sort-
1447 ing leading to an increase in recovery of waste.
- 1448 • Recovery of minerals is intensified with a stronger focus on closed-loop
1449 recycling (e.g., cement and aggregate are separated, aggregate is used, but
1450 cement is not treated).
- 1451 • Recovery of other materials like glass, plastics, and wood is also intensified.
- 1452 • Better separation of waste at source leads to a higher quality of secondary
1453 raw materials.
- 1454 • Repowering trends for wind turbines stay the same.
- 1455 • Improved recycling of wind turbine blades is notable, especially regarding
1456 plastics; permanent magnets are recycled at a functional level.



SLASH (*Slags and Ashes*)

Sources:

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

- 1463 • Advanced recovery technologies allow for the extraction of valuable metals
1464 and minerals from SLASH.
- 1465 • Despite improvements in energy production, SLASH generation remains
1466 significant due to the continued reliance on traditional energy sources.
- 1467 • New regulations incentivize the recovery and reuse of materials from SLASH.
- 1468 • Digital solutions enhance the traceability and management of SLASH.
- 1469 • SLASH remains a significant environmental challenge due to the volume



1470 generated.

- 1471 • Transferring down-cycling to recycling or even upcycling.
- 1472 • Recycling technology improvements (e.g., cement additives using biomass
1473 ash are under investigation)
- 1474 • More functional collection infrastructure.
- 1475 • Financial support provided to recyclers/operators.
- 1476 • Introduction of SRM/CRM recovery targets. For example, recovery of P from
1477 biomass ash for fertilizer. Recovery of Zn and Pb from Zn and Pb smelter
1478 slag.
- 1479 • Higher awareness and participation of relevant sectors on SLASH issues and
1480 management.
- 1481 • Strong regulations and monitoring are in place with higher collection and re-
1482 cycling targets.



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3.3. SCENARIO III: CIRCULARITY

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3.3.1. Storyline narrative

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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).

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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.

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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, where both policymakers and designers are moving away from short-lived products towards products designed for longevity.

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The emphasis is on re-X strategies that are integrated throughout the entirity of a product's lifecycle. 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. New economic models make it costly for producers to generate short-lived products and material waste. Companies are now giving priority to the design of products that are easily repairable, can be disassembled, and reused. The rise of technology has paved the way for predictive maintenance tools. These allow businesses to keep a tab on material conditions through sensors and carry out repairs before a malfunction occurs, a method gaining traction in transport and manufacturing.

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. Material composition, including raw materials, is transparent to all involved in the value chain, promoting closer collaboration. Producers see the advantage of being open about their product details to aid in repair, repurposing, and recycling activities. This transparency about product components, durability, and reparability increases consumer demand for products that are designed to last and can be reused or recycled.

3.3.2. Scenario needs and impacts

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

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

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

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

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

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

3.3.3. Waste stream specific scenario impacts



BATT (Battery waste)

Sources: [13, 14, 32, 33]

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

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



ELV (End-of-Life Vehicles)

Sources: [14, 31, 41, 42]



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

- Vehicle design shifts towards repairability, upgradability, and recyclability, increasing the lifespan of vehicles.
- Standardised systems for ELV collection are established, ensuring efficient waste management.
- Innovative technologies enable higher recovery rates of metals and other valuable materials from ELVs.
- Service-based models like vehicle leasing and sharing could reduce the total number of vehicles produced.
- Digital product passports provide information about vehicle components, aiding in effective recycling or reuse.
- Focus on managing the use-phase of vehicles.
- Circular strategies take place before material recovery so that material recovery is “delayed”.
- Information available to enable these strategies.
- EU vehicles policy has implications for materials in vehicles, such as ‘lightweighting’ and downsizing
 - Increase in average occupancy and average vehicle-kilometres per trip.
 - Decrease in average lifetime (in terms of years): As the utilisation factor increases.
- Increase in circular strategies due to an increase in participation from the public and businesses, i.e., target-based incentives with strong regulations and monitoring.



WEEE (Waste Electrical and Electronic Equipment)

Sources: [29, 30, 43, 44, 45, 46]

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



- Electronic products are designed for longevity, repairability, upgradability, and recyclability.
- Advanced technologies enable higher recovery rates of precious metals from WEEE.
- Collection systems for WEEE are improved, ensuring a steady supply of materials to feed the recovery system.
- Digitalisation and data use enhance traceability and efficiency in WEEE management.
- Service-based models for electronics promote the use of products as a service rather than ownership, reducing WEEE generation [20].
- Increased durability and lifespans.
- Increased repairability.
- More sharing and product-service systems, correspond to a reduction in the lifetime (for some equipment).
- More reuse practices (expanded second-hand market).
- Less hoarding.
- Higher formal collection and recycling rate.
- Focus is given more to the production and use phase rather than the EoL (End-of-Life).
- ‘Design for circularity’ principle: Ecodesign mandates repairability, durability, no obsolescence, modularity, and that continual software upgrades are possible [50, 51].
- Electronically compatible chargers and battery packs can be used by different products.
- The above also means that chargers and batteries are not integrated into the product and that the product is designed to be easily disassembled.
- Strong regulations and monitoring are in place with higher reuse and circular targets, which are set and implemented, and fines are imposed on the member states that fail to achieve the targets.
- Support and development of circular strategies infrastructure (e.g., easy information access for repairability, repair shops, accessibility to spare components on the market, etc.).
- Greater use of connected products, smart technologies, and the IoT. Used to monitor and diagnose product performance in situ which, can extend prod-

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uct and component life.

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MIN (Mining Waste)

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

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

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CDW (Construction and Demolition Waste)

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Sources: [47]

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

1696

- Less demolition and new construction results in a reduction of CDW.
- Buildings are designed for disassembly and reuse, increasing the lifespan of materials and reducing CDW.
- Longer lifetimes for buildings (more renovation and refurbishment) and wind turbines (less repowering, i.e. changing of wind turbines before the end of theoretical lifespan).
- Wind turbine blades are refurbished/repaired and reused.
- Recycling technologies for CDW improve, allowing higher recovery rates of materials and less 'downcycling'.

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- 1705 • Policies and regulations incentivise the use of recycled materials in construction.
- 1706
- 1707 • Standardised systems for CDW collection and separation are improved.
- 1708 • Digital tools like building information modelling (BIM) improve resource management in construction and renovation.
- 1709
- 1710 • Focus on dismantling and selective deconstruction: constructions are taken apart in a way that individual parts can be reused.
- 1711



SLASH (Slags and Ashes)

Sources:

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

- 1712 • A shift in perception treats SLASH as a valuable resource instead of waste.
- 1713
- 1714 • Advanced technologies enable the extraction of valuable metals and minerals from SLASH.
- 1715
- 1716 • New regulations incentivise the use of SLASH in various applications, such as in the construction industry.
- 1717
- 1718 • Digital solutions enhance the tracking and management of SLASH.
- 1719
- 1720 • Collaboration between industries utilises SLASH in new and innovative ways.
- 1721
- 1722 • Reduce the generation of SLASH by increasing the efficiency of the manufacturing side. For example, developing higher efficient production of metals and reducing by-products such as smelter slag.
- 1723
- 1724 • For ash from the incineration of solid biomass, maximizing the use of biomass by setting proper temperature, time, and furnace conditions to reduce ash contents and improve the efficiency of power and heat generation.
- 1725
- 1726 • For ash, developing other renewable technologies from bioenergy to reduce the incineration of solid biomass, e.g., biogas.
- 1727
- 1728 • Reduce the generation of SLASH by increasing the proportion of higher calorific waste and decreasing lower calorific waste, e.g., MSW (Municipal Solid Waste).
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- Developing domestic feedstock supply for bioenergy or metal production to reduce the cost of transportation and others.
- Higher formal collection and recycling rate compared to BAU, but lower compared to the Recovery scenario.



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Quantification

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CHAPTER CONTENTS

1747	4.1 Introduction	59
1748	4.2 Summary	61
1749	4.3 External elements	62
1750	4.3.1 Introduction	62
1751	4.3.2 Summary	64
1752	4.3.3 Demographic factors: <i>Population, age, urbanisation</i>	67
1753	4.3.4 Economic factors: <i>GDP growth</i>	79
1754	4.3.5 The Renewable Energy Transition	86
1755	4.3.6 Conclusion	103
1756	4.4 Internal elements — Technological Change	104
1757	4.4.1 Introduction	105
1758	4.4.2 Summary	106
1759	4.4.3 Future product and waste composition: <i>Description</i>	107
1760	4.4.4 Future product and waste composition: <i>Scenarios</i>	109
1761	4.4.5 Future recovery technology: <i>Description</i>	113



1762	4.4.6 Future recovery technology: <i>Scenarios</i>	115
1763	4.4.7 Future recovery system: <i>Description</i>	119
1764	4.4.8 Future recovery system: <i>Scenarios</i>	121
1765	4.5 Internal elements – The Circular Economy	126
1766	4.5.1 Introduction	127
1767	4.5.2 Summary	128
1768	4.5.3 The EU Circular Economy Indicators: <i>Description</i>	129
1769	4.5.4 The EU Circular Economy Indicators: <i>Scenarios</i>	136
1770	4.5.5 Refuse and Reuse: <i>Description</i>	140
1771	4.5.6 Refuse and Reuse: <i>Scenarios</i>	142
1772	4.5.7 Repairability and ‘Right to Repair’: <i>Description</i>	146
1773	4.5.8 Repairability and ‘Right to Repair’: <i>Scenarios</i>	155
1774	4.5.9 Remanufacturing: <i>Description</i>	159
1775	4.5.10 Remanufacturing: <i>Scenarios</i>	161
1776	4.5.11 The Sharing Economy: <i>Description</i>	165
1777	4.5.12 The Sharing Economy: <i>Scenarios</i>	169
1778	4.6 Conclusion	174



4.1. INTRODUCTION

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

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

Internal Elements:

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

External Elements:

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

Outside Elements:

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

The rationale behind this categorisation is to maintain focus and clarity in the scenario modeling. Including too many complex and indirectly related elements can convolute the scenarios, making them overly complex and less useful for practical decision-making and policy analysis. By concentrating on integral elements — or those that can be

controlled or influenced by associated policy decisions — FutuRaM ensures that its scenarios are both manageable and directly relevant to its objectives of exploring different futures of the SRM system. This approach strikes a balance between realism and practicality, ensuring the scenarios are both meaningful and actionable.



4.2. SUMMARY

REVIEW NOTICE

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

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4.3. EXTERNAL ELEMENTS

4.3.1. Introduction

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

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

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

- Demographic change
- Economic growth
- Renewable energy transition

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

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

These elements are detailed in Table 4.1.



Table 4.1: List of external scenario elements

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

F

Back to ToC

1842

4.3.2. Summary

REVIEW NOTICE

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

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Demographic change

1846

INDEPENDENT VARIABLES

- Population
- Median age
- Urbanisation

1847

DEPENDENT VARIABLES

- Demand
- Waste generation
- Waste composition

1848

1849

1850

Economic growth

1851

INDEPENDENT VARIABLES

- GDP growth

1852

DEPENDENT VARIABLES

- Demand
- Waste generation
- Waste composition

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1861 Renewable energy transition

1862 INDEPENDENT VARIABLES

- 1863 • Energy mix

1864 DEPENDENT VARIABLES

- 1865 • Demand
- 1866 • Waste generation
- 1867 • Waste composition
- 1868 • Recovery impacts

1869 Resource supply constraints

NOTE

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

1871 INDEPENDENT VARIABLES

- 1872 • Resource availability

1874 DEPENDENT VARIABLES

- 1875 • Resource prices
- 1876 • Settings of the recovery system to counteract supply crunch
- 1877 • Waste composition (incorporating lag and substitution effects)

1878 MARKET DYNAMICS



NOTE

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

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1881

INDEPENDENT VARIABLES

1882

- Raw material prices
- Secondary raw material prices

1884

DEPENDENT VARIABLES

1885

- Recovery system settings
- Recovery system capacity
- Recovery system profitability
- Secondary raw material supply

1889



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

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

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

Justification for setting as an external scenario factor

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

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

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

Population projections

Sources for demographic data

The population projections in this report have been produced from the most recent data provided by Eurostat and the UK Office of National Statistics (ONS) [52, 53, 54].

It was decided to 're-model' this data, rather than extract it from the population figures in the SSP2 baseline scenario datasets [55, 56] to which the background of FutuRaM's scenarios are (broadly) aligned. This allows the use of the most up-to-date and 'raw' data possible.

Figure 4.1 shows the normalised population projections for the EU27+3 and the UK. The index is set to 1 for the year 2020.

Normalised population forecasts for the EU27+4

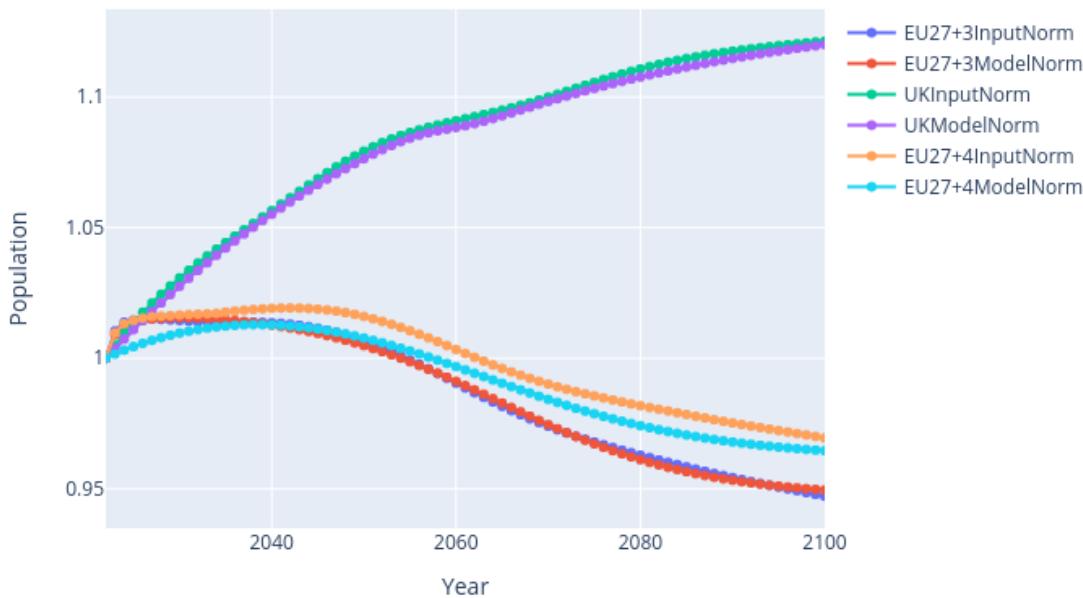


Figure 4.1: Population projections for the EU27+3 and the UK

EU27 + 4

Data source: [52]

POPULATION MODELLING RESULTS:

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

HIGHLIGHTS:

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

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

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

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

METHOD

Eurostat provides international projections for the European Union (EU) and the European Free Trade Association countries, which include Iceland, Liechtenstein, Norway, and Switzerland. Unlike the UN's projections, Eurostat's are deterministic in nature. Their most recent projection, dating from 2020, presents a base variant along with four other variants, starting with the baseline year 2019. In the base variant, it is forecasted that the EU-27 population will decline by nearly 7 percent or about 30 million people by 2100.

However, in the medium term, the population is expected to grow until 2025, reaching about 449 million people, before reducing to 416 million by 2100. Country-specific, sex, and age data are available in Eurostat's database.

The final projection starts with the 2022 population divided by sex and age. Mortality rates are applied to determine the number of deaths. Numbers for non-EU and EU immigrants are computed. For the years 2022 and 2023, refugees under TP are also included. Emigrants, including refugees under TP for the years 2024 to 3033, are then subtracted. Based on this, the end-of-year population and the working-age population are computed. Using these figures, additional non-EU immigrants are calculated, and the end-of-year population is re-assessed. This allows for the computation of live births, total deaths, immigration, and emigration for 2022.

SCENARIOS

Eurostat also considers five alternative scenarios besides the baseline for EUROPOP2023. These are: lower fertility, lower mortality, zero net migration, decreased non-EU immigration, and increased non-EU immigration. For instance, the lower fertility scenario posits a total fertility rate that's 20% less than the baseline for each projection year (2023 – 2100). This implies fewer live births yearly compared to the baseline. The lower mortality scenario suggests a life expectancy at birth in 2100 that's two years more than the baseline. Migration scenarios include zero net migration, 33% less non-EU immigration each year, and 33% more non-EU immigration every year throughout the projection horizon.

UK

Data source: [53]

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

POPULATION MODELLING RESULTS:

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

POPULATION PROJECTIONS

The UK population in mid-2020 was estimated at 67.1 million. Over the decade to mid-2030, it's projected to rise by 2.1 million (3.2% increase), in comparison to a 6.9%

increase between 2010 and 2020. Over the next 25 years, the projected growth is 3.9 million (5.8%), less than the 15.6% growth between mid-1995 and mid-2020.

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

ASSUMPTIONS:

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

METHODOLOGY

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

STRENGTHS AND LIMITATIONS

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

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

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

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

Projection Methodology

Methodology source: [54]

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

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

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

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

However, deterministic models face challenges. They:

- 2064 • Overlook the probabilistic nature of population processes.
- 2065 • Rely on rigid future assumptions with low individual probabilities of occurrence.
- 2066 • Limit the number of considered scenarios, inadequately reflecting future risk.
- 2067 • Lack probabilistic quantification for identified futures.
- 2068 • May be biased by experts' subjective assessments.

2071 In contrast, stochastic models view parameters as random variables. While deterministic
2072 models might assume fixed values for determinants like G_t , M_t , and S_t in certain
2073 scenarios, stochastic models see these as probabilistic, represented as:

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

2074 Yet, it's essential to understand that no forecast offers absolute truth. Their aim
2075 isn't predicting unexpected events, but extrapolating core demographic trends. Both
2076 deterministic and stochastic methods exist to quantify forecast uncertainty.

2077 Applying these results in real-world scenarios warrants a cautious approach. Past
2078 trends might not persist in the future. For instance, population growth isn't just about
2079 demographics but also infrastructure. Can a housing market accommodate growth? Will
2080 cities meet their limits? Projections inherently carry assumptions. For instance, regions
2081 must meet housing demands, and urban challenges arise from positive population
2082 growth, such as the need for expanded childcare or public transport infrastructure.

2083 Predicting and managing future global population growth stands as a paramount
2084 challenge for humanity. Most contemporary researchers believe there's a ceiling to
2085 the planet's 'carrying capacity'. Come 2022, Earth's population is anticipated to hit
2086 the eight billion mark. UN predictions suggest that by 2100, this number will rise to
2087 ten billion. However, there's an observable trend towards smaller family sizes, with
2088 birth rates currently hovering around the replacement rate of 2.1 children per woman.
2089 Should global fertility rates align with family replacement levels (2.0) by 2100, Earth's
2090 population is projected to stabilise between ten and eleven billion. The emergence of
2091 new statistical data necessitates updates to global population growth models. Where
2092 once the Verhulst logistic model was deemed inadequate for characterising global
2093 population growth dynamics, the tapering growth rate now reaffirms its applicability.
2094 Many recent studies have leveraged the logistic growth model. Our analyses confirm
2095 that Earth's population growth rate aligns closely with a quadratic function, mirroring
2096 the Verhulst equation (Fig. 4). All subsequent computations will employ the Verhulst

2097

logistic model:

$$\frac{dY}{dt} = a \cdot Y - b \cdot Y^2 \quad (4.1)$$

2098

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

$$Y = g + \frac{b}{1 + A \exp(-a(t - t_0))} \quad (4.2)$$

2099

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

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CURVE FITTING EXPLANATION

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

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

b₁

Represents the initial population at the start of the observation period - Europe's population in 1900 per the model's parameters.

b₁

Denotes the carrying capacity of population growth, effectively indicating the population apex achievable via the first logistic function.

A₁

Influences the gradient of the first growth phase. Higher values result in steeper population inclines.

a₁

Represents the growth rate of the initial logistic function, dictating how swiftly the population nears the carrying capacity b_1 .

t₁

Marks the inflection point in the first logistic phase, signifying the period of maximum growth velocity.

b₂

Illustrates the decline's carrying capacity, indicating the population decrease as

2125 projected by the second logistic function.

2126 **A₂**

2127 Determines the gradient of the decline phase, with larger values resulting in
2128 sharper declines.

2129 **a₂**

2130 Represents the rate of decline in the latter logistic function, determining the
2131 speed at which the population reaches the decline's carrying capacity b_2 .

2132 **t₂**

2133 Highlights the inflection point during the decline phase, marking the period where
2134 the decrease is most rapid.

REVIEW NOTICE

TBD: Data for urbanisation and other demographic factors can be added here if the waste stream models require it.

Table 4.2: Population projections for the EU27+4

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



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Incorporation of demographic factors into individual waste stream models

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WASTE STREAM NOTICE

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

2140

2141



BATT (BATTERY WASTE)

- X

2142



CDW (CONSTRUCTION AND DEMOLITION WASTE)

- X

2143



ELV (END-OF-LIFE VEHICLES)

- X

2144

2145

MIN (MINING WASTE)

- X

2146



SLASH (SLAGS AND ASHES)

- X

2147

2148



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

- X

2149

Conclusion

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REVIEW NOTICE

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



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4.3.4. Economic factors: *GDP growth*

Definitions

Gross Domestic Product (GDP) PPP

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

Purchasing Power Parity (PPP)

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

Sources of data

The GPD projections for FutuRaM's future scenarios are based on economic data from the OECD as well as population data from Eurostat and the UK's ONS [52, 53, 57]

Results of projections

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

The results of the projections are shown in ??.

Methodological Overview of OECD's GDP Projection Framework

[57, 58, 59, 60]

The OECD's approach to projecting GDP is rooted in the principle that income levels across various nations will gravitate towards those observed in the most advanced economies, an idea put forth by [61, 62]. This convergence is modelled through an enriched version of the Solow growth model, factoring in a dual-sector configuration [63], which the OECD dubs the ENV-Growth model. Rather than focusing solely on convergence in income, the ENV-Growth model prioritises the growth factors that will drive

2187 GDP over time.

2188 For GDP projections up to 2060, the OECD combines model-based assessments
2189 with expert evaluations, considering the economic dynamics of individual countries
2190 and the global market. These forecasts are denominated in the constant US dollars
2191 and PPPs of 2010, based on data from OECD and World Bank, which use the Atlas
2192 method for calculating PPPs [58, 64]. The data originate from the OECD Long-Term
2193 Baseline Scenario. This scenario, which is integral to the OECD Economic Outlook,
2194 serves as a comparative standard to gauge the possible effects of structural reforms,
2195 assuming a policy-neutral environment. Conversely, long-term projections diverge
2196 from the medium-term forecasting model, which is predominantly demand-driven,
2197 by focusing on a supply-side perspective that takes into account labour and capital
2198 availability and productivity growth rates.

2199 **Determinants of Long-term Growth**

2200 [58, 65]

2201 Recognizing the multifaceted nature of economic advancement, GDP growth pro-
2202 jections consider an array of influences such as demographics, educational attainment,
2203 technological progress, energy access, and capital flow patterns. The MaGE framework
2204 facilitates GDP estimation by charting dynamic paths that reflect the structural interplay
2205 defining the economic landscape until 2050 [65].

2206 The ENV-Growth model's projections span a century and include a wider selection of
2207 countries, enhancing the original methodologies developed by the OECD Economics
2208 Department [59, 60]. It introduces considerations for energy usage and resource
2209 revenue from oil and gas sectors, aligning with the enhanced sectoral approach for
2210 fossil fuels presented by [66].

2211 The model's foundation lies in its projection of the five pivotal elements driving
2212 economic growth:

- 2213 • Physical capital
- 2214 • Employment, shaped by population trends, age demographics, participation
2215 rates, and unemployment scenarios
- 2216 • Human capital, based on education and its consequential effect on labour
2217 productivity
- 2218 • Energy demand and resource extraction for exporting countries
- 2219 • Total factor productivity (TFP)

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

In the context of employment, projections from IIASA inform the total employment figures, combining time-specific participation rates for different age cohorts with projected unemployment trends. Education assumptions translate gender and age-specific educational projections into a human capital index, which then informs labour productivity enhancements.

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

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

FutuRaM's economic forecasts, while not based directly on the SSP data, are consistent with the SSP2 baseline derived from similar sources and models [55, 56, 67, 68, 69, 70], offering a comprehensive picture of potential economic trajectories.

Implications of GDP Growth on FutuRaM's Waste Models

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



BATT (BATTERY WASTE)

As GDP grows, the demand for electronic devices and electric vehicles typically

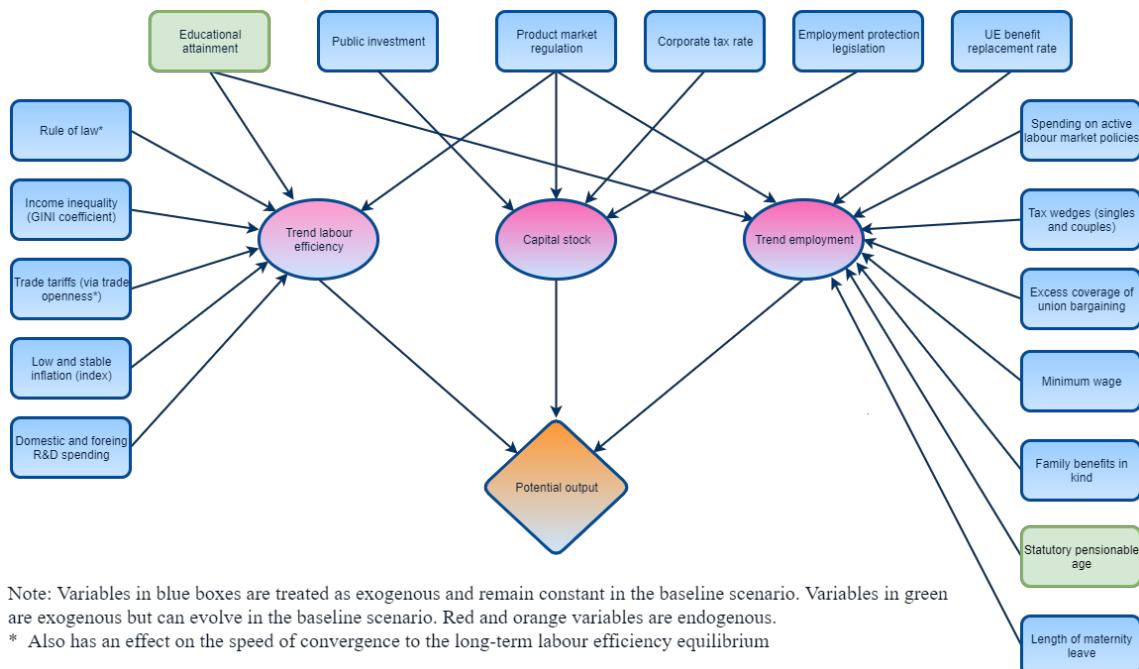


Figure 4.2: Factors incorporated in the long-term model [58]

increases, leading to a higher turnover of batteries. This could necessitate advancements in recovery methods for battery components, such as lithium and cobalt, to reduce reliance on primary sources and mitigate environmental impact.



CDW (CONSTRUCTION AND DEMOLITION WASTE)

Economic growth often spurs construction activity, thereby increasing CDW. Improved GDP can lead to enhanced recycling processes, promoting the circular economy by converting waste into secondary raw materials for new construction projects.



ELV (END-OF-LIFE VEHICLES)

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



MIN (MINING WASTE)

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



SLASH (SLAGS AND ASHES)

Higher GDP can correlate with increased industrial activity, producing more slags and ashes. Enhanced recovery techniques can transform these by-products into useful

2272

secondary raw materials, such as aggregates in construction.

2273



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

2274

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

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Incorporation of economic growth into individual waste stream models

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WASTE STREAM NOTICE

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

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2280



BATT (BATTERY WASTE)

2281

- X

2282



CDW (CONSTRUCTION AND DEMOLITION WASTE)

2283

- X

2284



ELV (END-OF-LIFE VEHICLES)

2285

- X

2286



MIN (MINING WASTE)

2287

- X

2288



SLASH (SLAGS AND ASHES)

2289

- X

2290



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

2291

- X

2292

Conclusion

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

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REVIEW NOTICE

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

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4.3.5. The Renewable Energy Transition

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Definition

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

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Future energy mix in the EU

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The projected electricity mix for the EU is presented in Figure 4.3.

**Forecasted EU electricity mix
under the 'IEA Stated Policies base scenario'**

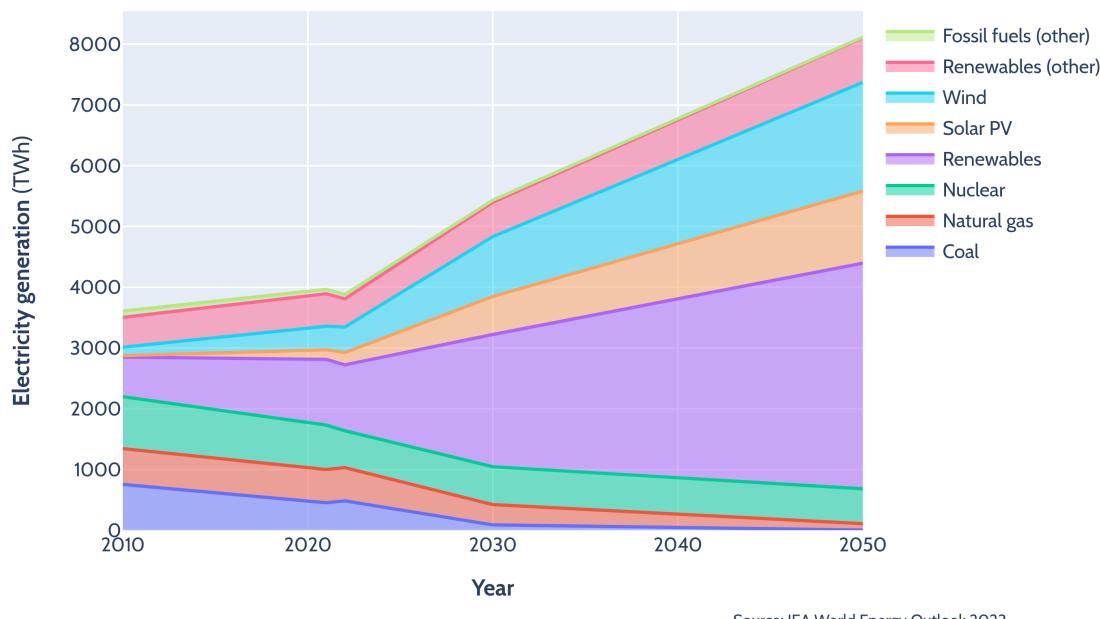


Figure 4.3: EU electricity mix forecast until 2050

Brief context of renewable energy in the EU

Renewable energy is integral to the EU's shift towards a low-carbon economy and reducing reliance on imported fossil fuels—a response accentuated by the urgency to curtail dependence on Russian energy sources. The EU's strategic move is encapsulated in the REPowerEU Plan of Action, introduced in May 2022, and agreed upon in 2023 which prescribes an aggressive uptake of renewables, emphasizing wind and solar PV, alongside hydrogen, heat pumps, and batteries, vital for energy storage and transportation decarbonisation [71, 72, 73].

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

Justification for setting as an external scenario factor

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

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

Moreover, the scenario architecture within FutuRaM is constructed with inherent flexibility, permitting later incorporation of amendments to the background energy transition trends. This adaptability is essential to ensure that, as the energy landscape

2351 evolves and new data becomes available, the scenarios can be revised and updated,
2352 thereby preserving the relevance and accuracy of the project's findings over time.

2353 ***Relevant technologies in the renewable energy sector***

2354 The cornerstone technologies in renewable energy—batteries, electrolyzers, wind turbines,
2355 heat pumps, and solar PV—play pivotal roles across various sectors (Figure 85).
2356 Heat pumps serve industrial processes, while solar PV and batteries support ICT, defence,
2357 and mobility with energy and uninterrupted power supplies, respectively [71].

2358 Wind energy, expected to surge, will benefit from cost-efficient, innovative turbines
2359 designed for increased productivity in offshore and low-wind conditions. Projections
2360 from GECO present two scenarios: a conservative estimate shows wind capacity ex-
2361 panding from 732 GW (2020) to 1,400 GW (2030), and to 4,050 GW by 2050. An
2362 optimistic forecast anticipates a rise to 2,500 GW by 2030 and 8,400 GW by 2050.

2363 Solar PV is poised for exponential growth due to advancements enhancing efficiency
2364 and lowering costs. GECO's cautious scenario predicts growth from 710 GW (2020) to
2365 2,950 GW (2030), reaching 7,500 GW by 2050. The optimistic scenario projects a
2366 tenfold increase by 2030 and sixteenfold by 2050 compared to 2020 levels.

2367 Addressing the intermittency of wind and solar power necessitates adequate storage
2368 solutions and robust grid systems, with electrolyzers emerging as a crucial technology
2369 for renewable hydrogen production, forecasted to exceed 1 GW capacity by the end of
2370 2022 [74].

2371 Additionally, digitalisation, robotics, and 3D printing are set to boost the renewable
2372 sector's productivity and optimisation across its value chain. Heat pump sales are also
2373 on an upward trend, with a peak expected in 2045, ranging between 15 million (low
2374 demand) and 38 million units (high demand) by 2050.

2375 Material demand in the renewable sector is dominated by wind turbines, electroly-
2376 sers, and solar PV, with wind energy leading in consumption of critical materials.

2377 ***Supply Chain bottlenecks in renewable energy***

2378 Supply chain bottlenecks present a significant challenge in the deployment of renew-
2379 able energy technologies, particularly for wind turbines, solar PV, electrolyzers, and
2380 heat pumps. The production of NdFeB permanent magnets for wind turbines demands
2381 rare earth elements (REEs) like neodymium, dysprosium, praseodymium, and terbium,
2382 with the EU being highly dependent on imports for both raw and processed materials

2383 such as permanent magnet alloys and components like blades.

2384 Solar PV technologies necessitate strategic raw materials, including silicon metal
2385 and rare metals like gallium and germanium, with China dominating the production
2386 of silicon ingots and wafers. This reliance on imports extends across the value chain,
2387 including the crystalline silicon cell production where the EU's contribution is minimal.

2388 The battery industry utilizes strategic raw materials such as lithium, manganese,
2389 and cobalt, with raw materials and components largely imported. A shift is anticipated
2390 towards nickel-rich batteries or alternative chemistries to reduce reliance on high-cobalt-
2391 content lithium-ion batteries (LIBs) due to the oligopoly control of critical components
2392 in Asia.

2393 Electrolysers for hydrogen production use a range of strategic raw materials, par-
2394 ticularly from the platinum group metals (PGMs), but also silicon metal, aluminium,
2395 copper, and magnesium, with the EU facing challenges in sourcing these materials.
2396 For heat pumps, strategic raw materials needed include magnesium and copper, but
2397 no significant bottlenecks have been identified, with most critical materials used in
2398 microchips and IT controllers.

2399 Across all technologies analysed, a common pattern of heavy reliance on imports,
2400 particularly from China, is observed at different stages of the value chains. The EU's
2401 primary sourcing and processing capabilities for critical raw materials are notably low,
2402 creating dependencies at multiple levels. Despite a strong manufacturing capacity
2403 for wind turbine assembly, the EU is entirely reliant on imports for the value chain of
2404 rare-earth permanent magnets. Similarly, for solar PV, the dependence on imports
2405 is comprehensive. The recent surge in Chinese manufacturing market share for heat
2406 pumps and the developing value chain for batteries in the EU are also noteworthy.

2407 A breakdown of the materials required for each technology is given in Table 4.3.

Table 4.3: Raw materials essential to the renewable energy sector

SUPPLY RISK	MATERIAL	CRM	BATT	H2	WIND	SOLAR (PV)	HEAT PUMPS
5.3	HREE (rest)	x		x			
4.8	Gallium	x				x	
4.4	Niobium	x		x	x		
4.1	Magnesium	x		x			
4.1	REE (magnets)	x		x	x		x
3.8	Boron	x		x	x	x	x
3.5	LREE (rest)	x		x			
3.3	Phosphorus	x	x			x	
2.7	PGM	x		x			
2.6	Strontium	x		x			
2.4	Scandium	x		x			
2.3	Vanadium	x		x			
1.9	Lithium	x	x				
1.8	Geranium	x				x	
1.8	Natural graphite	x	x	x			
1.8	Antimony	x				x	
1.7	Cobalt	x	x	x			
1.6	Arsenic	x				x	
1.4	Silicon metal	x		x	x	x	x
1.3	Baryte	x		x			
1.3	Tantalum	x		x			
1.2	Manganese	x	x	x			x
1.2	Tungsten	x		x			
1.2	Aluminium	x	x	x	x	x	x
1.1	Fluorspar	x	x			x	x
0.9	Tin			x		x	
0.8	Molybdenum			x	x	x	x
0.8	Silver			x		x	x

Continued on next page

Table 4.3 – Continued from previous page

SUPPLY RISK	MATERIAL	CRM	BATT	H2	WIND	SOLAR (PV)	HEAT PUMPS
0.8	Zirconium			x			
0.7	Chromium			x	x		x
0.7	Potash			x			
0.6	Indium					x	
0.5	Nickel	x	x	x	x	x	x
0.5	Iron ore		x	x	x	x	x
0.5	Titanium			x			
0.4	Gold			x			x
0.3	Tellurium					x	
0.3	Limestone			x			
0.3	Selenium					x	
0.3	Silica				x	x	
0.2	Cadmium						x
0.2	Zinc			x	x	x	x
0.1	Copper	x	x	x	x	x	x
0.1	Aggregates				x		
0.1	Lead				x	x	

The integration of the energy transition has specific implications for the management of Critical Raw Materials (CRMs) across various waste streams due to changing material requirements and waste profiles.

For example:



BATT (BATTERY WASTE)

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



ELV (END-OF-LIFE VEHICLES)

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



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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



CDW (CONSTRUCTION AND DEMOLITION WASTE)

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



MIN (MINING WASTE)

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

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SLASH (SLAGS AND ASHES)

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

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Implementation in EU Law

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FIT FOR 55 PACKAGE (2021)

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The "Fit for 55" package is a collection of policy initiatives proposed by the European Commission in July 2021 aimed at revising and updating EU legislation to reflect the increased ambition of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels [75]. This target was a significant step up from the previous goal of a 40% reduction and is part of the European Union's plan to become climate-neutral by 2050 — an objective set out in the European Green Deal[27].

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

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REPOWEREU PLAN (2022)

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The invasion of Ukraine by Russia has caused significant disruption to energy markets in Europe and globally. To eliminate reliance on an unreliable supplier, the European Commission has devised the REPowerEU plan [73]. This initiative focuses on energy conservation, the production of clean energy, and the diversification of energy sources, supported by financial and legal measures to develop Europe's necessary new energy infrastructure and systems.

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

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

2472

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- Increasing the EU's 2030 renewable energy target of the 'Fit for 55 package' from 40% to 45%.



- 2474 • Accelerating the deployment of photovoltaic (PV) energy.
- 2475 • Introducing the European Solar Rooftop Initiative.
- 2476 • Doubling the deployment rate of individual heat pumps.
- 2477 • Decarbonising the industry by promoting electrification and renewable hy-
- 2478 • Hydrogen.
- 2479 • Speeding up renewable energy project and grid infrastructure permit pro-
- 2480 cesses.
- 2481 • Increasing the EU's binding energy savings target for 2030 to 13%.

2482 The May 2022 REPowerEU plan by the European Commission, in response to the
2483 energy market disruptions due to Russia's invasion of Ukraine, is designed to rapidly cut
2484 down on the EU's reliance on Russian fossil fuels. It raises the renewable energy target
2485 of the Fit for 55 package from 40% to 45%.

2486 This ambitious goal for renewable energy use, coupled with REPowerEU's strategies
2487 to reduce energy demand, necessitates substantial increases in renewable capacity
2488 across the electricity, transport, and heating and cooling sectors. The Commission
2489 forecasts that to meet the 2030 objectives, renewable electricity should reach 69%,
2490 32% in transport, and a yearly growth of at least 2.3 percentage points in heating and
2491 cooling.

2492 RENEWABLES ENERGY DIRECTIVE (2023)

2493 The recent legislation strengthening the EU Renewable Energy Directive marks an
2494 advancement towards the European Green Deal and REPowerEU ambitions. With the
2495 provisional agreement, the EU's binding renewable energy target for 2030 is now at
2496 least 42.5%, aiming potentially to reach 45%. This target significantly surpasses the
2497 previous goal of 32% and is nearly double the present proportion of EU renewable
2498 energy.

2499 A distinct enhancement over the REPowerEU plan is the establishment of definitive
2500 binding targets for renewable energy. The legislation optimises permitting procedures,
2501 acknowledges renewable energy as an overriding public interest, and designates accel-
2502 eration zones for expedited development in strategically identified regions.

2503 The directive also introduces specific directives across various sectors:

- 2504 • In heating and cooling, it sets forth progressive annual renewable targets
2505 and a 49% renewable energy consumption benchmark in buildings by 2030.
- 2506 • It for the first time includes the industrial sector under its ambit, establishing
2507 indicative and binding targets for the use of renewable energy and renew-
2508 able hydrogen, respectively.
- 2509 • For the transport sector, it specifies a reduction in greenhouse gas inten-
2510 sity and sets sub-targets for advanced biofuels and renewable fuels of non-
2511 biological origin, underpinning the EU's renewable hydrogen objectives.

- It further enhances the "guarantees of origin" system to improve consumer information and supports the integration of the energy system through electrification and waste heat capture.

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

While the reinforced EU Renewable Energy Directive is a pivotal step towards the EU's "Fit for 55" framework and the overarching European Green Deal goals, it has not been without its critics. The Directive's ambitious targets for 2030 have spurred a range of responses from member states and institutions, with concerns centered around feasibility, economic impact, and the varying capabilities of nations to meet these objectives [76].

The following is a summary of the key points raised by member states and the European Commission in their statements on the directive [76]:

Belgium

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

Poland

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

Romania

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

Slovak Republic

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

European Commission

The Commission acknowledges the significant efforts required from Member States to meet the targets, noting the high adaptation costs for certain industries.

2553 It concedes that achieving the directive's objectives will involve significant public
2554 and private investment and national budget implications. The Commission em-
2555 phasizes the need for complementary decarbonisation efforts involving other
2556 non-fossil energy sources.

2557 ***Challenges to the expansion of renewable energy in the EU***

2558 In addition to the internal conflict among member states [76], a recent IEA analysis
2559 concluded that EU's renewable energy expansion is constrained by inadequate policy
2560 support, complex permitting, and grid upgrades' pace. [74]

2561 Current forecasts indicate that the solar PV and wind capacity expansions fall short
2562 of the REPowerEU plan's renewable electricity targets for 2030. The European Commis-
2563 sion Staff Working Document states that achieving a 69% share of renewable electricity
2564 requires 592 GW of solar PV and 510 GW of wind by 2030, translating to annual addi-
2565 tions of 48 GW for solar PV and 36 GW for wind [77]. These figures significantly exceed
2566 the IEA's main case projections of 39 GW for solar PV and 17 GW for wind between
2567 2022 and 2027, resulting in a renewable generation share of 54% in the electricity
2568 sector—15 percentage points below the desired 69% by 2030. Therefore, to fulfill the
2569 necessary installed capacity for generating 69% of electricity from renewables by 2030,
2570 the annual net additions for solar PV need to increase by 22%, and for wind, more than
2571 double [78]. The EU estimates that the total amount required for these investments
2572 will exceed €360bn before 2030 [77].

2573 **Policy Support:**

2574 Uncertainty from infrequent auctions and limited visibility hampers utility-scale
2575 solar PV and distributed PV projects, with issues in current auction designs and
2576 support scheme extensions affecting growth and profitability.

2577 **Permitting:**

2578 A primary bottleneck due to complex regulations, land restrictions, social oppo-
2579 sition, and permitting office inefficiencies increases costs and extends project lead
2580 times.

2581 **Grid Congestion:**

2582 Insufficient grid capacity and upgrade challenges caused by permitting hurdles,
2583 labour shortages, and opposition slow the integration of new renewable plants.

2584 The IEA analysis states that improvements addressing these issues could boost solar
2585 and wind deployment by 30% by 2027. An accelerated case requires increased policy
2586 support, regulatory reforms, and quicker infrastructure development [78].

2587 For utility-scale solar PV, competitive auctions must be introduced or extended, with
2588 revised auction designs to reflect current market conditions. Distributed PV could see
2589 growth with better support and remuneration for self-consumption.

2590 Despite potential policy and regulatory advances, wind energy, particularly onshore,

2591 faces persistent permitting difficulties, and offshore wind is bogged down by grid
2592 connection delays.

2593 Finally, market interventions and the energy crisis debate could influence renewable
2594 investments, stressing the need for careful reform processes involving all stakeholders
2595 to maintain investor confidence.

2596

Incorporation of the energy transition into the FutuRaM scenarios

REVIEW NOTICE

There will need to be a discussion about the use of this data:

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

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2598

In light of the information presented above, as well as the nature of the three scenarios, FutuRaM will use a moderate growth scenario for the energy transition. The data for this is sourced from the projections of the International Energy Agency (IEA) using the "base case" of their "Stated Policies (STEP)" scenario [79].

The IEA's World Energy Outlook 2023 presents a range of scenarios, including the Stated Policies (STEP) scenario, the Sustainable Development Scenario (SDS) — which is the IEA's pathway to achieving the Paris Agreement goals — and the Net Zero Emissions scenario. Full details of the scenarios are available in the documentation of the IEA's Global Energy and Climate (GEC) Model [80].

An excerpt of the IEA's projections for the energy transition in the EU is presented in ??.

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

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

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

THE STATED POLICIES SCENARIO (STEP)

The Stated Policies Scenario (STEPS) is an energy model that offers a conservative projection based on existing and developing energy policies, without assuming full achievement of governments' announced goals. It undertakes a detailed, sector-by-sector assessment including a variety of factors such as pricing, efficiency standards, and infrastructure projects as of the end of August 2023. Although it incorporates far-reaching governmental targets, such as net zero emissions and complete energy access, these are not presumed to be fully implemented without evaluating the regulatory, financial, and infrastructural context of each country.



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

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

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

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



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THE FUTURE ENERGY MIX IN THE EU

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In a global sense, the energy transition manifests in FutuRaM's forecasts by way of the background energy mix. In Figure 4.3 is the IEA's projection of the energy mix in the EU for the Stated Policies scenario.

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IMPACT OF THE ENERGY TRANSITION ON THE FUTURAM SCENARIOS

REVIEW NOTICE

Many more details to be added later once we have confirmed the scenario choice and the alignment with the WSs

NOTE: One advantage of the IEA data is that it is aligned with other data sets, such as CRM supply and demand forecasts
NOTE: The figures below are just an example of some of the impacts that we could portray here. Better figures will be generated later.

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The following figures illustrate some of the impacts that scenario choice can have on raw material demand forecasts [18]

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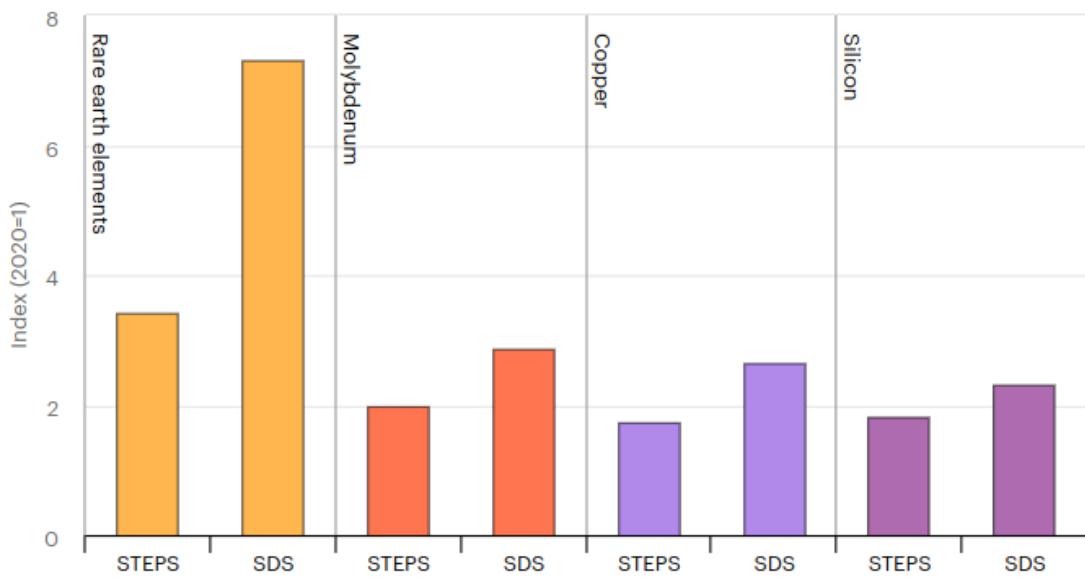


Figure 4.4: Change in demand for selected elements

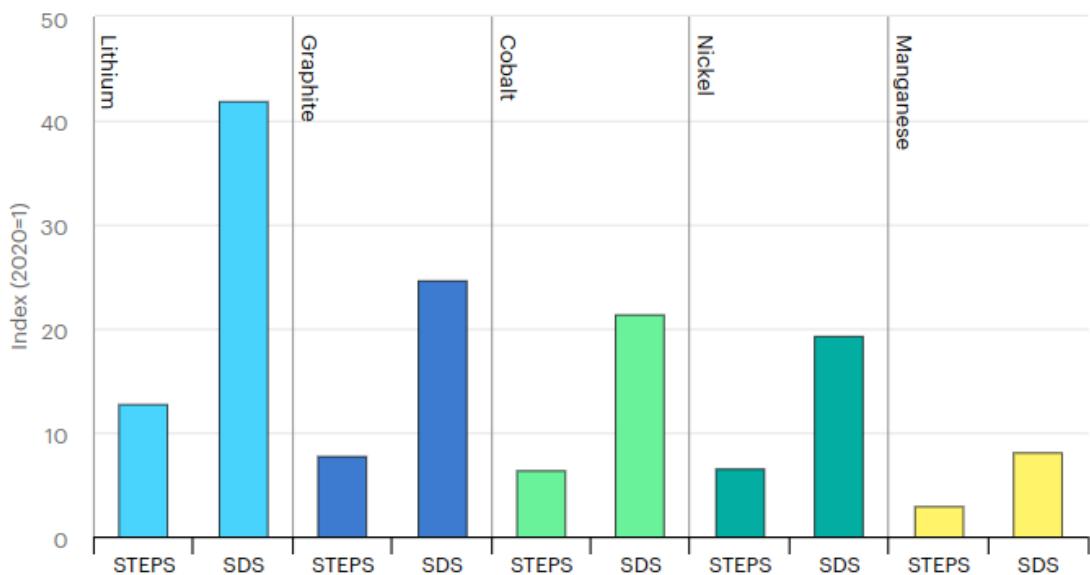


Figure 4.5: Change in demand for battery relevant elements

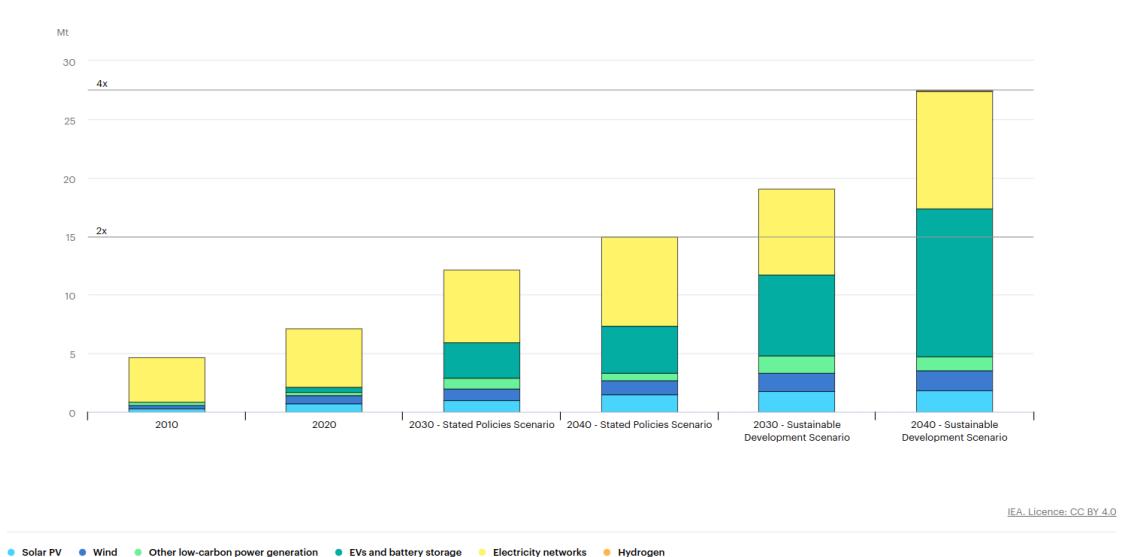


Figure 4.6: Global mineral demand (total) under various scenarios



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Incorporation of the energy transition into individual waste stream models

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WASTE STREAM NOTICE

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

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2641



BATT (BATTERY WASTE)

2642

- X

2643



CDW (CONSTRUCTION AND DEMOLITION WASTE)

2644

- X

2645



ELV (END-OF-LIFE VEHICLES)

2646

- X

2647



MIN (MINING WASTE)

2648

- X

2649



SLASH (SLAGS AND ASHES)

2650

- X

2651



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

2652

- X



2653

4.3.6. Conclusion

REVIEW NOTICE

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

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4.4. INTERNAL ELEMENTS — TECHNOLOGICAL CHANGE



4.4.1. Introduction



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4.4.2. Summary

REVIEW NOTICE

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

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4.4.3. Future product and waste composition: *Description*

2662

Definition

2663

Context

2664

International and European Trends

2665

Implementation in EU Law

2666

Development of a metric for XXX

2667

Benefits and risks

2668

ENVIRONMENTAL BENEFITS AND RISKS

2669

MANUFACTURERS' PERSPECTIVE

2670

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

2671

Relevance of XXX to Critical Raw Materials in Waste Streams

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

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2676

BATTERIES (BATT)

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- X

2678

END-OF-LIFE VEHICLES (ELV)

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- X

2680

WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

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- X

2682

CONSTRUCTION AND DEMOLITION WASTE (CDW)

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-



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4.4.4. Future product and waste composition: *Scenarios*

WASTE STREAM NOTICE

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

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2689

Summary

REVIEW NOTICE

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

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

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X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

2697

**MIN (MINING WASTE)**

2698

**SLASH (SLAGS AND ASHES)**

2699

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

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2701



Scenario II: Recovery

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X

2703

**BATT (BATTERY WASTE)**

2704

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2705

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

2706

**MIN (MINING WASTE)**

2707

**SLASH (SLAGS AND ASHES)**

2708

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

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2710



Scenario III: Circularity

2711 X

2712

**BATT (BATTERY WASTE)**

2713

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

2714

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

2715

**MIN (MINING WASTE)**

2716

**SLASH (SLAGS AND ASHES)**

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

2718

2719

[Back to ToC](#)WP2: Scenario Storylines | www.futuram.eu | 112

2720

4.4.5. Future recovery technology: *Description*

2721

Definition

2722

Context

2723

International and European Trends

2724

Implementation in EU Law

2725

Development of a metric for XXX

2726

Benefits and risks

2727

ENVIRONMENTAL BENEFITS AND RISKS

2728

MANUFACTURERS' PERSPECTIVE

2729

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

2730

Relevance of XXX to Critical Raw Materials in Waste Streams

2731

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

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BATT (Battery waste)

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ELV (End-of-Life Vehicles)

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WEEE (Waste Electrical and Electronic Equipment)

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

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**MIN (*Mining Waste*)**

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

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4.4.6. Future recovery technology: *Scenarios*

WASTE STREAM NOTICE

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

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Summary

REVIEW NOTICE

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

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

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario II: Recovery

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X

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario III: Circularity

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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4.4.7. Future recovery system: *Description*

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Definition

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Context

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International and European Trends

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Implementation in EU Law

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Development of a metric for XXX

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Benefits and risks

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ENVIRONMENTAL BENEFITS AND RISKS

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MANUFACTURERS' PERSPECTIVE

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BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

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Relevance of XXX to Critical Raw Materials in Waste Streams

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

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BATT (Battery waste)

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ELV (End-of-Life Vehicles)

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WEEE (Waste Electrical and Electronic Equipment)

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

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**MIN (*Mining Waste*)**

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

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4.4.8. Future recovery system: *Scenarios*

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WASTE STREAM NOTICE

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

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Summary

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REVIEW NOTICE

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

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

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario III: Circularity

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BATT (BATTERY WASTE)

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CDW (CONSTRUCTION AND DEMOLITION WASTE)

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ELV (END-OF-LIFE VEHICLES)

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MIN (MINING WASTE)

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SLASH (SLAGS AND ASHES)

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WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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Conclusion

REVIEW NOTICE

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

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4.5. INTERNAL ELEMENTS — THE CIRCULAR ECONOMY



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4.5.1. Introduction

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Main sources: [81, 82, 83, 84, 85, 86]



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4.5.2. Summary

REVIEW NOTICE

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

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4.5.3. The EU Circular Economy Indicators: *Description*

[83, 87, 88]

Economic Indicators

CEI_CIE011: PERSONS EMPLOYED IN CIRCULAR ECONOMY SECTORS & CEI_CIE012: PRIVATE INVESTMENT AND GROSS ADDED VALUE RELATED TO CIRCULAR ECONOMY SECTORS

Indicator metadata: 

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

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

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

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

CEI_CIE020: PATENTS RELATED TO RECYCLING AND SECONDARY RAW MATERIALS

Indicator metadata: 

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

Indicator Description: The indicator enumerates the number of patent families

pertinent to recycling and secondary raw materials, leveraging the Cooperative Patent Classification to ensure unique counts.

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

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

CEI_PC030: RESOURCE PRODUCTIVITY

Indicator metadata:

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

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

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

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

Waste and Material Indicators

CEI_PC020: MATERIAL FOOTPRINT

Indicator metadata:

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

Indicator Description: This indicator assesses the global demand for material extraction driven by EU consumption and investment. The Material Footprint provides insight into the environmental burden shifted to other regions due to the EU's consump-

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

Unit: The unit of measure is tonnes per capita.

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

CEI_PC031: GENERATION OF MUNICIPAL WASTE PER CAPITA

Indicator metadata: ↗

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

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

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

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

CEI_PC032: GENERATION OF WASTE EXCLUDING MAJOR MINERAL WASTES PER GDP UNIT

Indicator metadata: ↗

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

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

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

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

CEI_PC034: WASTE GENERATION PER CAPITA

Indicator metadata:

Context: The 'Waste generation per capita' indicator is a key component of the Circular Economy monitoring framework, aimed at assessing the effectiveness of EU policies focused on waste reduction and resource efficiency within the 'production and consumption' thematic area.

Indicator Description: This indicator reflects the total waste generation within a country, including major mineral wastes from all economic activities and households. It is an essential measure for evaluating the impact of waste prevention measures, allowing comparison of Member States' performance over time.

Unit: The unit of measure is kilogram per capita

Source Data: The data originates from the European Statistical System (ESS), specifically Eurostat, which collates information reported by countries under the Waste Statistics Regulation (EC) No 2150/2002.

CEI_SRM030: CIRCULAR MATERIAL USE RATE

Indicator metadata:

Context: As a core metric within the Circular Economy indicator set, the 'Circular material use rate' is crucial for monitoring advancements in the utilization of 'secondary raw materials'. It encapsulates the circular economy's goal to enhance material recycling, reduce waste, and curb the reliance on primary raw material extraction.

Indicator Description: This indicator assesses the proportion of recycled material re-entering the economy against the overall material consumption, serving as a benchmark

for the 'circularity rate'. It signifies the efficiency of resource use by contrasting the circular use of materials against the aggregate domestic material consumption (DMC), adjusted for waste trade.

Unit: The indicator is presented as a percentage, depicting the share of recycled material in total material usage, reflecting the level at which secondary materials replace primary resources.

Source Data: Data is sourced from the European Statistical System (ESS) and Eurostat, employing a trio of statistical resources: waste treatment statistics, material flow accounts, and international trade data.

CEI_WM010: RECYCLING RATE OF ALL WASTE EXCLUDING MAJOR MINERAL WASTE

Indicator metadata:

Context: This indicator is pivotal for measuring advancements in 'waste management'. It gauges the efficiency of resource use by monitoring the volume of materials recycled and reincorporated into the economy, thus encapsulating the essence of material conservation and loss reduction.

Indicator Description: The recycling rate is formulated by the proportion of waste recycled versus the total waste treated, excluding significant mineral waste, rendered in percentage terms. It encompasses both hazardous and non-hazardous waste across all sectors, including household and secondary waste from waste treatment processes, thereby providing a comprehensive snapshot of the national recycling efforts.

Unit: Expressed in percentage

Source Data: Eurostat, under the aegis of the ESS, supplies this data. It incorporates waste treatment information aligned with the Waste Statistics Regulation, fine-tuned with international trade data, to accurately reflect the recycling of domestically produced waste.

CEI_WM011: RECYCLING RATE OF MUNICIPAL WASTE

Indicator metadata:

Context: As an integral part of the Circular Economy indicators, this measure serves as a barometer for the progression towards a more circular economy, with a focus on 'waste management'. It assesses the re-utilisation of consumer waste in the economy, capturing the complexities inherent in the diverse composition of municipal waste.

Indicator Description: This indicator quantifies the proportion of municipal waste that is recycled, relative to the total amount of municipal waste produced, presented as

a percentage. The breadth of municipal waste includes household refuse and similar commercial and public waste, representing a snapshot of the waste management quality from a consumer perspective.

"In order to comply with the objectives of this Directive, and move to a European circular economy with a high level of resource efficiency, Member States shall take the necessary measures designed to achieve the following targets: (a) by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight;" — Article 11.2 of the Waste Framework Directive. [47]

Unit: The metric of evaluation is a percentage

Source Data: Data source: European Statistical System (ESS) Data provider: Statistical Office of the European Union (Eurostat) based on data reported by the countries: Municipal waste by waste operations ↗ collected via a subset of the OECD/Eurostat Joint Questionnaire, section waste. Data are provided under a so-called gentlemen's agreement.

CEI_WM060: RECYCLING RATE OF WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) SEPARATELY COLLECTED

Indicator metadata: ↗

Context: This indicator is a crucial component of the Circular Economy suite, offering insights into the progression towards enhanced sustainability in 'waste management'. WEEE, or e-waste, is a rapidly expanding waste stream within the EU that encapsulates items like computers, TVs, refrigerators, and mobile phones. Given the valuable materials found in e-waste, improving recycling processes is of paramount importance.

Indicator Description: The indicator measures the efficiency of WEEE recycling by calculating the ratio of the weight of WEEE processed for recycling/re-use against the total weight of WEEE collected separately, in compliance with Article 11(2) of the WEEE Directive 2012/19/EU [29, 30]. The indicator's transition from 'Recycling rate of e-waste' to its current form is to align more closely with the CE monitoring framework revisions.

The applicability of Directive 2012/19/EU is twofold:

- Applicable up to the year 2018 for EEE classified under 10 product categories as outlined in Annex I of the Directive, with Annex II providing a corresponding indicative product list.
- Applicable from the year 2019 forward, where all EEE will be classified within

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6 product categories as delineated in Annex III.

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Unit: The percentage serves as the unit of measure

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Source Data: Data procurement is executed by the ESS and supplied by Eurostat.

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The indicator's underlying data stems from:

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- For WEEE by waste operations: (env_waselee) ↗
- For WEEE by waste management operations - open scope, 6 product categories (from 2018 onwards): (env_waseleeos) ↗

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4.5.4. The EU Circular Economy Indicators: *Scenarios*

WASTE STREAM NOTICE

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

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Summary

REVIEW NOTICE

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

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Scenario I: Business-as-usual

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario III: Circularity

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XX **BATT (BATTERY WASTE)**

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CDW (CONSTRUCTION AND DEMOLITION WASTE)

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ELV (END-OF-LIFE VEHICLES)

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MIN (MINING WASTE)

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SLASH (SLAGS AND ASHES)

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WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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4.5.5. Refuse and Reuse: *Description*

Definition

Context

International and European Trends

Implementation in EU Law

Development of a metric for XXX

Benefits and risks

ENVIRONMENTAL BENEFITS AND RISKS

MANUFACTURERS' PERSPECTIVE

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

Relevance of XXX to Critical Raw Materials in Waste Streams

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



BATT (Battery waste)

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ELV (End-of-Life Vehicles)

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WEEE (Waste Electrical and Electronic Equipment)

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

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**MIN (*Mining Waste*)**

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

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4.5.6. Refuse and Reuse: *Scenarios*

WASTE STREAM NOTICE

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

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Summary

REVIEW NOTICE

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

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Scenario I: Business-as-usual

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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Scenario II: Recovery

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**BATT (BATTERY WASTE)**

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**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

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

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**MIN (MINING WASTE)**

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**SLASH (SLAGS AND ASHES)**

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

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[Back to ToC](#)WP2: Scenario Storylines | www.futuram.eu | 144

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Scenario III: Circularity

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XX **BATT (BATTERY WASTE)**

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CDW (CONSTRUCTION AND DEMOLITION WASTE)

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ELV (END-OF-LIFE VEHICLES)

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MIN (MINING WASTE)

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SLASH (LAGS AND ASHES)

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WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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4.5.7. Repairability and 'Right to Repair': *Description*

[89, 90, 91, 92, 93]

Definition

Right to repair refers to the concept that end users, business users as well as consumers, of (generally) technical, electronic or automotive devices should be allowed to freely repair these products. Four requirements are of particular importance:

- The device should be constructed and designed in a manner that allows repairs to be made easily;
- End users and independent repair providers should be able to access the original spare parts and necessary tools (software as well as physical tools) at fair market conditions;
- Repairs should, by design, be possible and not be hindered by software programming; and
- The repairability of a device should be clearly communicated by the manufacturer.

Context

Discarded products are often viable goods that can be repaired but are often tossed prematurely, resulting in 35 million tons of waste, 30 million tons of resources and 261 million tons of greenhouse gas emissions in the EU every year [94]

Repairing is one of the most relevant strategies within the Circular Economy (CE) concept since it contributes to waste prevention and extends product and components' lifespan. Thus, reparability becomes an essential issue from the early product design phases, where materials, geometries, and joints are defined. Despite some repairability indicators that can be found in the literature and are applied worldwide, there is a lack of connection between reparability and the early decision-making process for improving it from the design of components or subsystems of a product.

However, repair is often seen as difficult by consumers. The 'right to repair' initiative complements several other proposals presented by the Commission to achieve sustainable consumption throughout the entire lifecycle of a product, setting the framework for a true 'right to repair' across the EU. Obstacles to owner repair can lead to higher consumer costs or drive consumers to single-use devices instead of making repairs.

The right to repair is a legal right for owners of devices and equipment to freely modify and repair products such as automobiles, electronics, and farm equipment. This right is framed in opposition to restrictions such as requirements to use only the manufacturer's maintenance services, restrictions on access to tools and components, and software barriers.

A right to repair can exist either in a closed access system, where the consumer is restricted to the repair services provided by the manufacturer or authorized repairers – a situation closer to the current reality. Or, a right to repair can evolve in an open access system, which implies full access to spare parts, tools, repair manuals and digital permission to repair. Policy options for a right to repair differ based on whether they encourage one or the other approach. Some argue an open access system is the only form of right to repair that is consumer-empowering and can yield the expected benefits. Others argue for a more complex system, moving towards open access but with some safeguards on a sectoral or product category basis. A cost-benefit analysis could help identify the sectors or product categories where a full open-access system would be most beneficial.

The goals of the right to repair are to favour repair instead of replacement and make such repairs more affordable leading to a more sustainable economy and reduction in waste.

International and European Right to Repair Initiatives

[91, 92, 93]

- **Availability of Spare Parts and Repair Information:**

- US state-level legislation includes laws like Massachusetts' requirement for car manufacturers to provide repair tools and information.
- The EU has measures like France's mandate for sellers to inform about the availability of spare parts, and Slovenia's requirement for maintenance and spare parts for at least 3 years after guarantee expiration.

- **Legal Guarantees:**

- European legal guarantee periods often exceed the EU directive's minimum, encouraging repair culture.
- For example, Sweden has a 3-year guarantee period, and Finland ties the period to the expected lifespan of the product.

- **Design Requirements:**

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- Legislation like Washington State's (USA) proposed fair repair bill is aimed at promoting repairable product designs by prohibiting the creation of electronics that obstruct repairability.

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- **Financial Incentives:**

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- Cities like Graz offer subsidies for electronic device repairs and countries like Belgium provide écochèques to incentivize repair over replacement.

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- **Copyright Law Exemptions:**

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- In the US, certain copyright law exemptions facilitate repairability, such as the ability to unlock phones, although the exemption renewal process is cumbersome.

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- **Consumer Information:**

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- France's reparability index helps inform consumers by rating products on repairability criteria, promoting repair-friendly designs.

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- **Voluntary Labels and Green Public Procurement:**

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- Ecolabels such as EPEAT and various national labels incorporate repairability to different degrees.
 - Green Public Procurement practices push the market towards sustainable, repairable products.

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- **Communication and Awareness:**

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- Initiatives include repair-focused websites, awareness campaigns, and the establishment of repair hubs to build a repair-oriented culture.

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Implementation in EU Law

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[94, 95]

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European Product Policy has to date focused on the environmental performance of products via the Ecodesign and Ecolabelling Directives. The Ecodesign Directive sets minimum standards of performance for products, which results in poorly performing products being removed from the market whilst also driving innovation in the design and manufacture of new products to improve their performance. The Ecolabelling Directive provides consumers with clear information on product performance to inform their buying decisions. Originally cast for energy-using products, the directives have been extended to energy-related products and the assessment methodologies have been developed to include other aspects including materials and water consumption.

3248 Further measures considered include:

- 3249 • Amending Directive 2005/29/EC to prohibit presenting products as allow-
3250 ing repair when such repair is not possible, as well as omitting to inform
3251 consumers that it is not possible to repair goods in accordance with legal
3252 requirements.
- 3253 • Amending Directive 2005/29/EC to prohibit omitting to inform the con-
3254 sumer that the good is designed to limit its functionality when using con-
3255 sumables, spare parts, or accessories that are not provided by the original
3256 producer.
- 3257 • Traders to provide, before the conclusion of the contract, for all types of
3258 goods, where applicable, the reparability score of the good as provided by
3259 the producer in accordance with Union law, to allow consumers to make an
3260 informed transactional decision and choose goods that are easier to repair.
- 3261 • Ensuring information such as on the availability of spare parts and a re-
3262 pair manual, should no reparability score be available at the Union level.

3263 To this end, new 'Digital Product Passports' providing information about products'
3264 environmental sustainability, will empower consumers and businesses to make in-
3265 formed choices when purchasing products, facilitate repairs and recycling, and improve
3266 transparency about products' lifecycle impacts on the environment. The passports also
3267 help public authorities to better perform checks and controls.

3268 In addition, as part of the implementation of the EU Circular Economy Action
3269 Plan [15], the European Commission has carried out a study for the analysis and devel-
3270 opment of a possible scoring system to inform about the ability to repair and upgrade
3271 products [93] and has an ongoing project in the Product Bureau to develop and propose
3272 new metrics [96, 97].

3273 ***Development of a metric for repairability***

3274 [93, 94, 95, 96, 97, 98, 99, 100]

3275 The trend in consumer goods towards reduced durability and repairability has been
3276 contributing to an increase in waste electronic and electrical equipment (WEEE). The
3277 Organization for Economic Co-operation and Development has suggested that extend-
3278 ing product lifetimes through enhanced durability and repairability is a viable solution
3279 to this growing issue. The European Commission's Circular Economy Action Plan re-
3280 inforces this viewpoint, advocating for maintaining the value in products for as long

as possible by imposing durability and repairability requirements. In response, several scoring systems for repairability have been developed to guide standardization efforts, aid market surveillance authorities, and inform consumer decision-making.

For a scoring system to be effective, it should provide an objective evaluation of repairability that aligns with the established design principles in the literature. Comparative analyses of various repairability scoring systems for different products have been undertaken in previous studies. However, the thoroughness of these systems is sometimes not fully evaluated, and some of the most recent systems have not been comprehensively reviewed.

Literature on the subject identifies specific design features and principles that significantly affect product repairability, and these should be central to any scoring system aimed at accurately measuring repairability. Assessing these design elements against selected scoring systems can shed light on their inclusiveness.

The objectivity of these scoring systems is another critical aspect, evaluated by examining their scoring methodologies. Selection criteria for these systems include their availability in English, the use of quantitative or semi-quantitative assessment methods to enable objective comparison, and their recognition as the most current versions from their respective issuing organizations or groups.

In 2021, France took a pioneering step by integrating the reparability index into national legislation. [101] This move compels producers to transparently communicate the repairability of their products through consumer labelling. The reparability index stands as a key development in empowering consumers to make informed choices regarding the repairability of products. The widespread issue of repairing common electronic devices like laptops and smartphones often stems from the unavailability of tools, spare parts, or repair instructions.

An exemplary repair index would encompass elements such as product design, the availability of repair information, and additional services like the availability of spare parts. These aspects are crucial for the repair process. Data indicates that a substantial number of electronic product repairs are hindered by the lack of available spare parts.

France's method mandates transparency regarding product repairability, yet relies on producers' self-assessment, prompting questions about the objectivity of such evaluations. The rapid implementation is advantageous, but the credibility of self-assessment remains a concern.

With sustainability becoming increasingly important, France's reparability index marks an assertive step towards the broader adoption of such measures. Looking ahead, enhancements like a durability index may offer greater insights into the long-term

3317 usability of products.

3318 In parallel, organizations such as TÜV SÜD are actively supporting the repairability
3319 testing landscape, aligning with standards like the French Repairability Scoring Index
3320 to ensure products fulfil specified repairability criteria [102]. Their approach factors
3321 in documentation, disassembly, and the availability of spare parts and repair services,
3322 highlighting a practical, though less detailed, framework compared to France's compre-
3323 hensive index.

3324 **Benefits and risks**

3325 ENVIRONMENTAL BENEFITS AND RISKS

3326 [93, 103]

3327 The implementation of the right to repair holds considerable promise for the re-
3328 duction of environmental impacts if applied appropriately. It must be recognized that
3329 electronic equipment replacement often occurs not solely due to product failure. Influ-
3330 encing factors such as perceived obsolescence contribute significantly, as evidenced by
3331 a study in Austria revealing only 30% of replacements were attributable to malfunc-
3332 tioning products [90].

3333 Direct measurement of the impact of a right to repair is challenging, with the need to
3334 consider additional variables such as obsolescence perception, device performance, and
3335 consumer behaviour trends in determining potential extensions in consumer electronics'
3336 average lifespan.

3337 Moreover, the environmental benefit of repair is contingent not only on the increased
3338 product lifespan post-repair but also on the environmental footprint of the spare parts
3339 required for repair. Circuit boards, for example, carry substantial environmental impacts,
3340 and their replacement could still result in significant environmental costs. Common
3341 repairs typically involve less impactful components such as screens, casings, batteries,
3342 or software [89].

3343 Cordella et al. [89] report that compared to the baseline of replacing smartphones
3344 every two years, extending the device's life through repair can substantially diminish the
3345 carbon footprint. A one-year extension, with a battery change, can reduce greenhouse
3346 gas (GHG) emissions by 29%, and by 44% with a two-year extension.

3347 With 472 million Europeans owning a mobile phone, there are 8.11 Mt CO₂-eq. in
3348 annual emissions solely from phones. Extending the life of a mobile phone by just one
3349 year, including component replacements, could reduce emissions to 6.23 Mt CO₂-eq.

annually [94]. A further extension by an additional year could decrease emissions to 4.91 Mt CO₂-eq., effectively removing the equivalent of over 2 million cars from European roads.

Nevertheless, these potential reductions should be interpreted with caution as they are based on estimations and may not account for potential rebound effects. For instance, economic savings from prolonged use of electronic devices could lead to rebound effects where savings are offset by additional consumption stemming from the economic savings [104].

Finally, repair activities offer a more energy-efficient alternative within the Circular Economy compared to recycling and remanufacturing, which demand extensive energy input and high material throughput. When feasible, repair should be prioritized over other circular economy strategies [93].

MANUFACTURERS' PERSPECTIVE

- Compliance with eco-design standards could reduce profit margins.
- Risk of increased liability and the need to ensure long-term availability of spare parts.
- Potential decrease in turnover due to extended product lifecycles.
- Reduction in EU imports could foster the EU's technological independence, as per the EU Chips Act.
- Loss in turnover potentially offset by repair services and spare parts supply.

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

- Right to Repair could enhance competitiveness by increasing product longevity and added value.
- Positive impact on professional repair services, spare parts provision, and tool providers.
- SMEs and local repair shops likely to benefit significantly.
- Potential for the development of new European leaders in repair services.
- A more repairable design could improve recycling processes and increase component harvesting.

Relevance of Repairability to Critical Raw Materials in Waste Streams

The integration of the 'Right to Repair' ethos and the promotion of repairability has implications for the management of Critical Raw Materials (CRMs) across various waste streams, such as BATT (waste batteries), ELV (end-of-life vehicles), WEEE (waste electrical and electronic equipment), and CDW (construction and demolition waste).

BATTERIES (BATT)

Batteries are a crucial repository of CRMs like lithium, cobalt, and nickel. Enhancing their repairability can lead to:

- Refurbishing batteries for second-life applications.
- Design modifications for easier replacement of battery cells.
- Reduced extraction of new raw materials, mitigating the environmental footprint.

END-OF-LIFE VEHICLES (ELV)

Vehicles are a significant source of CRMs such as platinum and palladium (catalytic converters) and rare earth elements (electronics and magnets). 'Right to Repair' can:

- Influence design changes for modularity and ease of part replacement.
- Prolong the utility of CRMs and lessen new resource extraction.

WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

The WEEE stream contains valuable CRMs like gold, silver, and rare earth elements. Promoting repairability results in:

- Prolonged life spans for electronic devices.
- A reduction in the volume of CRMs entering the waste stream.
- Conservation of valuable materials through repair and refurbishment.

CONSTRUCTION AND DEMOLITION WASTE (CDW)

CRMs feature in many building materials as well as wind turbines which are part of this waste stream, and advocating for repairability in construction can:

- Lead to buildings designed for deconstruction, not demolition.

The emphasis on repairability and 'Right to Repair' legislation can lead to reduced CRM demand, decreased environmental impact through less mining, creation of economic incentives for repair industries, and improved resource security by minimizing reliance on raw material extraction. This approach is in line with fostering a circular economy, aiming for a sustainable management of resources within the EU.

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4.5.8. Repairability and 'Right to Repair': Scenarios

WASTE STREAM NOTICE

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

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Summary

REVIEW NOTICE

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

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Scenario I: Business-as-usual

3420

**BATT (BATTERY WASTE)**

3421

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3422

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

3423

**MIN (MINING WASTE)**

3424

**SLASH (SLAGS AND ASHES)**

3425

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

3426



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Scenario II: Recovery

3428

**BATT (BATTERY WASTE)**

3429

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3430

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

3431

**MIN (MINING WASTE)**

3432

**SLASH (SLAGS AND ASHES)**

3433

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

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[Back to ToC](#)WP2: Scenario Storylines | www.futuram.eu | 157

3435



Scenario III: Circularity

3436

XX **BATT (BATTERY WASTE)**

3437



CDW (CONSTRUCTION AND DEMOLITION WASTE)

3438



ELV (END-OF-LIFE VEHICLES)

3439



MIN (MINING WASTE)

3440



SLASH (SLAGS AND ASHES)

3441



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

3442

3443



4.5.9. Remanufacturing: *Description*

Definition

Context

International and European Trends

Implementation in EU Law

Development of a metric for XXX

Benefits and risks

ENVIRONMENTAL BENEFITS AND RISKS

MANUFACTURERS' PERSPECTIVE

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

Relevance of XXX to Critical Raw Materials in Waste Streams

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



BATT (Battery waste)

•



ELV (End-of-Life Vehicles)

•



WEEE (Waste Electrical and Electronic Equipment)

•



3465

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

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3467

**MIN (*Mining Waste*)**

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

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4.5.10. Remanufacturing: Scenarios

WASTE STREAM NOTICE

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

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Summary

REVIEW NOTICE

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Scenario I: Business-as-usual

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**BATT (BATTERY WASTE)**

3481

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3482

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

3483

**MIN (MINING WASTE)**

3484

**SLASH (SLAGS AND ASHES)**

3485

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

3486



3487



Scenario II: Recovery

3488

- XX **BATT (BATTERY WASTE)**
- 3489 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**
- 3490 **ELV (END-OF-LIFE VEHICLES)**
- 3491 **MIN (MINING WASTE)**
- 3492 **SLASH (SLAGS AND ASHES)**
- 3493 **WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)**

3494



3495



Scenario III: Circularity

3496

XX **BATT (BATTERY WASTE)**

3497

CDW (CONSTRUCTION AND DEMOLITION WASTE)

3498

ELV (END-OF-LIFE VEHICLES)

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MIN (MINING WASTE)

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SLASH (LAGS AND ASHES)

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WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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4.5.11. The Sharing Economy: *Description*

[105, 106, 107, 108, 109, 110]

Definition

The sharing economy is a socio-economic system that emphasizes the collaborative sharing of goods and services via community-based online platforms. It represents a shift from traditional ownership, where assets were exclusively leased, to a flexible model allowing for both personal use and lease. This flexibility is a hallmark of the sharing economy, which has grown significantly in response to advancements in technology, such as e-commerce and mobile connectivity, coupled with a societal push for more sustainable living and efficient resource use.

Context

As the concept of ownership transforms, particularly among the younger generation, the sharing economy has increasingly taken root in the EU market. This shift towards more communal and cost-effective ways of accessing goods and services is supported by a new wave of consumer behavior, underpinned by technological innovation and a pressing need to reduce environmental waste and resource duplication.

While the sharing economy is broad and its definition fluid, it is often associated with collaborative consumption, though the two can differ in motives and mechanisms. Collaborative consumption may span consumer-to-consumer and business-to-consumer interactions, whereas the sharing economy typically operates within the consumer-to-consumer sphere. The sharing economy is thereby defined as an innovative marketplace where entities engage in the distribution and utilization of products and resources, with scalability achieved through technological means.

This socio-economic model has not only disrupted traditional business sectors but has also brought new value to the global economy, with rapid and profound market penetration. Financial forecasts have been bullish, with revenue for sharing platform providers expected to increase from USD 18.6 billion in 2017 to an estimated USD 40.2 billion in 2022. Moreover, the overall value of the global sharing economy is projected to expand significantly, from USD 14 billion in 2014 to USD 335 billion in 2025, reflecting an unprecedented growth trajectory over a mere twelve years[110]. Such growth reflects the substantial economic potential and transformative power of the sharing economy in contemporary markets.

Scope within the EU Economy

The sharing economy has made a significant economic contribution to the EU, with an estimated €26.5 billion added to the GDP in 2016 [106]. This figure is expected to grow, indicating the sharing economy's increasing importance within the EU's economic structure.

Environmental Prospects

[105, 106, 108]

See [110] Table 2 for a summary of the studies on the environmental impacts of the sharing economy.

The sharing economy has the potential to reshape consumption behaviors and reduce environmental impacts by promoting the sustainable use of resources. This economic paradigm encourages the efficient employment of underutilised goods, which can lead to a decrease in the need for new products, thus conserving resources and mitigating greenhouse gas emissions. It fosters a lifestyle that lessens the adverse environmental effects of consumption while improving quality of life.

Central to the sharing economy is the promotion of moderate consumption patterns. This approach aims to reduce the excessive purchasing habits of certain populations to alleviate ongoing environmental harm. The sharing economy's alignment with green consumption practices encompasses waste reduction, energy conservation, and the adoption of sustainable resources, all while managing and moderating excessive consumption.

The impact on the fast fashion industry serves as a pertinent example, with the sector's frequent turnover to keep pace with changing trends leading to significant textile waste. Collaborative consumption through the sharing economy can mitigate this waste by encouraging the reuse and extension of clothing's service life. Clothing libraries are an example of how the sharing economy can provide environmental benefits by prolonging the usable life of garments.

Eco-efficiency is enhanced when environmental resources are utilised more effectively, leading to an increased use of products with minimal environmental burden. This is exemplified in collaborative fashion consumption, which could reduce the prevalent overconsumption in the fashion industry. By facilitating the exchange of underused clothing, the sharing economy can increase the lifecycle of garments and encourage the production of more durable products.

3569 Beyond the realm of fashion, car sharing and shared accommodation are other
3570 aspects of the sharing economy with notable environmental benefits. Car sharing
3571 can significantly reduce the number of vehicles needed, thereby lowering exhaust
3572 emissions. Similarly, shared accommodations have been associated with significantly
3573 lower carbon dioxide emissions compared to conventional hotel stays.

3574 However, the question of whether the sharing economy indeed delivers environ-
3575 mental benefits remains contested. [110, 111] Detractors highlight the potential for an
3576 increase in environmental burdens, particularly if the heightened usability of shared
3577 goods escalates greenhouse gas emissions. The environmental and socio-economic im-
3578 pacts engendered by the collaborative economy are intricate and highly variable across
3579 different business models. Generally speaking, collaborative consumption models that
3580 optimise the use of existing assets tend to exhibit a lower environmental footprint
3581 compared to their traditional counterparts. Nevertheless, there is a risk that the financial
3582 savings afforded by collaborative consumption could spur additional spending and
3583 consumption, which might negate the direct environmental savings. Despite such reser-
3584 vations, the prevailing view is that the sharing economy, by transforming consumption
3585 from ownership to communal use, can yield considerable environmental advantages.

3586 **Implications for Waste Streams**

3587 The adoption of sharing economy principles can influence various waste streams, in-
3588 cluding:

- 3589 • **BATT (Waste Batteries):** As devices are shared and utilized more efficiently,
3590 the frequency of battery disposal could decline, mitigating the waste battery
3591 stream.
- 3592 • **CDW (Construction and Demolition Waste):** The sharing of construction
3593 equipment and machinery could potentially slow down the turnover rate of
3594 these items, reducing associated waste.
- 3595 • **WEEE (Waste Electrical and Electronic Equipment):** Sharing electronic de-
3596 vices extends their lifecycle and reduces the rate at which they are discarded,
3597 thereby impacting electronic waste volumes.
- 3598 • **ELV (End-of-Life Vehicles):** A shift towards car-sharing services could reduce
3599 the demand for manufacturing new vehicles, potentially leading to a down-
3600 turn in the generation of automotive waste.

3601 The trajectory of the sharing economy indicates a shift towards collective usage
3602 patterns. Its continuing evolution could play a critical role in the future of critical raw

3603 material recovery systems by affecting demand and the lifecycle of products, which, in
3604 turn, influences waste stream outputs. The broader implications for the raw materials
3605 sector are significant, suggesting a possible recalibration of recovery strategies for critical
3606 raw materials in light of emerging consumption patterns.

3607 ***Challenges in Measuring Sharing Economy Growth***

3608 Identifying a universal metric for the growth of the sharing economy is challenging due
3609 to its diverse and dynamic nature. Current measures, such as STOXX Global sharing
3610 economy indices, Solactive Sharing Economy Index and the INDXX US Sharing Econ-
3611 omy Index, largely revolve around the market sizes of prominent sharing economy
3612 companies, such as Uber and Airbnb. These indices, while useful, predominantly reflect
3613 the scalability of these businesses rather than the sharing economy's broader impacts
3614 on production and waste reduction.

3615 In the absence of a standardised metric, the assessment of the sharing economy's
3616 expansion is often best approached through product-specific data. This involves exam-
3617 ining the adoption rates and usage trends of sharing services at the product level to infer
3618 growth patterns. Such a detailed, product-centric analysis allows for a closer inspection
3619 of the sharing economy's implications on resource utilisation and waste generation,
3620 offering insights that aggregate economic data may overlook.

3623

4.5.12. The Sharing Economy: *Scenarios*

WASTE STREAM NOTICE

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Summary

REVIEW NOTICE

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Scenario I: Business-as-usual

3630

**BATT (BATTERY WASTE)**

3631

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3632

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

3633

**MIN (MINING WASTE)**

3634

**SLASH (SLAGS AND ASHES)**

3635

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

3636

[Back to ToC](#)WP2: Scenario Storylines | www.futuram.eu | 170

3637



Scenario II: Recovery

3638

**BATT (BATTERY WASTE)**

3639

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3640

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

3641

**MIN (MINING WASTE)**

3642

**SLASH (SLAGS AND ASHES)**

3643

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

3644



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Scenario III: Circularity

3646

XX **BATT (BATTERY WASTE)**

3647

CDW (CONSTRUCTION AND DEMOLITION WASTE)

3648

ELV (END-OF-LIFE VEHICLES)

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MIN (MINING WASTE)

3650

SLASH (SLAGS AND ASHES)

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WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

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Conclusion

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4.6. CONCLUSION

REVIEW NOTICE

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3667 Literature referred to in section 6.4 is excluded from the following lists of references,
3668 except for those titles cited elsewhere in the report.

3669

CHAPTER CONTENTS

3670	5.1 Legislation and Government Documents	176
3671	5.2 Reports	178
3672	5.3 Datasets	180
3673	5.4 Books	180
3674	5.5 Book Chapters	181
3675	5.6 Articles	181
3676	5.7 Online Sources	185
3677	5.8 Miscellaneous	186



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4101

4102

CHAPTER CONTENTS

4104	6.1 Terminology	188
4105	6.2 List of relevant policy actions	194
4106	6.3 Scenario development methods	197
4107	6.4 Marker scenario mapping	202
4108	6.5 Drivers and factors identified in the initial collection phase	211
4109	6.6 Drivers and factors identified in the screening phase	217
4110	6.7 Drivers and factors after categorisation	221
4111	6.8 Drivers and factors for quantification	225



6.1. TERMINOLOGY

The following is a suggested terminology for use in our discussions and reports related to scenarios.

This glossary is modelled on that used by [23]. Some additional definitions were sourced from [112].



F

[Back to ToC](#)

WP2: Scenario Storylines | www.futuram.eu | 189

Table 6.1: 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	[23]
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	[23]
Outlook	To provide a most likely estimate of future trends as a guide for decision-making	Scenario type	Forecast, projection	[23]

Continued on next page

[Back to ToC](#)

WP2: Scenario Storylines | www.futuram.eu | 190

F

Table 6.1 – Continued from previous page

TERM	DEFINITION	LEVEL/CONTEXT	ALSO CALLED	SOURCE
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	[23]
Scenario scale	Description of the spatial extent or temporal extent of a scenario. For us, mostly EU toward 2050.	Scenario component		[112]
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		[112]
Scenario literature	Journal articles, grey literature, etc., from which data is sourced that can be used to justify decisions in scenario development	Scenario component		[23]

Continued on next page

TERM	DEFINITION	LEVEL/CONTEXT	ALSO CALLED	SOURCE
Scenario logics	Methods for structuring the relationships between different drivers and assumptions in scenarios	Scenario component		[112]
Time horizon	End date of the scenario's forecast	Scenario attribute		[23]
Snapshot	The position of scenario/s at a particular point of time	Scenario attribute		[23]
Storyline and simulation	Combination of qualitative narrative development and quantitative modelling	Scenario component		[113, 114], in [112]
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	[23]

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Table 6.1 – Continued from previous page

TERM	DEFINITION	LEVEL/CONTEXT	ALSO CALLED	SOURCE
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		[115]
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	[116], in [112]
Factors	Causes of system change that are internal from the system of analysis. Can be (hopefully) quantified, or at least estimated	Scenario component (internal)		[23]

Continued on next page

Table 6.1 – Continued from previous page

TERM	DEFINITION	LEVEL/CONTEXT	ALSO CALLED	SOURCE
Factor variables	Discrete elements which are subject to change and have effects on one or more factors	Factor component		[23]
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		[23]
Trends	An inclination in a particular direction	Attribute of drivers or factors	System development	[23]
Likelihood	The likelihood of an occurrence, an outcome, or a result, where this can be estimated probabilistically	Attribute of drivers or factors	Probability	[112]

4117

6.2. LIST OF RELEVANT POLICY ACTIONS

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The following table contains a description of policy actions that are relevant to the future of secondary raw material supply in the EU.

4119



Table 6.2: List of relevant policy actions

POLICY	STATE	YEAR	STATUS	JURISDICTION	LINK
European Institute of Innovation and Technology: Raw Materials Project Call	European Union	2023	Announced	International	🔗
Minerals Security Partnership	European Union	2022	Announced	International	🔗
Resilience for the future: The UK's critical minerals strategy	United Kingdom	2022	In force	National	🔗
Circular Economy Action Plan	Spain	2021	In force	National	🔗
Horizon Europe Strategic Plan (2021 – 2024)	European Union	2021	In force	International	🔗
National Battery Strategy 2025	Finland	2021	In force	National	🔗
National Planning Policy Framework	United Kingdom	2021	In force	National	🔗
EU Sustainable Batteries Regulation	European Union	2020	Announced	Regional	🔗
Green Deal: Circular Economy Action Plan	European Union	2020	In force	International	🔗
Battery fund: 3.2 billion euros for research and innovation	European Union	2019	In force	International	🔗
Resources for France Plan	France	2018	In force	National	🔗
European Battery Alliance	European Union	2017	In force	National	🔗
National Strategy for Energy Research	France	2016	In force	National	🔗
Horizon 2020: Climate action, environment resource efficiency and raw materials	European Union	2013	Ended	International	🔗

Continued on next page

F

Back to ToC

POLICY	STATE	YEAR	STATUS	JURISDICTION	LINK
Resource Security Action Plan	United Kingdom	2012	In force	National	🔗
Supply of Mineral Resources (SoS MinErals)	United Kingdom	2012	In force	National	🔗
Finland's Minerals Strategy	Finland	2010	In force	National	🔗
Royal Decree 975/2009 about extractive industries waste management and the protection and rehabilitation of areas affected by mining activities	Spain	2009	In force	National	🔗
EU Directive 2006/66/EC Battery Directive	European Union	2006	In force	International	🔗

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6.3. SCENARIO DEVELOPMENT METHODS

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The following table 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.

4122

4123



[Back to ToC](#)

WP2: Scenario Storylines | www.futuram.eu | 198

F

Table 6.3: Scenario development methods

METHOD	DESCRIPTION	KEY CHARACTERISTICS	LIMITATIONS	APPLICATION
Delphi	Structured expert consultation to gather and distil knowledge and judgments	Iterative rounds of surveys/questionnaires, Expert consensus building	Time-consuming process, May be influenced by dominant opinions or group dynamics	Policy development, Technology foresight, Long-term planning
MCA	Decision-support technique to evaluate and rank scenarios based on criteria	Consideration of multiple dimensions in quantifying qualitative factors	Policy assessment, Project evaluation, Strategic planning	
Forecasting	Use of historical data and statistical methods to predict future trends	Reliance on quantitative models, Time series analysis	Assumption of future patterns based on past data, Sensitivity to data quality and accuracy	Economic forecasting, Demand/supply projections, Financial planning

Continued on next page

Table 6.3 – Continued from previous page

METHOD	DESCRIPTION	KEY CHARACTERISTICS	LIMITATIONS	APPLICATION
Backcasting	Working backward from a desired future vision to identify necessary steps	Focus on desired outcomes and future targets, Identification of necessary actions	Uncertainty in future outcomes, Difficulty in determining feasible pathways	Sustainable development planning, Policy design, Long-term goal setting
Scenario Planning	Development of multiple future scenarios to understand the range of possibilities	Identification of key drivers and uncertainties, Narrative construction for each scenario	Subjectivity in scenario construction, Lack of predictive accuracy	Strategic management, Risk assessment, Policy analysis
Morphological Analysis	Exploration of different combinations of variables/factors	Matrix-based exploration of variables and combinations	Complexity in analysing a large number of variables and combinations	Technology assessment, Innovation analysis, System design

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Table 6.3 – Continued from previous page

METHOD	DESCRIPTION	KEY CHARACTERISTICS	LIMITATIONS	APPLICATION
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

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Table 6.3 – Continued from previous page

METHOD	DESCRIPTION	KEY CHARACTERISTICS	LIMITATIONS	APPLICATION
Schwartz' 8-Step Scenario Model	Scenario building model consisting of eight steps: identify the focal issue, determine the key forces, construct the scenario framework, identify driving forces, assess the uncertainties, develop the scenarios, analyze the scenarios, and monitor and adjust the scenarios	Systematic progression through stages of scenario development	Requires detailed data and analysis	Strategic planning, Decision-making
Schoemaker's 10-Step Scenario Model	Scenario building model consisting of ten steps: identify the focal issue, determine the scope, identify the key driving forces, develop the scenarios, define the scenario logic, assess the scenarios, refine the scenarios, examine implications, formulate actions, and communicate results	Emphasis on thorough analysis and evaluation of scenarios	Can be time-consuming and resource-intensive	Strategic planning, Risk management

6.4. MARKER SCENARIO MAPPING

Table 6.4 below presents an overview of the marker scenarios that were considered in the scenario development phase of the FutuRaM project. The table is not intended to be exhaustive, but rather to provide an overview of the different scenarios that have been developed in the field of waste management, resource recovery, and circular economy.



Table 6.4: Overview of marker scenarios

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview	Academic	All (narratives)	Scenario to 2100	Global	5 SSPs	🔗
Environmental Impacts of Global Offshore Wind Energy Development until 2040	Academic	CDW	Scenario: 2019–2040	Global	4 (based on IEA)	🔗
Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060	Academic	CDW	Scenario: 2020–2060	Global	2 (based on SSP2)	🔗
Modelling global material stocks and flows for residential and service sector buildings towards 2050	Academic	CDW	Scenario: 2020–2060	Global	1 (SSP2)	🔗
The evolution and future perspectives of energy intensity in the global building sector 1971–2060	Academic	CDW	Scenario: 2020–2060	Global	1 (SSP2)	🔗

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Table 6.4 – 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	CDW	Scenario to 2060	Global	6 scenarios concerning per-capita floor area, building stock turnover, and construction material.	
Global construction materials database and stock analysis of residential buildings between 1970–2050	Academic	CDW	Scenario to 2060	Global	1 (SSP2)	
A comprehensive set of global scenarios of housing, mobility, and material efficiency for material cycles and energy systems modelling	Academic	CDW	Scenario to 2060	Global	Low energy demand, SSP1, SSP2	
Global scenarios of resource and emission savings from material efficiency in residential buildings and cars	Academic	CDW, ELV	Scenarios to 2050	Global	SSP1, SSP2	
Matching global cobalt demand under different scenarios for co-production and mining attractiveness	Academic	BAT	2050	Global	5	

Continued on next page

Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Copper at the crossroads: Assessment of the interactions between low-carbon energy transition and supply limitations	Academic	Copper	2050	Global	2: 2°C and 4°C	
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)	
The rise of electric vehicles—2020 status and future expectations	Academic	ELV, BAT	up to 2050	Global	various	
Scenarios for the Return of Lithium-ion Batteries out of Electric Cars for Recycling	Academic	ELV, Battery	Scenario to 2050	Global	2	
The dynamic equilibrium mechanism of regional lithium flow for transportation electrification	Academic	ELV, BAT	Scenario to 2050	Global	1 (projection)	
Future material demand for automotive lithium-based batteries	Academic	ELV, BAT	Scenario to 2050	Global	4 (based on IEA)	
Analysis of the Li-ion battery industry in light of the global transition to electric passenger light-duty vehicles until 2050	Academic	ELV, BAT	Scenario to 2050	Global	Combination of SSPs and RCPs	

Continued on next page

Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Circular economy strategies for electric vehicle batteries reduce reliance on raw materials	Academic	ELV, BAT	Scenario to 2050	Global	Reference + 4 technologies	
Summary and critical review of the International Energy Agency's special report: The role of critical minerals in clean energy transitions	Academic	Energy	2050	Global	n/a	
Review of critical metal dynamics to 2050 for 48 elements	Academic	Energy	Scenario to 2050	Global	1 compiled from various renewable technologies	
Major metals demand, supply, and environmental impacts to 2100: A critical review	Academic	Energy	Scenario to 2100	Global	1 review of 197 studies	
Requirements for Minerals and Metals for 100% Renewable Scenarios	Academic	Energy	Scenario to 2050	Global	1.5 degree scenario	
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	

Continued on next page

Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Modelling the demand and access of mineral resources in a changing world	Academic	Energy, Construction	2060	Global	RTS, BD2S IEA	
Rare earths in the energy transition: what threats are there for the 'vitamins of modern society'?	Academic	Rare earths	2050	Global	2: 2°C and 4°C	
A slag prediction model in an electric arc furnace process for special steel production	Academic	SLASH	None	Global	n/a	
Decarbonising the iron and steel sector for a 2°C target using inherent waste streams	Academic	SLASH	Scenario to 2050	Global	1 (2 degree climate goal)	
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)	
Resource Demand Scenarios for the Major Metals	Academic	Various	Scenario to 2050	Global	4 (UN GEO-4)	
Raw material depletion and scenario assessment in European Union – A circular economy approach	Academic	Various	None	EU	n/a	
Material bottlenecks in the future development of green technologies	Academic	Various	Scenario to 2050	Global	1 (BAU)	

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Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Reuse assessment of WEEE: Systematic review of emerging themes and research directions	Academic	WEEE	None	Global	n/a	
A systematic literature review on the circular economy initiatives in the European Union	Academic	Circularity	None	EU	Circular strategies	
Material Flow Accounting: Measuring Global Material Use for Sustainable Development	Academic	Various	Scenario to 2100	Global	1 (BAU)	
Circular Economy Action Plan	Action plan	Various	Scenario to 2050	EU	35 actions to climate neutrality	
Construction and demolition waste: challenges and opportunities in a circular economy	Report	CDW	None	EU	n/a	
IEA world energy model	Report	Energy	Scenario to 2050	Global	4	
Bloomberg scenarios	Report	Energy	Scenario to 2050	Global	3	
The Role of Critical Minerals in Clean Energy Transitions	Report	Energy	None	Global	n/a	

Continued on next page

Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Transitions to 2050 decide now act for climate	Report	Energy	Scenario to 2050	France	4 to reach 2.1C by 2100	
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	
Inventaires des besoins en matière, énergie, eau et sols des technologies de la transition énergétique	Report	Energy	Scenario to 2050	France	1	
Minerals in the future of Europe	Report	MinW	Scenario to 2050	EU	3 (2050 net-zero, digital, circular)	
Minerals, Critical Minerals and the US Economy	Report	MinW	None	US	n/a	
Minéraux stratégiques — État des lieux et propositions pour une vision partagée	Report	MinW	None	FR	n/a	
The Critical Raw Materials (CRM) initiative — Underpinning the strategic approach to the EU's raw materials policy	Report	MinW	None	EU	n/a	
Towards the Circular Economy: Accelerating the scale-up across global supply chains	Report	Circularity	None	Global	n/a	

Continued on next page

Table 6.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
The Circular Economy in Europe	Report	Circularity	None	EU	n/a	🔗
Global material flows and resource productivity: Forty years of evidence	Report	Circularity	None	Global	n/a	🔗
The circular economy concept: contextualisation and multiple perspectives	Report	Circularity	None	Global	n/a	🔗
Global material flows database	Database	Various	None	Global	n/a	🔗
International Resource Panel	Reports	Various	None	Global	n/a	🔗
World Business Council for Sustainable Development	Reports	Various	None	Global	n/a	🔗
Ellen MacArthur Foundation	Reports	Various	None	Global	n/a	🔗
European Environment Agency	Reports	Various	None	EU	n/a	🔗
International Energy Agency	Reports	Energy	None	Global	n/a	🔗
United Nations Environment Programme	Reports	Various	None	Global	n/a	🔗
United Nations Industrial Development Reports	Reports	Various	None	Global	n/a	🔗
World Bank	Reports	Various	None	Global	n/a	🔗
World Economic Forum	Reports	Various	None	Global	n/a	🔗

6.5. DRIVERS AND FACTORS IDENTIFIED IN THE INITIAL COLLECTION PHASE

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



Table 6.5: Drivers and factors identified in the initial collection phase

METHOD	DESCRIPTION
Stricter environmental regulations	Increased regulations and policies aimed at reducing environmental impact
Inflation	Increase in the general price level of goods and services over time
Employment rates	Percentage of the working-age population that is employed
Exchange rates	Value of one currency relative to another currency
Interest rates	Cost of borrowing money or the return on investment
Gasoline price	Cost of gasoline for vehicles
Electricity price	Cost of electricity for consumers or businesses
Raw material prices	Prices of primary materials used in production processes
CO2 market	Trading system for carbon emissions permits or credits
Education level	Level of education attained by individuals or the overall population
Volunteering	Engagement in unpaid activities for the benefit of others
Transparency	Openness, accountability, and information accessibility
Compliance with rules	Adherence to regulations, guidelines, or standards
Cultural values / Consciousness	Beliefs, attitudes, and awareness of individuals and society
Accessibility	Ease of access to goods, services, or infrastructure

Continued on next page

Table 6.5 – Continued from previous page

METHOD	DESCRIPTION
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
Change of products in the scope WEEE directive	Inclusion or exclusion of certain products within the scope of the WEEE directive

Continued on next page

Table 6.5 – Continued from previous page

METHOD	DESCRIPTION
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

Continued on next page

Table 6.5 – Continued from previous page

METHOD	DESCRIPTION
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
Improved recyclability	Increased ability of products or materials to be recycled or reused

Continued on next page

Table 6.5 – Continued from previous page

METHOD	DESCRIPTION
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

4134

6.6. DRIVERS AND FACTORS IDENTIFIED IN THE SCREENING PHASE

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

4136

4137



[Back to ToC](#)

WP2: Scenario Storylines | www.futuram.eu | 218

F

Table 6.6: List of drivers and factors identified in the screening phase

DOMAIN	DRIVER/FACTOR	DEFINITION	BAU	REC	CIR
Economic	CO2 market price	Price of carbon dioxide (CO2) emissions in carbon markets	I	I	I
	Economic growth	Rate of economic growth	I	I	I
	Energy prices	Prices of energy resources	I	I	I
	Market saturation	Level of saturation reached in the market for certain products or services	I	I	II
	Raw material vs SRM prices	Price comparison between raw materials and Secondary Raw Materials (SRMs)	I	I	I
	Re-industrialisation of EU	Process of revitalizing industrial activities in the European Union	I	I	I
	Climate change impacts (flooding, etc.)	Impacts of climate change such as flooding and other related events	I	I	I
	Climate change mitigation efforts	Efforts made to mitigate the effects of climate change	I	I	I
	Increased drive for env. protection	Growing motivation and drive to protect the environment	I	III	III
	Resource shortage	Shortage of natural resources	I	I	I

Continued on next page

[Back to ToC](#)WP2: Scenario Storylines | www.futuram.eu | 219

F

Table 6.6 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	BAU	REC	CIR
Legal/Political	Ecodesign/re-X mandates	Establishment of ecodesign requirements for specific product groups to improve circularity, energy performance, and other environmental sustainability aspects	I	II	III
Legal/Political	Governance: corruption vs compliance	Contrasting levels of corruption and compliance within governance systems	I	I	I
Legal/Political	International trade and co-operation (vs. autarky)	Level of international trade and cooperation versus self-sufficiency	I	I	I
Legal/Political	Product information transparency	Provision of transparent product information to consumers, manufacturers, importers, repairers, recyclers, or national authorities	I	III	III
Legal/Political	Progress toward renewable energy targets	Progress made in achieving renewable energy targets	I	I	I
Legal/Political	Stricter environmental regulations	Implementation of more stringent rules and regulations for environmental protection	I	III	III
Legal/Political	Subsidies/taxation to promote circularity	Provision of subsidies or implementation of taxation policies to incentivize circularity	I	I	I
Legal/Political	Supply chain due diligence laws	Implementation and enforcement of laws requiring companies to address negative human rights and environmental impacts in their value chains	I	II	III

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Table 6.6 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	BAU	REC	CIR
Social	Hoarding	The act of stockpiling and keeping excessive amounts of products	III	II	II
Social	NIMBY to projects	Opposition of local communities to the location of new projects, such as mining, in their vicinity	I	I	I
Social	Participation in re-X activities	"Involvement in activities related to the ""re-"" concepts, including refusing, reducing, repairing, and reusing products"	I	II	III
Social	Population	Size and growth of the population	I	I	I
Social	Urbanisation	Rate of urban population growth	I	I	I
Technical	Digitisation	Adoption and integration of digital technologies	I	I	I
Technical	Integration of SRM system across EU	Integration of a Secondary Raw Materials (SRM) system across the European Union	I	III	III
Technical	Product technology	Changes in product function or composition that lead to changes in waste stream composition and quantity	I	III	III
Technical	Recovery technology	Technologies and processes for recovering materials from waste	I	III	III

6.7. DRIVERS AND FACTORS AFTER CATEGORISATION

The 21 elements that were identified in this stage are listed in Table 6.7. Note that CIR and REC are very similar for many scenario elements, the main difference being the way in which the targets are achieved. That is, for CIR, re-X strategies are promoted, whereas, for REC, the focus is on technological advancements in the recovery system. This distinction will have a significant impact on how the scenarios are quantitatively modelled and on the subsequent outcomes of these models.



[Back to ToC](#)

WP2: Scenario Storylines | www.futuram.eu | 222

F

Table 6.7: List of drivers and factors identified in the screening phase

DOMAIN	DRIVER/FACTOR	DEFINITION	INTERNAL	BAU	REC	CIR
TECH	Recovery technology	Implementation and advancements in waste recovery technologies	TRUE	I	III	III
TECH	Product technology	Changes in product function or composition	TRUE	I	III	III
TECH	Integration of SRM system across EU	Integration of a secondary raw material recovery system across EU countries	TRUE	I	III	III
ENV	Increased drive for environmental protection	Growing concern and motivation for environmental conservation	TRUE	I	III	III
ECO	Progress toward renewable energy targets	Advancements and achievements in renewable energy generation	TRUE	III	III	III
ECO	Subsidies and taxation to promote circularity	Financial incentives or taxes to encourage circular economy	TRUE	I	II	III
SOC	Participation in re-X activities	Engagement in refuse-reduce-repair-reuse activities	TRUE	I	I	III
POL	Stricter environmental regulations	Tightening of environmental laws and regulations	TRUE	II	III	III
POL	Stricter waste management regulations	Strengthening of waste management laws and regulations	TRUE	II	III	III

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Table 6.7 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTERNAL	BAU	REC	CIR
POL	Supply chain due diligence laws: implementation and enforcement	Obligations for identifying and mitigating negative impacts in supply chains	TRUE	I	III	III
POL	Compliance with waste targets	Meeting specific waste management and recycling targets	TRUE	I	III	III
ENV	Resource shortages	Limited availability of natural resources	FALSE	na	na	na
ECO	Raw material vs SRM prices	Price dynamics and competition between raw materials and secondary raw materials	FALSE	na	na	na
ENV	Climate change impactsmitigation	Effects and actions related to climate change	FALSE	na	na	na
ECO	International trade and co-operation (vs. autarky)	Collaborative trade agreements and global cooperation	FALSE	na	na	na
ECO	Energy prices	Costs and fluctuations in energy prices	FALSE	na	na	na
ECO	Economic growth	Overall economic expansion and development	FALSE	na	na	na
ECO	Re-industrialisation of EU	Shift towards increased industrial activities in the EU	FALSE	na	na	na

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Table 6.7 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTERNAL	BAU	REC	CIR
SOC	NIMBY to projects	Opposition to local projects and developments	FALSE	na	na	na
SOC	Population and urbanisation	Growth and urban development of population	FALSE	na	na	na
ECO	CO2 market price	Price and market dynamics of carbon emissions	FALSE	na	na	na

4145

6.8. DRIVERS AND FACTORS FOR QUANTIFICATION

4146

The following table lists the categorised scenario elements that were quantified and incorporated into the modelling.

4147



Table 6.8: List of scenario elements categorised for quantification

DOMAIN	ELEMENT	INTERNA	EXTERNA	OUTSIDE	BAU	REC	CIR	MODEL PARAMETERS AFFECTED
ECO	Primary vs. secondary raw material prices			✓				considered in sensitivity analysis
ECO	Energy prices			✓				considered in sensitivity analysis
ECO	Carbon price			✓				considered in sensitivity analysis
ENV	Resource supply constraints			✓				considered in sensitivity analysis:
ECO	International trade and co-operation (vs. autarky)			✓	n/a	n/a	n/a	not model input (resource supply constraints is a proxy)
ECO	Re-industrialisation of EU			✓	na	na	na	not model input
SOC	Resistance to recovery projects (NIMBY)			✓	na	na	na	not model input (considered in UNFC assessments)

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Table 6.8 – Continued from previous page

DOMAIN	ELEMENT	INTERNA	EXTERNA	OUTSIDE	BAU	REC	CIR	MODEL PARAMETERS AFFECTED

F

[Back to ToC](#)

4148

4149

4150

END OF REPORT

4151

4152

4153

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Future availability
of secondary
raw materials