

FutuRaM

Future availability
of secondary
raw materials

Work Package 2

Future Availability of Secondary Raw Materials

Scenario Storylines & Scenario Quantification
Draft Report – Version 3



Funded by
the European Union

Project funded by



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

DRAFT REPORT – VERSION 3

2

REVIEW NOTICE

Latest Revision: Friday 17th November, 2023 at 01:05

This is a draft report for internal review

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

3

4

CONTRIBUTING

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

5

6

WASTE STREAM NOTICE

Waste Streams, please check your sections

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

7

8

QUANTIFICATION

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

9

10

DISCUSSION POINTS

- How to transfer general targets?

general CRM/SRM → waste streams → product groups

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

- Consideration of possible future resource constraints in the scenarios.

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

- Economic considerations (prices, subsidies, PPP vs. GPD etc.).

- Geopolitical Considerations (supply risk, trade, etc.).

- Scenarios relationship with the United Nations Framework Classification (UNFC).

- E-mobility.

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...

11

12

SOME LINKS

- Quantification: chapter 4

- Interpretation: chapter 5

- Appendices: chapter 13

- WP2 folder on the FutuRaM Sharepoint See  for more details.

13

14

15



16

Front Matter

17

CHAPTER CONTENTS

18	I	Report Details	v
19	II	Notice	vi
20	III	Preface	vii
21	IV	Report Contents	viii
22	V	List of Tables	xii
23	VI	List of Figures	xiv
24	VII	Executive Summary	xvi
25	VIII	Overview of the scenario storylines	xviii
26	IX	Abbreviations	xxiii
27	X	Terminology (abbreviated)	xxv
28	XI	Description of FutuRaM work package 2	xxvi
29	XI.1	Objectives	xxvi
30	XII	Task Descriptions	xxvii
31	XII.1	Interconnection with other work packages in FutuRaM	xxviii
32	XII.2	Work package two milestones	xxx
33	XII.3	Subtasks for Task 2.1— Scenario storyline development	xxxi
34	XII.4	Consortium partner contributions to WP2	xxxii



I. REPORT DETAILS

Project:	Future Availability of Secondary Raw Materials
Acronym:	FutuRaM
Grant Agreement:	1010585
Funding Scheme:	Horizon Europe
Webpage:	www.futuram.eu
Work Package:	2
Work Package Leader:	
Deliverable Title:	Scenario Storylines
Deliverable Leader:	Stewart Charles McDowall
Version:	3.0
Status:	Draft
Author (s):	Stewart Charles McDowall
E-Mail:	s.c.mcdowall@cml.leidenuniv.nl
Reviewed By:	
Due Date:	2023-12-01
Date Of Submission:	2023-11-22
Dissemination Level:	Internal document

Table 1.1: Version history

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

36 II. NOTICE

37 The contents of this document are the copyright of the FutuRaM consortium and shall not be copied in
38 whole, in part, or otherwise reproduced (whether by photographic, reprographic or any other method),
39 and the contents thereof shall not be divulged to any other person or organisation without prior written
40 permission. Such consent is hereby automatically given to all members who have entered into the FutuRaM
41 Consortium Agreement, dated 1st June 2022, and to the European Commission to use and disseminate this
42 information.

43 This information and the content of this report are the sole responsibility of the FutuRaM consortium
44 members and do not necessarily represent the views expressed by the European Commission or its services.
45 Whilst the information contained in the documents and webpages of the project is believed to be accurate,
46 the author(s) or any other participant in the FutuRaM consortium makes no warranty of any kind with regard
47 to this material.

III. PREFACE

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

THE WASTE STREAMS COVERED IN FUTURAM ARE:

- 54  Waste batteries (BAT)
- 55  Construction and demolition waste (CDW)
- 56  End-of-life vehicles (ELV)
- 57  Mining waste (MIN)
- 58  Slags and ashes (SLASH)
- 59  Waste electrical and electronic equipment (WEEE)

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

THE THREE SCENARIOS THAT HAVE BEEN DEVELOPED IN FUTURAM ARE:

- 66  I. Business-as-usual (BAU)
- 67  II. Recovery (REC)
- 68  III. Circularity (CIR)

IV. REPORT CONTENTS

1	Front Matter	iv
72	I Report Details	v
73	II Notice	vi
74	III Preface	vii
75	IV Report Contents	viii
76	V List of Tables	xii
77	VI List of Figures	xiv
78	VII Executive Summary	xvi
79	VIII Overview of the scenario storylines	xviii
80	IX Abbreviations	xxiii
81	X Terminology (abbreviated)	xxv
82	XI Description of FutuRaM work package 2	xxvi
83	XI.1 Objectives	xxvi
84	XII Task Descriptions	xxvii
85	XII.1 Interconnection with other work packages in FutuRaM	xxviii
86	XII.2 Work package two milestones	xxx
87	XII.3 Subtasks for Task 2.1 – Scenario storyline development	xxxi
88	XII.4 Consortium partner contributions to WP2	xxxii
89	2 Methodology	1
90	2.1 The conceptual framework for scenario development	2
91	2.2 Scenario storyline development process	3
92	2.2.1 Step 1: Define the scope and objectives	3
93	2.2.2 Step 2: Determine methodology	10
94	2.2.3 Step 3: Marker-scenario mapping	15
95	2.2.4 Step 4: Identification of key drivers of change	16
96	2.2.5 Step 5: Develop storyline themes	26
97	2.2.6 Step 6: Qualitative narrative development	26
98	2.2.7 Step 7: Definition of scenario parameters	26
99	2.2.8 Step 8: Quantitative modelling	26

100	2.2.9 Step 9: Implementation	26
101	2.2.10 Step 10: Review process	27
102	3 Scenario storylines	28
103	3.1 Scenario I: Business-as-usual	29
104	3.1.1 Context	29
105	3.1.2 Storyline narrative	29
106	3.1.3 Waste stream specific scenario impacts	32
107	3.2 Scenario II: Recovery	37
108	3.2.1 Context	37
109	3.2.2 Storyline narrative	37
110	3.2.3 Waste stream specific scenario impacts	40
111	3.3 Scenario III: Circularity	46
112	3.3.1 Context	46
113	3.3.2 Storyline narrative	47
114	3.3.3 Scenario needs and impacts	49
115	3.3.4 Waste stream specific scenario impacts	51
116	4 Quantification	57
117	4.1 Introduction	59
118	4.1.1 Quantification and Implementation of scenario elements in the models	60
119	4.2 Summary	67
120	4.3 External elements	68
121	4.3.1 Introduction	68
122	4.3.2 Summary	71
123	4.3.3 Demographic factors: <i>Population, age, urbanisation</i>	74
124	4.3.4 Economic factors: <i>GDP growth</i>	86
125	4.3.5 The Renewable Energy Transition	94
126	4.3.6 Supply constraints and market dynamics	111
127	4.3.7 Conclusion	118
128	4.4 Internal elements — Technological Change	119
129	4.4.1 Introduction	119

130	4.4.2 Methodology	120
131	4.4.3 Summary	121
132	4.4.4 Future product and waste composition: <i>Description</i>	122
133	4.4.5 Future product and waste composition: <i>Scenarios</i>	124
134	4.4.6 Future recovery technology: <i>Description</i>	128
135	4.4.7 Future recovery technology: <i>Scenarios</i>	131
136	4.4.8 Future recovery system: <i>Description</i>	135
137	4.4.9 Future recovery system: <i>Scenarios</i>	137
138	4.5 Internal elements — The Circular Economy	142
139	4.5.1 Introduction	142
140	4.5.2 Summary	150
141	4.5.3 The EU Circular Economy Indicators: <i>Description</i>	151
142	4.5.4 The EU Circular Economy Indicators: <i>Scenarios</i>	159
143	4.5.5 Refuse, Reduce, Reuse: <i>Description</i>	163
144	4.5.6 Refuse, Reduce, Reuse: <i>Scenarios</i>	165
145	4.5.7 Repair: <i>Description</i>	169
146	4.5.8 Repair: <i>Scenarios</i>	177
147	4.5.9 Remanufacturing and Refurbishing: <i>Description</i>	181
148	4.5.10 Remanufacturing: <i>Scenarios</i>	186
149	4.5.11 The Sharing Economy: <i>Description</i>	190
150	4.5.12 The Sharing Economy: <i>Scenarios</i>	195
151	4.6 Conclusion	200
152	5 Interpretation	201
153	5.1 Introduction	202
154	5.2 Conclusion	203
155	6 Modelling — Waste generation	204
156	6.1 Introduction	205
157	7 Modelling — Recovery system	207
158	7.1 Introduction	208

159	8 Modelling – Integration	210
160	8.1 Introduction	211
161	9 Impacts	213
162	9.1 Introduction	214
163	10 Bottlenecks	216
164	10.1 Introduction	217
165	11 Conclusion	219
166	12 References	221
167	12.1 Legislation and Government Documents	222
168	12.2 Reports	224
169	12.3 Datasets	227
170	12.4 Books	228
171	12.5 Book Chapters	228
172	12.6 Articles	229
173	12.7 Online Sources	235
174	12.8 Miscellaneous	235
175	13 Appendices	237
176	13.1 Terminology	238
177	13.2 List of relevant policy actions	241
178	13.3 Scenario development methods	243
179	13.4 Marker scenario mapping	246
180	13.5 Drivers and factors identified in the initial collection phase	251
181	13.6 Drivers and factors identified in the screening phase	255
182	13.7 Drivers and factors after categorisation	258
183	13.8 Drivers and factors for quantification	261
184	13.9 Work breakdown structure for WP2	264

V. LIST OF TABLES

Front Matter

iv

188	1.1 Version history	v
189	1.2 List of abbreviations	xxiii
190	1.3 List of terminology (abbreviated)	xxv
191	1.4 WP2.1 – Milestone list	xxx
192	1.5 WP2.1 – Subtask list	xxxi
193	1.6 Consortium partner contributions to WP2 (person months per sub-task)	xxxii

Methodology

1

195	2.1 Selected objectives of the FutuRaM project	5
196	2.2 FutuRaM WP2 aims and objectives	6
197	2.3 Types of scenario	14
198	2.4 List of drivers and factors identified in the screening phase	23

Quantification

58

200	4.1 List of external scenario elements	70
201	4.2 Population projections for the EU27+4	83
202	4.3 Raw materials essential to the renewable energy sector	98
203	4.4 Normalized renewable energy supply in the EU using the year 2010 as a base reference	106
204	4.5 Definitions and Objectives of the GEC Model 2023 Scenarios	107
205	4.6 EU Circular Economy Indicators (CEIs) and their targets for 2023 [123]	145
206	4.7 EU circular indicators (CEIs) and their significance for FutuRaM's models	146

Appendices

237

208	13.1 Terminology	239
209	13.2 List of relevant policy actions	242
210	13.3 Scenario development methods	244
211	13.4 Overview of marker scenarios	247
212	13.5 Drivers and factors identified in the initial collection phase	252

213	13.6 List of drivers and factors identified in the screening phase	256
214	13.7 List of drivers and factors identified in the screening phase	259
215	13.8 List of scenario elements categorised for quantification	262
216	13.9 Work breakdown structure for work package two	265
217	13.10 Gaant chart for the entire FutuRaM project	266

VI. LIST OF FIGURES

218	Front Matter	iv
220	1.1 Interconnection between WP2 and the other work packages in FutuRaM	xxix
222	Methodology	1
223	2.1 Scenario storyline development process	4
224	2.2 An illustration of the process used for identifying key drivers of change	18
225	2.3 An excerpt of a spreadsheet used as part of the screening process	21
226	Scenario storylines	28
227	3.1 The linear economy model in the business-as-usual scenario	30
228	3.2 The reuse economy model in the recovery scenario	38
229	3.3 The simplified circular economy model in the circularity scenario	48
230	Quantification	58
231	4.1 Quantification and Implementation of scenario elements in the models	61
232	4.2 Development of correlations between elements and parameters in the waste stream models and the scenarios	63
233	4.3 An example of a sigmoidal function (s-curve)	65
234	4.4 The word 'sustainable' is unsustainable	66
235	4.5 Population projections for the EU27+3 and the UK	76
236	4.6 GDP projections for the EU27+4	87
237	4.7 Factors incorporated in the long-term model [85]	89
238	4.8 EU electricity mix forecast until 2050	94
239	4.9 Change in demand for selected elements	108
240	4.10 Change in demand for battery relevant elements	109
241	4.11 Global mineral demand (total) under various scenarios	109
242	4.12 A detailed mapping of the re-X strategies in the circular economy	144
243	4.13 EU Circular Economy Indicators (CEIs) - trends from 2000-2022 and linear forecasts.	148
244	4.14 An example of a generic remanufacturing process for vehicle components [149]	183

VII. EXECUTIVE SUMMARY

247

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

248

249

250

251

252

253

254

The scenario development process employs a methodology that integrates both forecasting and back-casting techniques to build a comprehensive, future-facing knowledge base that can aid fact-based decision-making [5–11].

255

256

257

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

258

259

260

261

262

263

264

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

265

266

FUTURAM'S THREE FUTURE SCENARIOS

267



268

Scenario I: Business-as-usual (BAU)

269

270

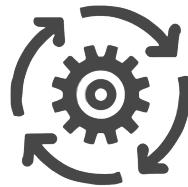
271

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

272

practice.

273



274

Scenario II: Recovery (REC)

275

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

276

277

278

279

280



281

Scenario III: Circularity (CIR)

282

283

284

285

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

286

287

VIII. OVERVIEW OF THE SCENARIO STORYLINES

288

289

290

291

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

298

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

- A forecasting model is used to predict the future based on the current situation and the development of existing trends.
- EU targets including those for eco-design, recycling and recovery are not met, and the current linear model largely persists.
- Material demand remains coupled with economic growth, perpetuating a trend of increasing consumption.
- Primary mining and extraction persist as the leading sources of raw materials, underlining the dependency on traditional extraction methods.
- Recycling and recovery rates continue to lag, leading to increased production of SRM-containing waste that signals missed opportunities for resource reuse.
- The EU's dependency on imports of SRMs escalates, heightening the risk of supply disruptions [18].
- Investment in new SRM recovery technologies remains minimal, stifling innovation and advancements in this field.
- The industrial focus remains on cost-effective material production and use, disregarding the long-term sustainability aspect.
- Material scarcity and price fluctuations pose potential risks to the EU industry, highlighting the vulnerability of this business model [19].
- Without any significant updates to environmental regulations, the negative impacts on ecosystems and biodiversity intensify.
- Mining activity in the EU remains limited and concentrated in only a few member states. Current exploration projects (e.g., for Lithium in PT, FR, UK and rare earths in SE) are not realised.
- The transitions to renewable energy and e-mobility continue at their current pace.

322



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

292

293

294

295

296

297

298

299

300

301

302

303

304

305

306

307

308

309

310

311

312

313

314

315

316

317

318

319

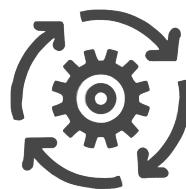
320

321

323

Scenario II: Recovery (BAU)

324

325
See section 3.2 for the full scenario description and the waste-stream-specific scenario impact narratives.326
327
328
329
330
In the recovery scenario, the central emphasis is on harnessing sophisticated technologies to salvage SRMs from waste streams at the end of their lifecycle. While there are noticeable strides towards the incorporation of 'circular design' principles and re-X strategies (which focus on reducing, reusing, recycling, repairing, and refurbishing), material demand increases similarly to the BAU scenario. This is, however, mitigated to some extent by the implementation of a comprehensive material recovery system.331
Key features of this technology-promoted recovery scenario include:

- 332
-
- 333
- This scenario uses a combination of forecasting and backcasting methods to envision the future.
 - The backcasting method is used for scenario factors that are covered by governmental targets, starting with the desired outcome and working backwards to the present.
 - 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.
 - EU targets for recycling and recovery are met, due to the EU's waste management system becoming more expansive, efficient and effective.
 - Technological innovation drives increased recovery rates of SRMs, enabling the more efficient use of waste.
 - Digitalisation and automation are more extensively used in recycling processes, leading to enhanced productivity and efficiency.
 - Business models like leasing and take-back schemes emerge, altering traditional consumption patterns (here, the focus is on take-back for recycling).
 - Ecodesign mandates are implemented, again, here, with a focus on end-of-life recovery.
 - There is greater exploration and exploitation of alternative sources such as urban mining, waste streams, and tailings, presenting novel opportunities for resource acquisition.
 - New waste regulations and guidelines for SRM recovery are implemented, enforcing better management and extraction of SRMs.
 - Investment in research and development for SRM recovery technologies experiences an upswing, promoting continuous innovation in this field.
 - Closer collaboration and information sharing between industry and government institutions (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.
- 334
-
- 335
-
- 336
-
- 337
-
- 338
-
- 339
-
- 340
-
- 341
-
- 342
-
- 343
-
- 344
-
- 345
-
- 346
-
- 347
-
- 348
-
- 349
-
- 350
-
- 351
-
- 352
-
- 353
-
- 354
-
- 355
-
- 356
-
- 357
-
- 358
-
- 359

361

Scenario III: Circularity

362

363
See section 3.3 for the full scenario description and the waste-stream-specific scenario impact narratives.364
365
366
367
368
369
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).370
371
372
373
374
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.375
376
377
378
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.379
The circular economy scenario is characterised by the following:

- 380
-
- 381
-
- 382
-
- 383
-
- 384
-
- 385
-
- 386
-
- 387
-
- 388
-
- 389
-
- 390
-
- 391
-
- 392
-
- 393
-
- 394
-
- 395
-
- 396
-
- 397
-
- 398
-
- This scenario uses a combination of forecasting and backcasting methods to envision the future.
 - The backcasting method is used for scenario factors that are covered by governmental targets, starting with the desired outcome and working backwards to the present.
 - 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.
 - EU targets for recycling and recovery are met, as are those for circularity, due to advances in waste management, ecodesign and re-X strategies.
 - A circular economy is implemented, prioritising waste reduction, resource efficiency, and a shift from the 'take-make-dispose' model.
 - A notable increase in SRM recycling and recovery rates, indicating an efficient use of resources.
 - A larger emphasis on designing products for reuse and recycling, making waste a valuable resource rather than a problem.
 - More extensive use of renewable energy and clean technologies in SRM production and use, supporting a low-carbon economy.
 - Collaboration between stakeholders — including industry, government, and consumers — improves, enhancing the implementation of circular practices.
 - New business models like leasing and take-back schemes emerge, altering traditional consumption patterns [20].

- 399 • Digitalisation and data use are heightened to improve efficiency and traceability, aiding in
400 effective resource management.
 - 401 • Investment in research and development for circular economy technologies increases, driving
402 innovation and adoption.
 - 403 • Awareness and education around sustainable consumption and production practices are ampli-
404 fied, leading to behavioural changes in society.
 - 405 • Reliance on imports decreases, suggesting greater self-sufficiency and sustainability.
 - 406 • The creation of new jobs within the recycling, recovery and re-X sectors boosts the economy
407 and alleviates social inequality.
 - 408 • Stricter waste regulations and product design guidelines are introduced, accelerating the transi-
409 tion towards circularity.
-
- 410
-
- 411
-

IX. ABBREVIATIONS

Table 1.2: List of abbreviations

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

Continued on next page

Table 1.2 – Continued from previous page

ACRONYM	DEFINITION
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

413

X. TERMINOLOGY (ABBREVIATED)

414

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

415

Table 1.3: List of terminology (abbreviated)

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

XI. DESCRIPTION OF FUTURAM WORK PACKAGE 2

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

More information can be found in the grant agreement [21], the consortium agreement [22], the project management plan [23] and the Milestone 6 report [24].

DELIVERABLE

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

XI.1. Objectives

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

Context

Source: [21]

MODELLING THE FUTURE OF WASTE GENERATION AND SRM RECOVERY

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

OPEN SCIENCE

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

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

449 the use of the EC and respecting FutuRaM's open science principles.

450 **GENDER**

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

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

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

461 **XII. TASK DESCRIPTIONS**

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

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

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

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

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

F
490

XII.1. Interconnection with other work packages in FutuRaM

REVIEW NOTICE

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

491

492

⁴⁹³Figure 1.1 shows the interconnection between WP2 and the other work packages in FutuRaM [21].

Back to ToC

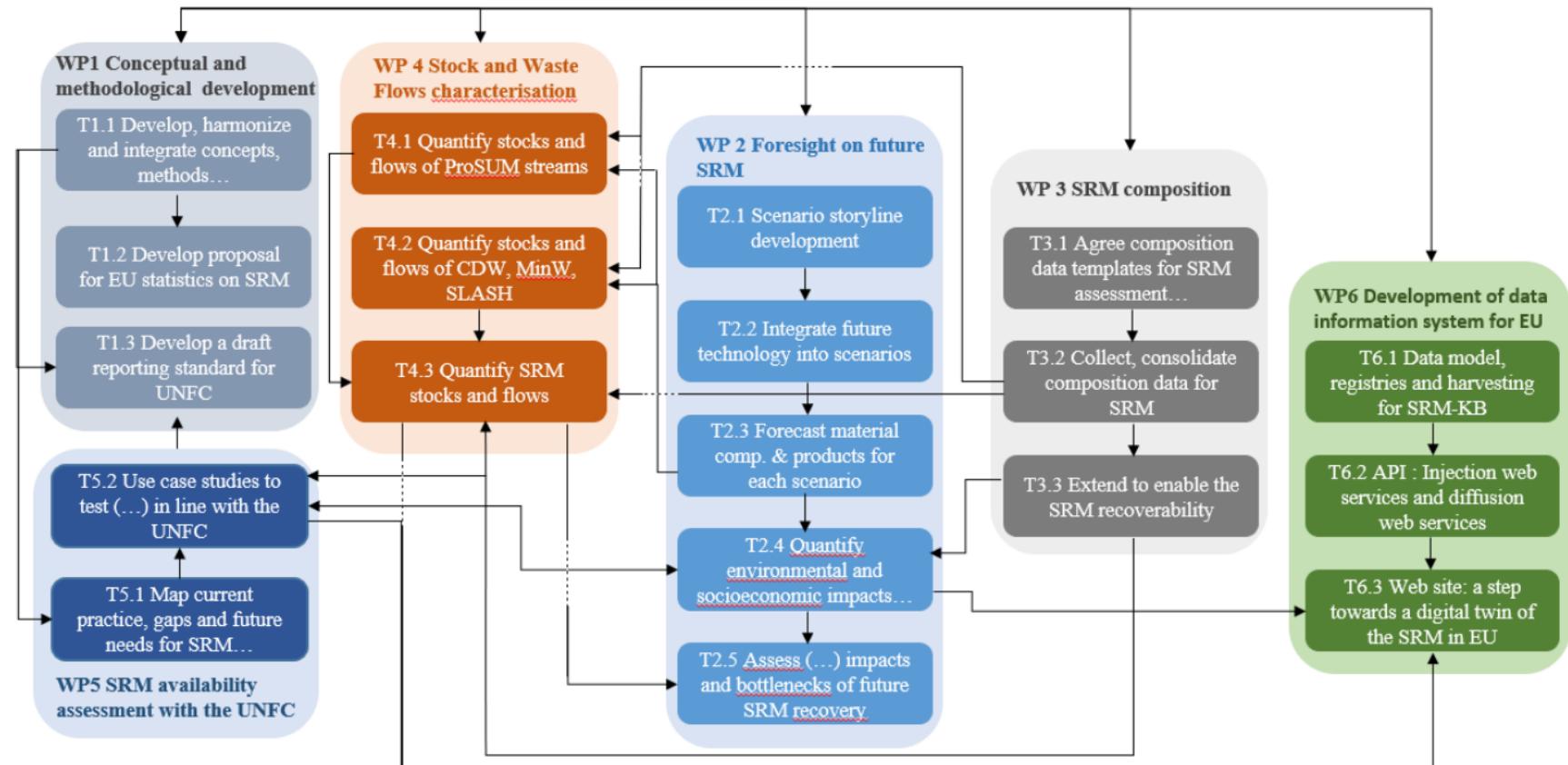


Figure 1.1: Interconnection between WP2 and the other work packages in FutuRaM

XII.2. Work package two milestones

Table 1.4: WP2.1 – Milestone list

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

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

Table 1.5: WP2.1 – Subtask list

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

XII.4. Consortium partner contributions to WP2

Table 1.6 lists the consortium partner contributions to WP2, in terms of person months for each sub-task. The table is based on the FutuRaM grant agreement [21].

WP #	WP Name	Total PMs	Task No.	Start	End	ALL TASKS	WEEE Forum UNITAR BRGM Chalmers GTK LMU RECHARGE SGU TUB Leiden Uni VITO Empa UCL												Total	
							3	19	8	10	2	12	1	1	21	28	4	8	7	
2	Foresight on Secondary Raw Materials	151.0	2.1	2022-06-01	2023-11-30	Develop scenario storyline	1	5	1	2				.5	2	1		1	13.5	
			2.2	2022-08-01	2024-01-30	Integrate future technologies into the scenarios	1	4	2	6	1	1	.5	.5	6	1	2	1	3	29
			2.3	2022-12-01	2024-01-30	Forecast material composition and products for each scenario	1	4	2	2	1		.5		8	4	2	2		26.5
			2.4	2023-11-01	2025-05-31	Quantify environmental and socioeconomic impacts of SRM recovery under each scenario		2	2			11			2	11		3	4	35
			2.5	2025-06-01	2026-04-30	Assess the environmental and socioeconomic impacts and bottlenecks of future SRM recovery			4	1					3	11		1		20

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

500



501



502



503



504

Methodology

505

CHAPTER CONTENTS

506	2.1	The conceptual framework for scenario development	2
507	2.2	Scenario storyline development process	3
508	2.2.1	Step 1: Define the scope and objectives	3
509	2.2.2	Step 2: Determine methodology	10
510	2.2.3	Step 3: Marker-scenario mapping	15
511	2.2.4	Step 4: Identification of key drivers of change	16
512	2.2.5	Step 5: Develop storyline themes	26
513	2.2.6	Step 6: Qualitative narrative development	26
514	2.2.7	Step 7: Definition of scenario parameters	26
515	2.2.8	Step 8: Quantitative modelling	26
516	2.2.9	Step 9: Implementation	26
517	2.2.10	Step 10: Review process	27



2.1. THE CONCEPTUAL FRAMEWORK FOR SCENARIO DEVELOPMENT

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

The scenarios should:

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

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

2.2. SCENARIO STORYLINE DEVELOPMENT PROCESS

Building scenarios involves several steps and various methodologies, these will differ depending on the specific context and objectives of the exercise [5–9, 25–28].

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

2.2.1. Step 1: Define the scope and objectives

Scope and objectives of the scenario development process

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

Aim of FutuRaM:

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

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

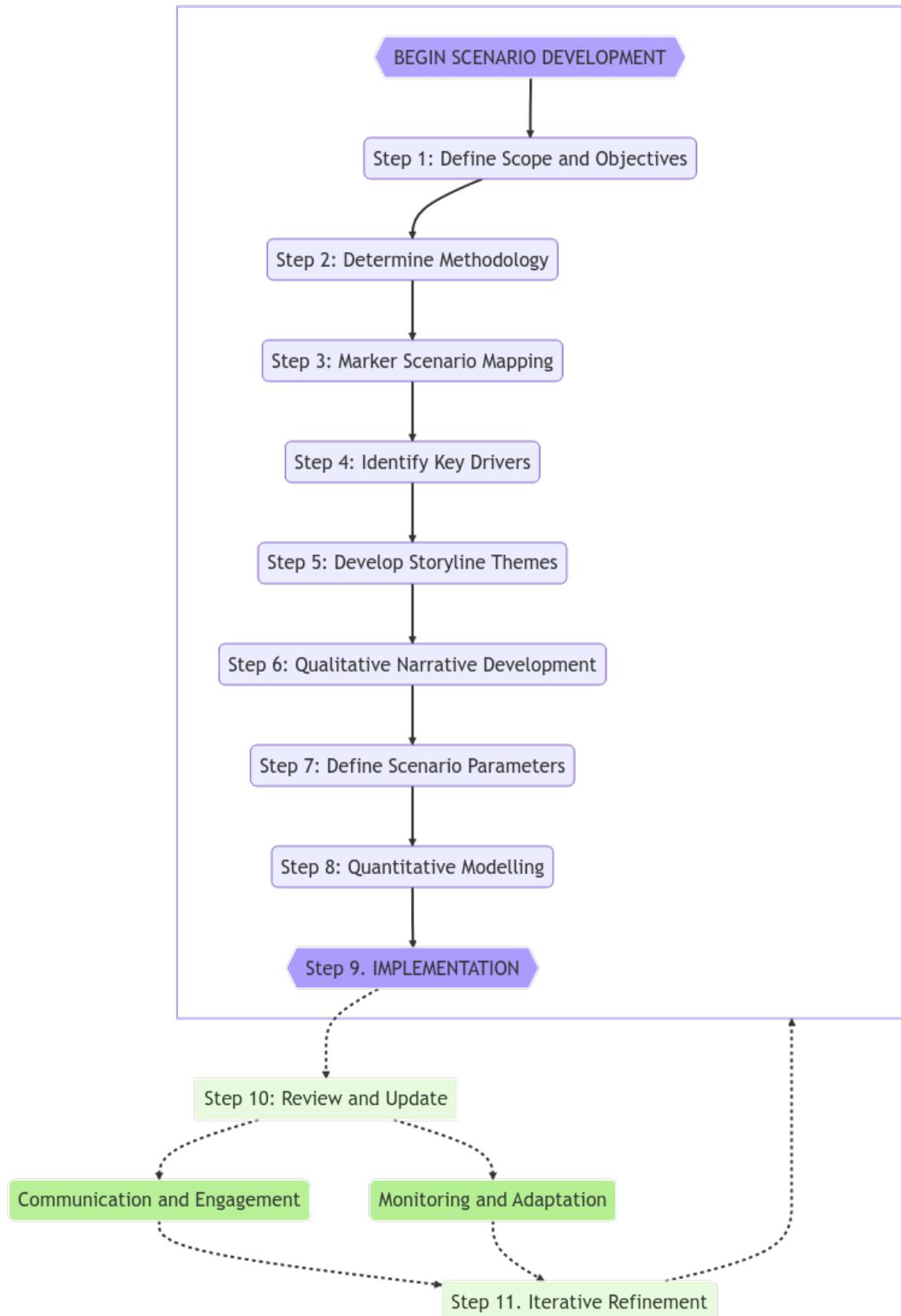


Figure 2.1: Scenario storyline development process

Table 2.1: Selected objectives of the FutuRaM project

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

590

advancements.

591

Thematic scope

592

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.

593

594

595

596

597

Geographic scope

598

599

600

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.

601

602

603

604

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

605

Temporal scope

606

607

608

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.

609

610

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

611

612

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

613

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, 29, 30].

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 [31] 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 [32–37].

GENERAL POLICIES AND LEGISLATION

The EU Green Deal [31] 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 emphasis on investments towards building local, 'sustainable' industries.

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

The EU Circular Economy Action Plan [15] is a policy framework developed by the

639 European Commission to promote the circular economy in the European Union.

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

645 **The Circular Economy Action Plan:**

- 646 • Aims to promote the transition to a more circular economy in the EU.
- 647 • Sets out a range of measures to promote the sustainable use of resources,
648 reduce waste, and increase recycling.
- 649 • Includes proposals for new legislation, such as an EU-wide framework for the
650 circular economy, and revisions to existing legislation, such as the WEEE Direc-
651 tive.
- 652 • Emphasises the importance of product design for the circular economy and
653 proposes measures to promote eco-design and repairability.
- 654 • Includes initiatives to promote the use of secondary raw materials, such as the
655 establishment of a European Raw Materials Alliance.
- 656 • Aims to reduce greenhouse gas emissions and improve resource efficiency in
657 the EU.
- 658 • Calls for increased cooperation and dialogue among stakeholders in the circu-
659 lar economy.

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

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

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

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

- 671 • Extract at least 10% of the EU's annual consumption
- 672 • Process at least 40% of the EU's annual consumption
- 673 • Recycle at least 15% of the EU's annual consumption

674 These benchmarks have been included in the scenarios developed in FutuRaM. Specif-

675
676
677
ically, in the Recovery scenario (REC), where the emphasis is on the recovery of materials
from waste streams, and the Circularity scenario (CIR) where the emphasis is on the
implementation of 're-X' strategies, such as recycling, remanufacturing, and reuse.

678
679
680
681
682
Many of these targets, benchmarks and mandates — despite being included in legis-
lation — are considered too optimistic to be included in the Business-as-usual scenario
(BAU) as they often make expectations whose attainment is likely highly unrealistic with-
out radical reform of the waste management system. For example, the targets in the
Battery Act suggest near-complete recovery for several elements [37].

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

684
685
686
687
688
The targets that result from the planned and ongoing review processes are non-negotiable
and legally binding and thus should be incorporated into our scenarios. These targets,
however, are only applicable to post-consumer products, namely WEEE, BAT and ELV.
This envisioned future in which legally binding targets for collection, reuse and/or material
recycling are achieved can be implemented as the Recovery scenario.

689
690
691
692
693
If there are no targets set for a specific consumer product category, then approach
targets similar to the WEEE directive and in line with the EU Green Deal. For the Recovery,
and especially for the Circularity scenario, FutuRaM will also consider the effects of pro-
posed ecodesign requirements for sustainable products (e.g., longer lifetimes, increased
reusability, repairability, recyclability).

694
695
696
697
However, for waste that does not consist of discarded consumer products, but instead
results from industrial production activities, in particular for MIN and SLASH, we must still
produce specific scenarios related to mining, metallurgy, and waste and fuel combustion.
The production of new mining wastes will depend on new local mining activity.

698
699
700
701
702
Predicted production in the EU until 2050 will be forecast (equally across the three
scenarios) and the flows into the MIN waste stream can be calculated with the respective
transfer coefficients. The recovery of historical MIN stock, which is a target of the CRM Act,
should be modelled differently. It requires a hypothesis about the percentage of historical
tailings recoverable by commodity and country.

703
704
705
706
707
708
The scenarios will account for increasing resource use effectiveness and production
process efficiency thus indicating lower volumes and quality of generated production
residues (both by-products and waste such as red mud, waste rock, slags, etc.) per unit of
product (expressed either as product mass or product value), whether that product is a
metal (e.g., a copper cathode), metal alloy (e.g., aluminium alloy n° 5183) or metal product
(e.g., cold rolled stainless steel sheet).

709
710
Excepting the BAU storyline, WEEE, ELV, and BATT waste material recovery will follow
the targets in the EU.

711
712
For SLASH and MIN, we will evaluate recent trends in waste generation and extract
plausible ranges of generation toward 2050.

713 For CDW, embedded WEEE will follow EU targets, and bulk waste will incorporate sto-
714 rylines and scenarios that are congruent with predicted demolition rates (where renovation
715 is the alternative emphasised in the CIR storyline).

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

719 ***Consideration of geopolitical developments***

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

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

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

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

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

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

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

747 However, '...most experts predict that reshoring or nearshoring will be of limited
748 importance. With time, though, resilience may improve through international cooperation,
749 diversification and the accelerated uptake of digital technologies.' [38]

750 **Note: supply constrictions will be considered in the model's sensitivity analysis and**

751
752
**the codebase will be designed to allow for the optimisation of the SRM recovery system
based on any supply-demand value statements.**

753 2.2.2. Step 2: Determine methodology

754 ***Methodology types and selection criteria***

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

759 **Relevance:**

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

762 **Applicability:**

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

765 **Feasibility:**

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

768 **Transparency:**

769 The methodology should be transparent and well-documented, allowing for repli-
770 cation and further analysis.

771 **Flexibility:**

772 The methodology should be flexible and adaptable, allowing for updates and ad-
773 justments as new information becomes available.

774 **Accessibility:**

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

777 **Effectiveness:**

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

780 **Efficiency:**

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

783 **Acceptability:**

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

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

790 **Choice of methodology**

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

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

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

800 **Considered dimension — Energy transition:**

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

805 **Method — Multi-criteria analysis and cross-impact analysis**

806 In order to assess the potential inclusion of these additional scenario dimensions, a
807 multi-criteria analysis and a cross-impact analysis were conducted [39]. The addition of
808 extra dimensions increases the possible number of scenarios significantly. By assessing
809 the consistency and plausibility of these combinations with a matrix-based method, it
810 was possible to reduce the number of scenarios.

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

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

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

Method — Delphi

The Delphi method [40] was used in the initial stages of the scenario-building process to gather and aggregate the opinions of experts or stakeholders. Internal consultation with consortium members who were experts in their respective waste streams or other aspects of the recovery system was conducted.

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

Choice of Scenario Type

The general types of scenarios are summarized in Table 2.3. In the context of futures studies, various approaches and methodologies are employed to understand the potential trajectories of future developments [6–8, 25–27].

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

867 In practice, a combination of qualitative and quantitative techniques can be employed
868 to create scenarios tailored to specific needs. For instance, a blend of techniques may
869 be used to generate forecasts, especially when external factors are uncertain. Likewise,
870 strategic scenarios often begin with external scenario generation and proceed to identify
871 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

872
873
The scenarios developed in the FutuRaM project are a combination of predictive and normative:



BAU:

874
875
876
877
878
What will happen if current trends continue?

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



Recovery:

880
881
882
883
What will it take to achieve the EU's targets for material use and recovery? Focus on technology

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



Circularity:

884
885
886
887
888
889
What will it take to achieve the EU's targets for material use and recovery? Focus on re-X strategies

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

890
891
892
The methodology and scenario types were selected based on their relevance, applicability, feasibility, transparency, flexibility, accessibility, effectiveness, efficiency, and acceptability to the scenario development process.

893 2.2.3. Step 3: Marker-scenario mapping

894 **Justification and methodology**

895
896
897
898
899
900
This preliminary step in the scenario development process involves conducting a literature study to identify existing scenarios that are relevant to the FutuRaM project. This step is crucial as it serves several important purposes and provides valuable insights for the overall scenario development process. It helps the scenario development team to build on existing knowledge, identify relevant scenarios, gain insights and inspiration, fill knowledge gaps, and enhance credibility and comparability.

901 **Building on existing knowledge:**

902
903
904
905
906
907
Conducting a literature study allows the FutuRaM project team to tap into existing knowledge and expertise in the fields of waste management, resource recovery, and circular economy. It provides a foundation of existing scenarios that have been developed by other researchers, organizations, or institutions. By building on this existing knowledge, the FutuRaM project can leverage the insights, methodologies, and findings from previous scenario studies, saving time and resources.

Identifying relevant scenarios:

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

Gaining insights and inspiration:

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

Filling knowledge gaps:

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

Enhancing credibility and comparability:

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

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

Table 13.4 in section 13.4 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.

2.2.4. Step 4: Identification of key drivers of change

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

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

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

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

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

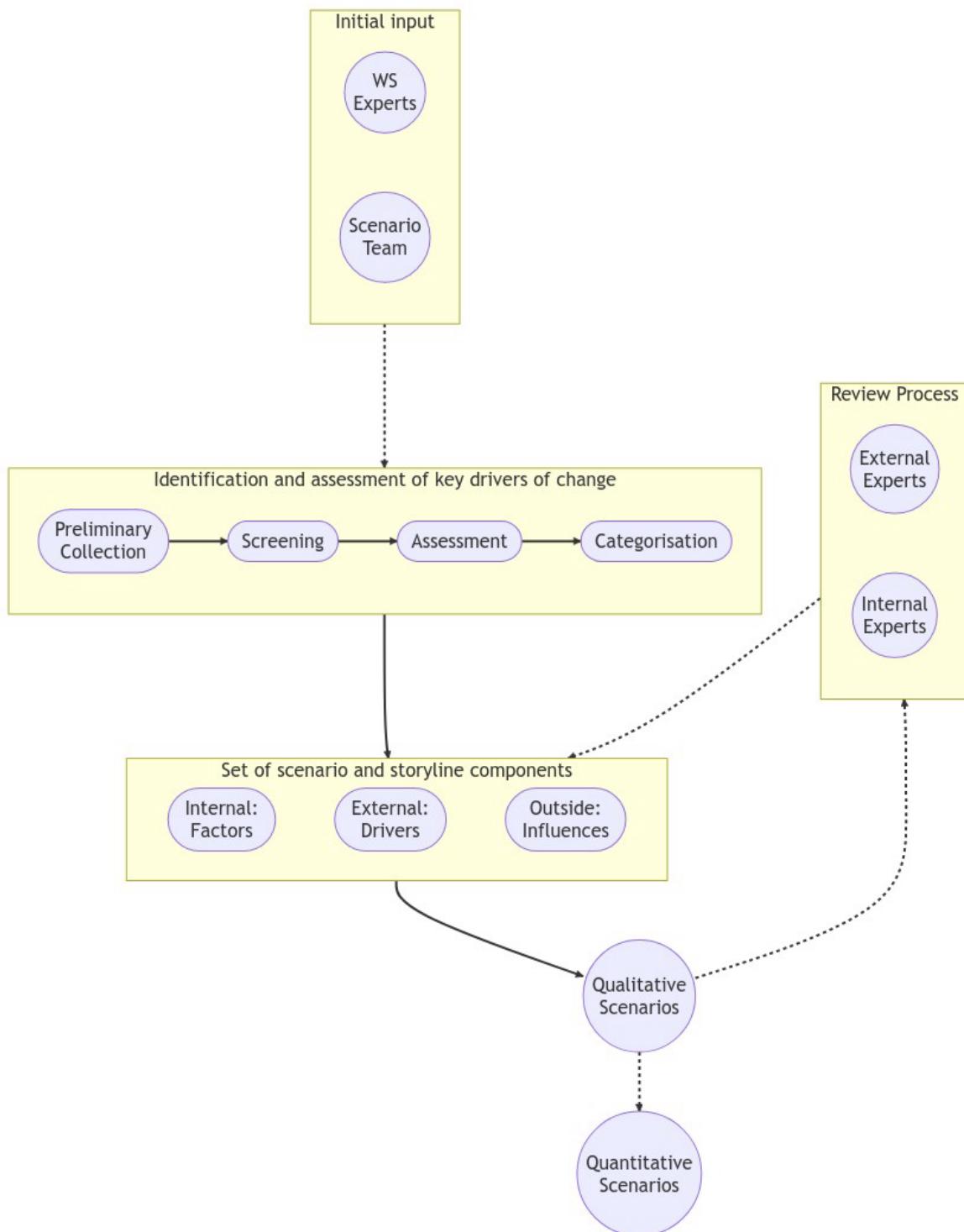


Figure 2.2: An illustration of the process used for identifying key drivers of change

956
957

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

958
959

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

960
961
962

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

963

1. Preliminary collection:

964
965

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

966
967
968

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

969
970
971

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

972
973

A PESTEL analysis can help identify opportunities and threats linked to each of these factors, understand the broader context, and shape scenarios accordingly [41, 42].

974

The acronym PESTEL stands for:

975
976
977

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

978
979
980
981

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

982
983
984
985

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

986
987
988

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

989
990
991

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

992
993
994

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

995

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

2. Screening:

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

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

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

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

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

F

Back to ToC

WP2: Scenario Storylines | www.futuram.eu | 21

3. Assessment:

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

The 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	BAI	REC	CIR
TECH	Recovery technology	Implementation and advancements in waste recovery technologies	TRUE	I	III	III
TECH	Product technology	Changes in product function or composition	TRUE	I	III	III
TECH	Integration of SRM system across EU	Integration of a secondary raw material recovery system across EU countries	TRUE	I	III	III
ENV	Increased drive for environmental protection	Growing concern and motivation for environmental conservation	TRUE	I	III	III
ECO	Progress toward renewable energy targets	Advancements and achievements in renewable energy generation	TRUE	III	III	III
ECO	Subsidies and taxation to promote circularity	Financial incentives or taxes to encourage circular economy	TRUE	I	II	III
SOC	Participation in re-X activities	Engagement in refuse-reduce-repair-reuse activities	TRUE	I	I	III
POL	Stricter environmental regulations	Tightening of environmental laws and regulations	TRUE	II	III	III
POL	Stricter waste management regulations	Strengthening of waste management laws and regulations	TRUE	II	III	III
POL	Supply chain due diligence laws: implementation and enforcement	Obligations for identifying and mitigating negative impacts in supply chains	TRUE	I	III	III
POL	Compliance with waste targets	Meeting specific waste management and recycling targets	TRUE	I	III	III

Continued on next page

Table 2.4 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTER	BAI	REC	CIR
ENV	Resource shortages	Limited availability of natural resources	FALSE	n/a	n/a	n/a
ECO	Raw material vs SRM prices	Price dynamics and competition between raw materials and secondary raw materials	FALSE	n/a	n/a	n/a
ENV	Climate change impactsmitigation	Effects and actions related to climate change	FALSE	n/a	n/a	n/a
ECO	International trade and co-operation (vs. autarky)	Collaborative trade agreements and global cooperation	FALSE	n/a	n/a	n/a
ECO	Energy prices	Costs and fluctuations in energy prices	FALSE	n/a	n/a	n/a
ECO	Economic growth	Overall economic expansion and development	FALSE	n/a	n/a	n/a
ECO	Re-industrialisation of EU	Shift towards increased industrial activities in the EU	FALSE	n/a	n/a	n/a
SOC	NIMBY to projects	Opposition to local projects and developments	FALSE	n/a	n/a	n/a
SOC	Population and urbanisation	Growth and urban development of population	FALSE	n/a	n/a	n/a
ECO	CO2 market price	Price and market dynamics of carbon emissions	FALSE	n/a	n/a	n/a

4. Categorisation

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

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

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

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

Justification for keeping certain elements outside of the scenario models:

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

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

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

Examples:

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.

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.

2.2.5. Step 5: Develop storyline themes

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.

2.2.6. Step 6: Qualitative narrative development

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.

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

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



1126



1127

Scenario storylines

1128

CHAPTER CONTENTS

1129	3.1 Scenario I: Business-as-usual	29
1130	3.1.1 Context	29
1131	3.1.2 Storyline narrative	29
1132	3.1.3 Waste stream specific scenario impacts	32
1133	3.2 Scenario II: Recovery	37
1134	3.2.1 Context	37
1135	3.2.2 Storyline narrative	37
1136	3.2.3 Waste stream specific scenario impacts	40
1137	3.3 Scenario III: Circularity	46
1138	3.3.1 Context	46
1139	3.3.2 Storyline narrative	47
1140	3.3.3 Scenario needs and impacts	49
1141	3.3.4 Waste stream specific scenario impacts	51



3.1. SCENARIO I: BUSINESS-AS-USUAL

1142

1143



1144

3.1.1. Context

“

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

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

— Julian Lincoln Simon in *The Ultimate Resource* [43, 44]

”

1145

1146

“

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

— Paul Ehrlich [45], see also [46–48]

”

1147

1148

1149

3.1.2. Storyline narrative

1150

1151

1152

1153

1154

1155

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 [49]. 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.

1156

1157

1158

1159

1160

1161

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.

1162

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 (see Figure 3.1). 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.

Linear economy

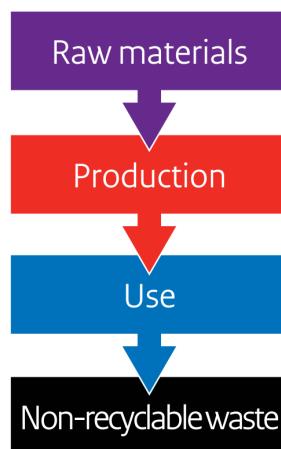


Figure 3.1: The linear economy model in the business-as-usual scenario [50]

Moreover, the environmental impacts of mining and extraction persist as a significant concern. These operations continue to degrade ecosystems, leading to loss of biodiversity and contributing to climate change [51]. Simultaneously, the EU becomes increasingly dependent on imports of SRMs, raising concerns about supply chain security and geopolitical risks [51].

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

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.

1190 In essence, the BAU scenario is characterised by a continuation of current trends and
1191 practices, a future where the potential for a sustainable SRM system is unrealised due to
1192 the stranglehold of prevailing economic, social, and political constraints.

1193 In the Business-as-usual (linear economy) scenario, the following are key characteris-
1194 tics:

- 1195 • A forecasting model is used to predict the future based on the current situation
1196 and the development of existing trends.
 - 1197 • Many EU targets for recycling and recovery are not met, and the current linear
1198 model largely persists.
 - 1199 • Material demand keeps pace with GDP growth, perpetuating a trend of increas-
1200 ing consumption. Primary mining and extraction persist as the leading sources
1201 of raw materials, underlining the dependency on traditional extraction meth-
1202 ods.
 - 1203 • Recycling and recovery rates continue to lag, leading to an accumulation of
1204 SRM waste that signals missed opportunities for resource reuse.
 - 1205 • The environmental repercussions of mining and extraction, such as land degra-
1206 dation and water pollution, continue to be a pressing concern, reflecting the
1207 ecological toll of this linear model.
 - 1208 • The EU's dependency on imports of SRMs escalates, heightening the risk of
1209 supply disruptions. While supply disruption can serve to stimulate investment
1210 in new SRM recovery, volatility stifles innovation and advancements in this
1211 field.
 - 1212 • The industrial focus remains on cost-effective material production and use, dis-
1213 regarding the long-term sustainability aspect.
-

3.1.3. Waste stream specific scenario impacts

BATT (Battery waste)

Sources: [13, 14, 36, 37]

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

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

ELV (End-of-Life Vehicles)

Sources: [14, 35, 52–55]

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.

- 1247 • Consumer demand continues to drive high production of new vehicles.
- 1248 • ELV collection systems remain at their current efficiency.
- 1249 • A significant proportion of vehicle components continue to end up as waste.
- 1250 • Gradual and slow improvement of recycling chain technology efficiency
- 1251 • No new legislation to improve recovery and support circular strategies in com-
- 1252 parison to 2023



WEEE (*Waste Electrical and Electronic Equipment*)

Sources: [33, 34, 56–59]

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.

- 1258 • Limited improvements in the recovery of valuable materials from WEEE.
- 1259 • High consumer demand for new electronics continues to drive high WEEE
- 1260 generation.
- 1261 • Ineffective collection systems and lack of public interest result in significant
- 1262 amounts of WEEE ending up in landfills.
- 1263 • No significant growth in collaboration between government and industry for
- 1264 WEEE recovery.
- 1265 • The majority of WEEE continues to be treated with common domestic waste,
- 1266 with low recycling rates.
- 1267 • No groundbreaking technologies and practices to improve recovery and circu-
- 1268 larity.
- 1269 • Reuse of products and components is not widely utilised
- 1270 • Changes in legislation (e.g., circular economy and product design targets, tar-
- 1271 gets for collection and recycling) are not strictly implemented.
- 1272 • The BAU and the REC scenarios are similar from the put-on-market perspec-
- 1273 tive (e.g., production and consumption remain the same), but it's the recovery
- 1274 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.



- 1280 • Limited technological advancements lead to static recovery rates of valuable
1281 materials from mining waste.
- 1282 • Continued reliance on primary extraction as the dominant source of raw mate-
1283 rials.
- 1284 • Minimal advances in collaboration between government and industry for min-
1285 ing waste recovery.
- 1286 • Low levels of traceability and management of mining waste.
- 1287 • Mining waste remains a significant environmental challenge.
- 1288 • Mining waste recovery projects remain too expensive.
- 1289 • Little incentive for the private sector and public sector, except for monitoring
1290 environmental risks of existing deposits.



CDW (Construction and Demolition Waste)

Sources: [60]

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

- 1295 • Focus on new construction to meet demand, no changes in CDW generation
1296 rate.
- 1297 • No increase or refurbishment or renovation activities relative to new construc-
1298 tion rates.
- 1299 • Continue meeting the 2020 EU target from the Waste Directive [60] of 70%
1300 CDW recovery (including preparation for re-use, recycling, and other material
1301 recovery, including backfilling)
- 1302 • Recovery of metals remains on already high levels (90%) [61].
- 1303 • Recovery of minerals remains on already high levels (70%) by using them as
1304 aggregates in road construction and backfilling [61].
- 1305 • Recycling of wind turbines stays around 85% (mainly metals), permanent
1306 magnets continue to be recycled as part of the metal fractions.[CITATION]
- 1307 • Base metals are recovered as they have been, though there are limited im-
1308 provements in recovery technologies and regulatory incentives.
- 1309 • Repowering trends for wind turbines persist.
- 1310 • Excluding wind turbines, there is no particular focus on the recovery of CRMs
1311 from CDW, where they constitute only a small fraction of the total mass (e.g.,
1312 embedded in scrap steel).



SLASH (*Slags and Ashes*)

Sources: [62–66]

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.

SLAGS

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

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

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

Slags containing high concentrations of heavy metals are landfilled.

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

ASHES

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

The fractions that are rich in ferrous metals, aluminium, copper, and zinc are separated and used as input materials for the Fe, Cu, Zn, Al industries. By processing the Cu-rich fractions, PGMs, Ag, and Au are also recovered. The main part of the bottom ashes consists of mineral aggregates, which are used in the construction industry (when they are in line



1346 with the environmental criteria). In case the ashes are not treated (or only partly treated),
1347 they will be landfilled.

- 1348
- 1349 • In the last 10–20 years in some EU countries, we have seen a shift from land-
1350 filling towards incineration. This will lead to an increase in the volume of ashes
1351 from waste incineration.
 - 1352 • There was a drop in the use of coal as a fuel source, so the volume of coal
1353 ashes dropped over the last 10 years and is expected to drop further.
 - 1354 • At the same time the volume of biomass incineration went up. It is uncertain if
1355 this volume will increase in the future further (due to the high pressure on land
1356 that is needed to produce this biomass).
 - 1357 • Almost all coal fly ashes are used as SCM (high-value stream up to 80 EUR/-
1358 ton). For Biomass fly ashes there are no sorting facilities, while for waste incera-
1359 tion bottom ashes, there are sorting installations in place, but for the moment,
1360 they are not present in all EU countries, and therefore, there is still room for
improvement.

1361 •

1362

1363

3.2. SCENARIO II: RECOVERY

1364

1365



1366

3.2.1. Context

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

— Robert U. Ayres [67]

1367

1368

One does not require much of an imagination to picture how complex it is to physically and chemically separate these components again to ultimately retrieve the metals. **It's just about as difficult as recycling your morning cup of coffee into its ingredients...** There are no simple answers here — at some point, the amount of effort also outweighs the value of the metal content. This knowledge should prompt a consciousness shift in our utilization of our limited resources... **The inconvenient truth is that closing the loop is impossible!** Therefore, an honest discussion involves speaking transparently about losses in the process: in the form of energy, metals, and dust, for example. There are technological and economic limits to closing the loop.

— Prof. Dr. Dr. h.c. mult. Markus Reuter [68]

1369

1370

1371

3.2.2. Storyline narrative

1372

1373

1374

1375

1376

1377

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

material flow paths in the recovery scenario.

Reuse economy

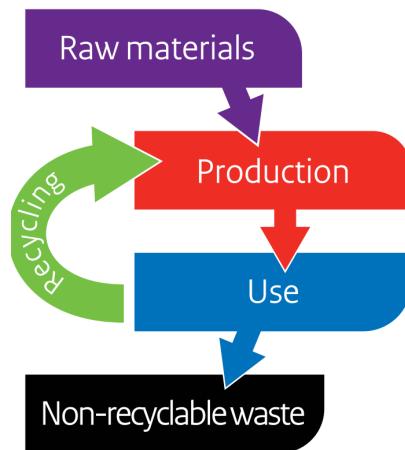


Figure 3.2: The reuse economy model in the recovery scenario [50]

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.

Key characteristics of this technology-promoted recovery scenario include:

- This scenario uses a combination of forecasting and backcasting methods to envision the future.
- The backcasting method is used for scenario factors that are covered by governmental targets, starting with the desired outcome and working backwards to the present.

- 1405 • The forecasting method is used for scenario factors that are not covered by
1406 governmental targets, starting with the current situation and extending to the
1407 future.
- 1408 • EU targets for recycling and recovery are met, due to the EU's waste manage-
1409 ment system becoming more expansive, efficient and effective.
- 1410 • Technological innovation drives increased recovery rates of SRMs, enabling the
1411 more efficient use of waste.
- 1412 • Digitalisation and automation are more extensively used in recycling pro-
1413 cesses, leading to enhanced productivity and accuracy.
- 1414 • There is greater exploration and exploitation of alternative sources such as
1415 urban mining, waste streams, and tailings, presenting novel opportunities for
1416 resource acquisition.
- 1417 • New waste regulations and guidelines for SRM recovery are implemented,
1418 enforcing better management and extraction of SRMs.
- 1419 • Investment in research and development for SRM recovery technologies expe-
1420 riences an upswing, promoting continuous innovation in this field.
- 1421 • Closer collaboration and information sharing between industry and govern-
1422 ment institutions streamline processes and expedite decision-making.
- 1423 • New jobs are created in the recycling and recovery sector, offering economic
1424 benefits and improving overall employment rates.
- 1425 • SRM production and use become more efficient and cost-effective, fostering
1426 economic sustainability.
- 1427 • Environmental impact from mining and extraction is reduced, signalling a
1428 more sustainable approach to resource acquisition.
- 1429 • The EU's dependence on primary extraction is reduced, with SRM recovery be-
1430 coming a more significant source of raw materials.

3.2.3. Waste stream specific scenario impacts

BATT (Battery waste)

Sources: [13, 14, 36, 37]

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

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

- Material and composition selection for recycling [14].
- Higher requirements on disassemblability.
- Information available to promote efficient recovery.



ELV (*End-of-Life Vehicles*)

Sources: [14, 35, 52–55]

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

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





WEEE (Waste Electrical and Electronic Equipment)

Sources: [33, 34, 56–59]

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

- Advanced technologies enable higher recovery rates of valuable materials from WEEE
- Despite advancements in design for recyclability, WEEE generation remains high due to the consumer demand for new electronics
- Standardised and segregated collection systems for WEEE are implemented, improving the supply of materials for recovery
- Increased industry-government collaboration leads to further development in WEEE recovery technologies
- Consumer behaviour remains a significant hurdle for more efficient WEEE management
- Higher recycling rate — make full use of the disposed parts. For instance:
 - more automation of the dismantling and processing steps (e.g., AI)
 - recycling technologies improvements (e.g., small components recovery is also happening)
 - more effective collection infrastructure
 - financial support provided to recyclers/operators
 - bans on WEEE exports push for increased domestic recycling [69]
- ‘Design for recovery’ principle — Ecodesign mandates changes in weight and composition of EEE so complexity and the type of materials used
- Higher public awareness and participation on WEEE issue and management
- Higher compliance from the public, the producers and the businesses
- Strong regulations and monitoring are in place with higher collection and recycling targets which are set and implemented and fines are set for those who fail to achieve the targets
- Focus is given more to the EoL management of WEEE



MIN (Mining Waste)

Sources:

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



1537 source.

- 1538 • Technological advancements facilitate the extraction of valuable materials
1539 from mining waste.
- 1540 • Despite progress in recovery technologies, primary extraction remains the
1541 dominant source of raw materials due to high consumer demand.
- 1542 • Government and industry collaboration support the development of technolo-
1543 gies for the recovery of materials from mining waste.
- 1544 • Increased traceability and management of mining waste through digitalisation.
- 1545 • Mining waste remains a significant environmental challenge.

1546 CDW (Construction and Demolition Waste)

1547 Sources: [60]

1548 Under the recovery scenario, Construction and Demolition Waste (CDW) becomes
1549 an important resource for secondary raw materials, though mostly base metals and ag-
1550gregates. Despite some progress in eco-design and material efficiency, the construction
1551 industry continues to generate significant amounts of waste or 'downcycled' materials.
1552 Some progress in eco-design and material efficiency, but the construction industry con-
1553 tinues to generate significant amounts of waste or 'downcycled' materials.

- 1554 • Focus on new construction to meet demand, no changes in CDW generation
1555 rate.
- 1556 • No increase or refurbishment or renovation activities.
- 1557 • Enhancement of the quality of recycling to recover materials at higher value.
- 1558 • Increased investment and enhanced regulatory system in waste management,
1559 contributing to increased recovery.
- 1560 • Creation of new waste recovery infrastructure that improves recovery.
- 1561 • Widespread application of selective demolition and strict on-site waste sorting
1562 leading to an increase in recovery of waste.
- 1563 • Recovery of minerals is intensified with a stronger focus on closed-loop recy-
1564 cling (e.g., cement and aggregate are separated, aggregate is used, but cement
1565 is not treated).
- 1566 • Recovery of other materials like glass, plastics, and wood is also intensified.
- 1567 • Better separation of waste at source leads to a higher quality of secondary raw
1568 materials.
- 1569 • Repowering trends for wind turbines stay the same.
- 1570 • Improved recycling of wind turbine blades is notable, especially regarding plas-
1571 tics; permanent magnets are recycled at a functional level.



SLASH (*Slags and Ashes*)

Sources: [62–66]

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.

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

SLAGS

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

ASHES

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



1603 with a low landfill rate, and a high volume of incineration: this will lead to lower
1604 volumes of ashes, and a shift in the composition (with less CRM content in the
1605 ashes, due to better pre-sorting)

1606

1607

3.3. SCENARIO III: CIRCULARITY

1608

1609

1610

1611

1612

1613

1614

1615

1616



3.3.1. Context

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

— Ellen MacArthur Foundation [70]

A Circular Economy in the Netherlands by 2050!

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

... The Netherlands now has a circular economy.

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

— National Circular Economy Programme, Government of the Netherlands [71]

Circularity of the Dutch economy has barely increased

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

— CBS (Statistics Netherlands) [72]

The circular economy promises radical technological transformations in a couple of decades, "nothing less than to open up new and immense horizons for industry", "provide multiple value creation mechanisms", produce "better welfare, GDP, and employment outcomes" [70]. Looking at these claims, one wonders whether policymakers really believe that in 30 years EU citizens will live in an inclusive economy with zero waste, zero emissions, with a perpetual economic growth, continuously absorbing massive flows of immigrants while protecting and enhancing the ecological processes and environmental biodiversity.

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

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

— M. Giampietro and S.O. Funtowicz [73]

1617

1618

1619



3.3.2. Storyline narrative

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

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

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).

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

Further, being enabled by the widespread adoption of 'circular design' principles and improvements in information transparency (e.g., waste tracking and digital product pass-

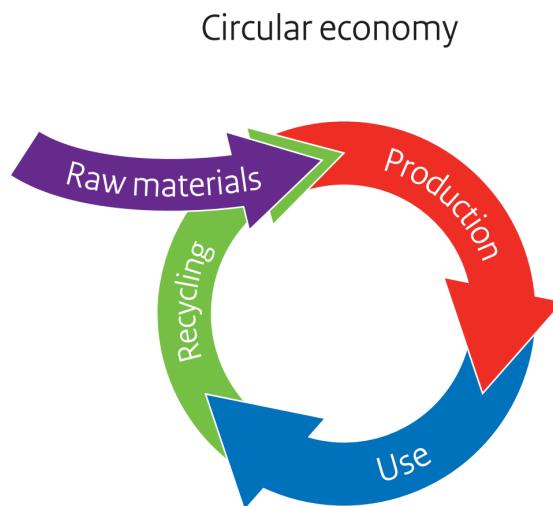


Figure 3.3: The simplified circular economy model in the circularity scenario [50]

ports) the system for the treatment of post-consumer waste can divert a significant amount of their inflows (to, for example, re-use and re-manufacture) with the residual fraction being readily segregated into purer, more efficiently recoverable, material streams.

This scenario envisions a future where government policies are in synergy with private sector innovation and societal changes, driving a wholesale transition towards a circular economy. Unlike the recovery scenario, where the focus is on the end-of-life recovery of materials, this scenario emphasises minimising waste at all stages, starting from the design phase itself, where both policymakers and designers are moving away from short-lived products towards products designed for longevity.

The emphasis is on re-X strategies that are integrated throughout the entirety 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

1668 allows for efficient management of waste flows, aiding in effective resource planning,
1669 while digital product passports provide information about a product's composition and
1670 how it can be properly disassembled, reused, or recycled. Material composition, including
1671 raw materials, is transparent to all involved in the value chain, promoting closer collabora-
1672 tion. Producers see the advantage of being open about their product details to aid in
1673 repair, repurposing, and recycling activities. This transparency about product components,
1674 durability, and reparability increases consumer demand for products that are designed to
1675 last and can be reused or recycled.

1677 3.3.3. Scenario needs and impacts

1678 In the proposed scenario, the European Union (EU) embarks on a pivotal transition towards
1679 a circular economy. This framework emphasises the retention of product, material, and
1680 resource value within the economic matrix for extended durations, simultaneously min-
1681 imising waste generation. This transition is integral to the EU's strategic goal of cultivating
1682 a sustainable, low-carbon, resource-efficient, and globally competitive economy.

1683 The implications of this shift are multifaceted. It presents an avenue for the EU to
1684 rejuvenate its economic architecture while providing businesses with a protective shield
1685 against challenges such as resource scarcity and price volatility. This revised economic
1686 model fosters the emergence of efficient, innovative production and consumption meth-
1687 ods, thus offering novel business opportunities. Moreover, the circular economy approach
1688 has palpable socio-economic benefits, including diverse job creation and enhanced social
1689 integration.

1690 From an environmental perspective, the transition aids in the reduction of the cumu-
1691 lative energy footprint and helps mitigate irreversible ecological damages. This encom-
1692 passes challenges related to climate shifts, biodiversity conservation, and comprehensive
1693 pollution control. Several studies accentuate the overarching benefits of this economic
1694 approach, highlighting potential reductions in prevalent carbon dioxide emissions.

1695 The successful implementation of this vision necessitates a collaborative approach
1696 involving various stakeholders, encompassing businesses, consumers, and regulatory
1697 entities. A robust regulatory framework is indispensable, designed to promote optimal
1698 practices and delineate clear progression benchmarks. This comprehensive framework
1699 encompasses the entirety of the circular economy's value chain, from production to
1700 consumption, extending into realms of repair, remanufacturing, and waste management,
1701 culminating in the reintroduction of secondary raw materials into the economic cycle.

1702 Environmental fiscal reforms are crucial for a circular economy transition. Taxes should
1703 pivot from labour to resource depletion, promoting a double dividend. The EU can leverage
1704 the VAT directive and the European semester process to endorse flexible rates on circular
1705 services like repair. It's imperative to abolish harmful subsidies, notably on fossil fuels,
1706 which are inherently linear and which Member States have pledged to eliminate. The

1707 tax framework should incentivise pioneers challenging the established linear economy.
1708 Analysing tax shifts at the national level can determine tax effectiveness and pinpoint
1709 instruments that best bolster circularity.

1710 The contribution of member states is paramount. They play a dual role, both in the
1711 actualisation of EU directives and in the integration of complementary regional initiatives.
1712 The principles of a circular economy possess global applicability, necessitating harmonised
1713 strategies within the EU and with external international partners. Such synergised ef-
1714 forts are crucial for the fulfilment of broader international commitments, notably the
1715 U.N. 2030 Agenda for Sustainable Development [74]. The ultimate objective remains
1716 the establishment of a sustainable future characterised by judicious consumption and
1717 production protocols.

1718

3.3.4. Waste stream specific scenario impacts

BATT (Battery waste)

Sources: [13, 14, 36, 37]

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, 35, 52–55]

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: [33, 34, 56–59]

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.



- 1789 • Service-based models for electronics promote the use of products as a service rather than ownership, reducing WEEE generation [20].
- 1790
- 1791 • Increased durability and lifespans.
- 1792 • Increased repairability.
- 1793 • More sharing and product-service systems, correspond to a reduction in the lifetime (for some equipment).
- 1794
- 1795 • More reuse practices (expanded second-hand market).
- 1796 • Less hoarding.
- 1797 • Higher formal collection and recycling rate.
- 1798 • Focus is given more to the production and use phase rather than the EoL (End-of-Life).
- 1799
- 1800 • 'Design for circularity' principle: Ecodesign mandates repairability, durability, no obsolescence, modularity, and that continual software upgrades are possible [75, 76].
- 1801
- 1802 • Electronically compatible chargers and battery packs can be used by different products.
- 1803
- 1804 • The above also means that chargers and batteries are not integrated into the product and that the product is designed to be easily disassembled.
- 1805
- 1806 • 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.
- 1807
- 1808 • Support and development of circular strategies infrastructure (e.g., easy information access for repairability, repair shops, accessibility to spare components on the market, etc.).
- 1809
- 1810 • Greater use of connected products, smart technologies, and the IoT. Used to monitor and diagnose product performance in situ which, can extend product and component life.
- 1811
- 1812
- 1813
- 1814
- 1815



MIN (Mining Waste)

Sources:

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

- 1818 • A Decrease in primary mining reduces the generation of mining waste.
- 1819
- 1820 • Advanced technologies are employed to extract valuable materials from mining waste.
- 1821

- Policies and regulations incentivise the reuse of mining waste in various applications.
- Digital solutions improve tracking and management of mining waste.
- Collaboration between stakeholders promotes circular practices in the mining industry.



CDW (Construction and Demolition Waste)

Sources: [60]

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

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



SLASH (Slags and Ashes)

Sources: [62–66]

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



- 1859 • Digital solutions enhance the traceability and management of SLASH.
- 1860 • More functional collection infrastructure.
- 1861 • Financial support provided to recyclers/operators.
- 1862 • Introduction of SRM/CRM recovery targets. For example, recovery of P from biomass ash for fertiliser.
- 1863 • Higher awareness and participation of relevant sectors on SLASH issues and management.
- 1864 • Strong regulations and monitoring are in place with higher collection and recycling targets.
- 1865
- 1866
- 1867

1868 SLAGS

- 1869 • Advanced recovery technologies allow for the extraction of valuable metals and minerals from slags.
- 1870 • New recovery technologies are installed in the metallurgical industry.
- 1871 • All metals are recovered from the slags, and the slag itself only contains minerals or metals as trace elements.
- 1872 • Due to the low metal content, the slags are ideal resources for the construction industry.
- 1873
- 1874
- 1875

1876 ASHES

- 1877 • New recovery technologies are installed in the incineration industry.
- 1878 • We expect a shift in the volume and quality of the ashes.
- 1879 • Coal fly ashes are the same as in BAU reducing over time to almost zero.
- 1880 • Biomass ashes have the same volume and quality.
- 1881 • Waste incineration ashes: due to the recovery scenario there will be a shift from landfill and incineration towards recycling, reuse, and repair. In countries with a high landfill rate, this will lead to higher volumes of ashes. In countries with a low landfill rate, and a high volume of incineration: this will lead to lower volumes of ashes, and a shift in the composition (with less CRMs in the ashes, due to better pre-sorting)
- 1882
- 1883
- 1884
- 1885
- 1886

1887



1888



1890



1891

Quantification

1892

CHAPTER CONTENTS

1893	4.1 Introduction	59
1894	4.1.1 Quantification and Implementation of scenario elements in the	
1895	models	60
1896	4.2 Summary	67
1897	4.3 External elements	68
1898	4.3.1 Introduction	68
1899	4.3.2 Summary	71
1900	4.3.3 Demographic factors: <i>Population, age, urbanisation</i>	74
1901	4.3.4 Economic factors: <i>GDP growth</i>	86
1902	4.3.5 The Renewable Energy Transition	94
1903	4.3.6 Supply constraints and market dynamics	111
1904	4.3.7 Conclusion	118
1905	4.4 Internal elements — Technological Change	119
1906	4.4.1 Introduction	119
1907	4.4.2 Methodology	120
1908	4.4.3 Summary	121
1909	4.4.4 Future product and waste composition: <i>Description</i>	122



1910	4.4.5 Future product and waste composition: <i>Scenarios</i>	124
1911	4.4.6 Future recovery technology: <i>Description</i>	128
1912	4.4.7 Future recovery technology: <i>Scenarios</i>	131
1913	4.4.8 Future recovery system: <i>Description</i>	135
1914	4.4.9 Future recovery system: <i>Scenarios</i>	137
1915	4.5 Internal elements – The Circular Economy	142
1916	4.5.1 Introduction	142
1917	4.5.2 Summary	150
1918	4.5.3 The EU Circular Economy Indicators: <i>Description</i>	151
1919	4.5.4 The EU Circular Economy Indicators: <i>Scenarios</i>	159
1920	4.5.5 Refuse, Reduce, Reuse: <i>Description</i>	163
1921	4.5.6 Refuse, Reduce, Reuse: <i>Scenarios</i>	165
1922	4.5.7 Repair: <i>Description</i>	169
1923	4.5.8 Repair: <i>Scenarios</i>	177
1924	4.5.9 Remanufacturing and Refurbishing: <i>Description</i>	181
1925	4.5.10 Remanufacturing: <i>Scenarios</i>	186
1926	4.5.11 The Sharing Economy: <i>Description</i>	190
1927	4.5.12 The Sharing Economy: <i>Scenarios</i>	195
1928	4.6 Conclusion	200

4.1. INTRODUCTION

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

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

Internal Elements:

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

External Elements:

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

Outside Elements:

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

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

4.1.1. Quantification and Implementation of scenario elements in the models

External drivers

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

Internal elements

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

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

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

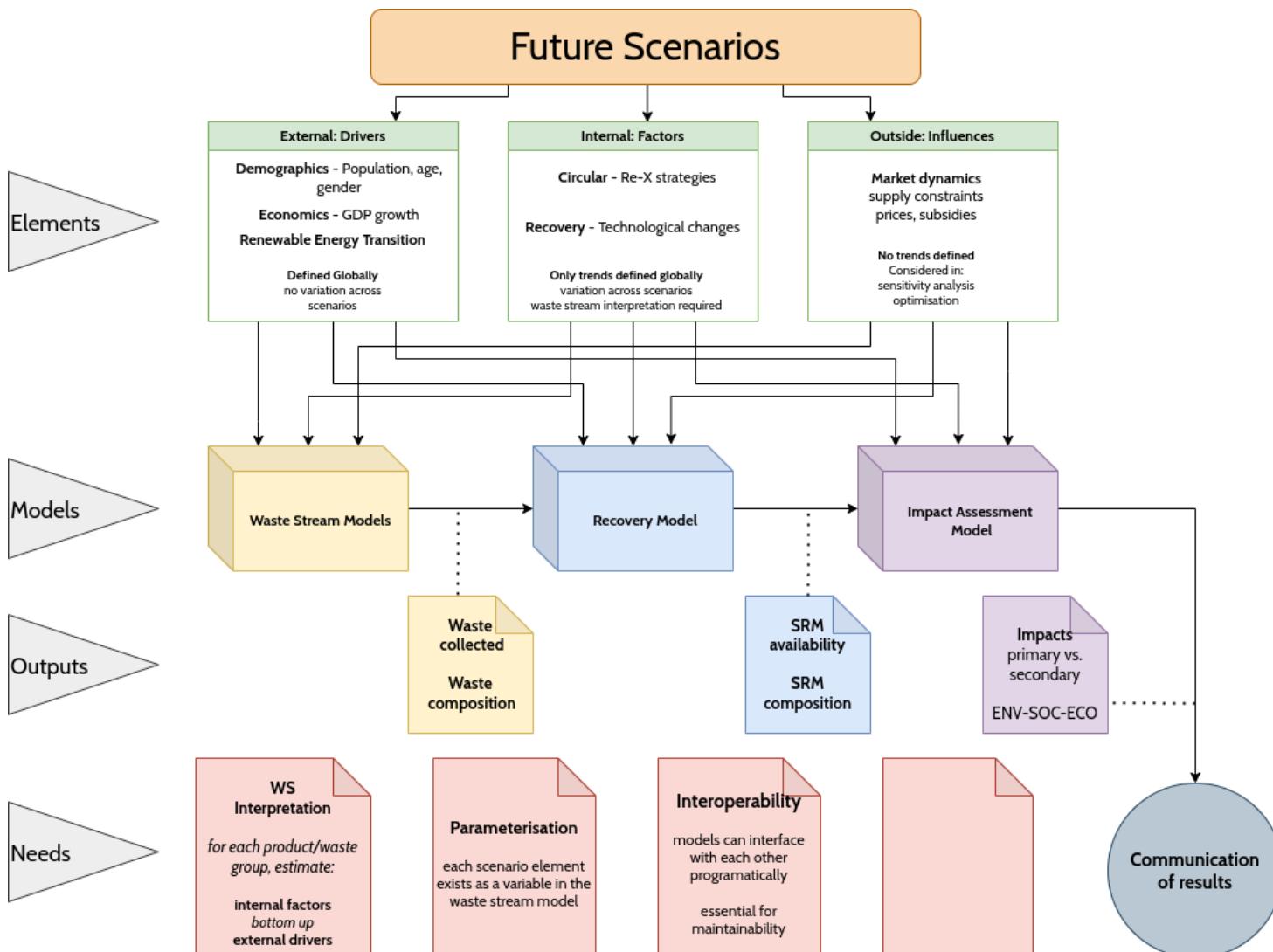


Figure 4.1: Quantification and Implementation of scenario elements in the models

Methodology for quantification

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

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

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

Interpretation

- Waste -

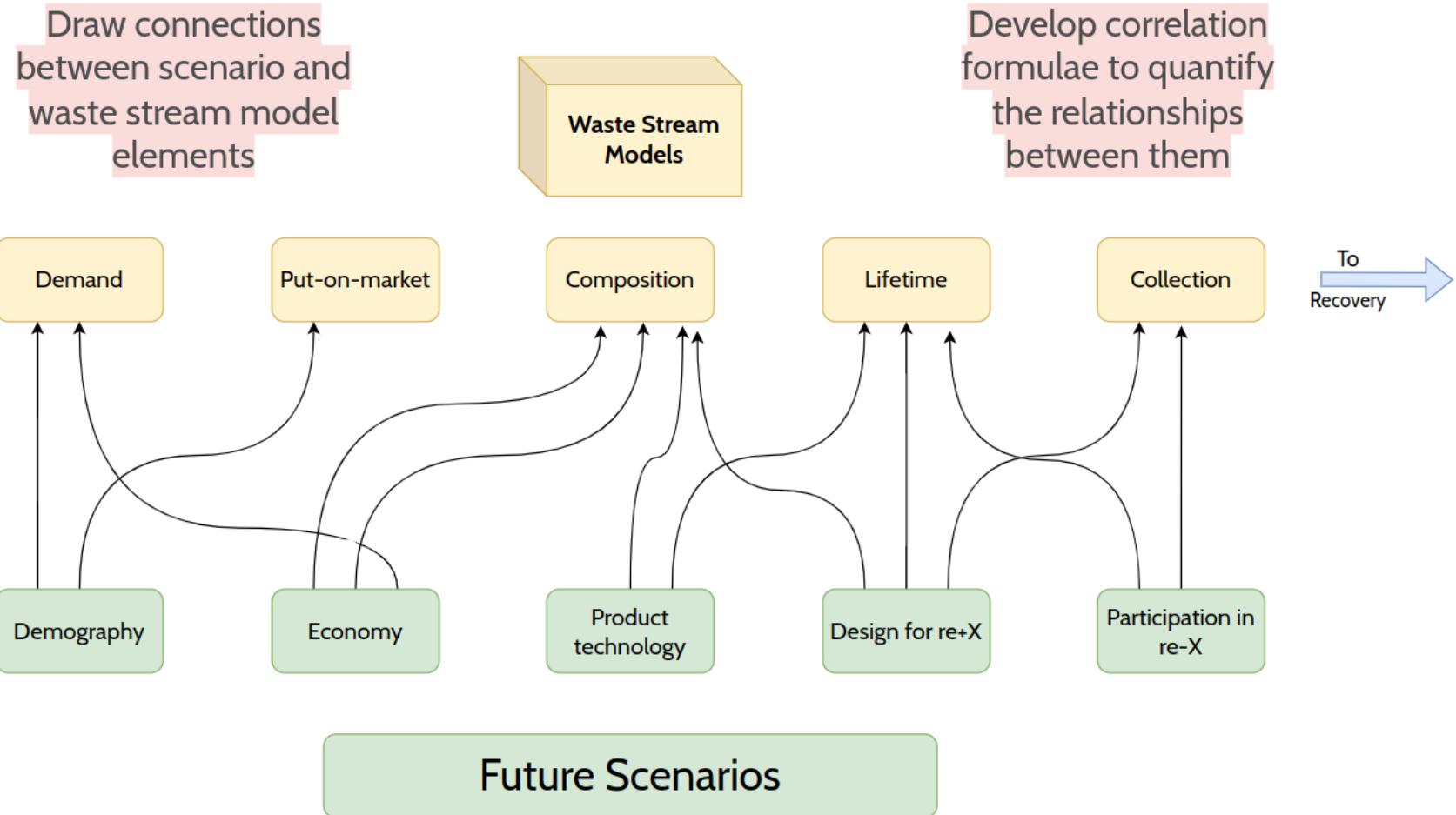


Figure 4.2: Development of correlations between elements and parameters in the waste stream models and the scenarios

Methodology for estimating future trends

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

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

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

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

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

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

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

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

where:

- x_0 = the x-value of the sigmoid's midpoint,
- L = the curve's maximum value, and

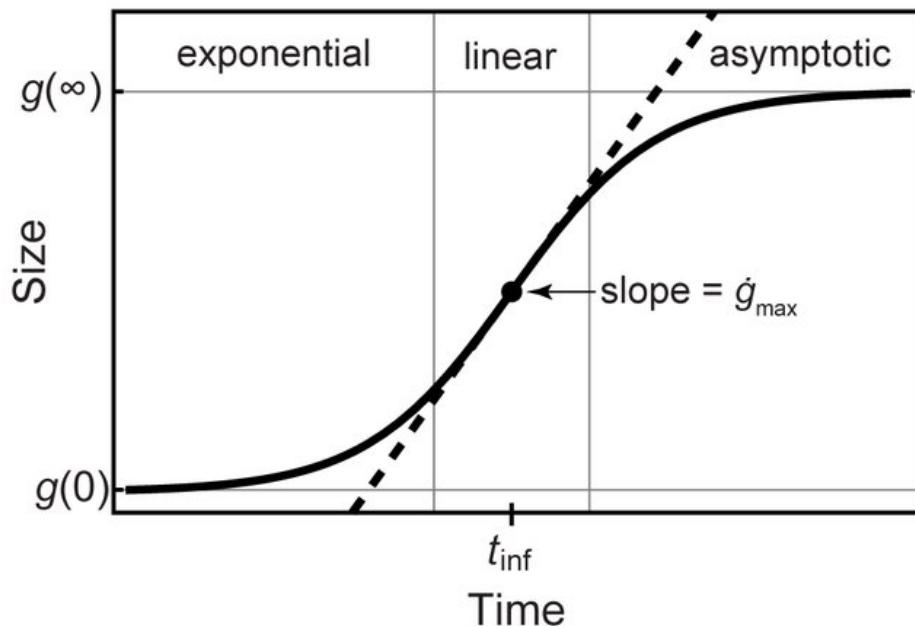


Figure 4.3: An example of a sigmoidal function (s-curve)

- 2032 • k = the logistic growth rate or steepness of the curve.
- 2033 • e = the natural logarithm base (also known as Euler's number),

2034 Important to note here is that what, during some period, may appear to be a constant
 2035 linear (or other) change, may in fact be a segment of a sigmoidal curve. This is important to
 2036 consider when estimating future trends, for some changes, the period from 2020-2050
 2037 may be short enough that the nature of the transition does not change, although it would
 2038 when viewed over a longer time range.

2039 The comic in Figure 4.4 plots the frequency of the usage of the term 'sustainable' over
 2040 time, forecasting that by 2109, all sentences will consist only of the word 'sustainable',
 2041 repeated again and again. 'Fittingly', the author also notes that '100 years is a lot longer
 2042 than many of our resources will last'.

2043 It is of course a generalisation to assume that all growth rates follow this trend, but
 2044 it is mostly close enough to reality to be useful. This will be the standard approach for
 2045 estimating future trends in the FutuRaM project unless there is reason to believe that the
 2046 nature of the transition is different (which it often is!).

2047 Further details are provided in the relevant sections of this chapter and will be updated
 2048 as the project progresses.

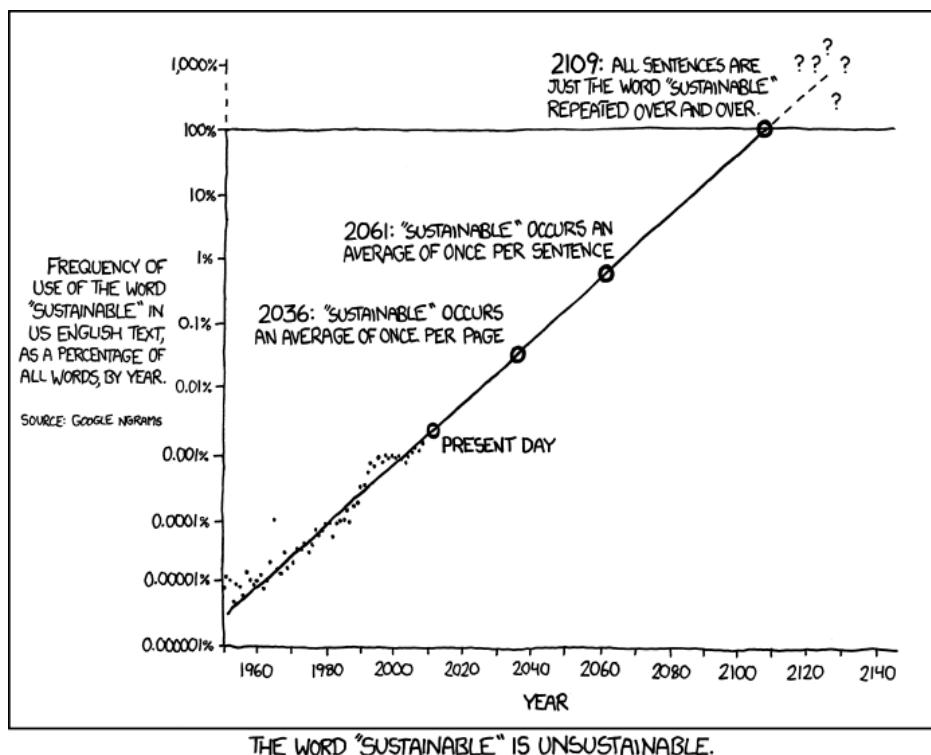


Figure 4.4: The word 'sustainable' is unsustainable [77]

2049

4.2. SUMMARY

REVIEW NOTICE

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

2050

2051

2052

4.3. EXTERNAL ELEMENTS

2053

4.3.1. Introduction

External drivers
<p>Scenario elements</p> <ul style="list-style-type: none"> • Demographic change: population, median age, urbanisation, gender • Economic growth: GDP • Renewable energy transition: energy mix <p>Waste model parameters include:</p> <ul style="list-style-type: none"> • Put-on-market • Composition <p>Recovery model parameters include:</p> <ul style="list-style-type: none"> • Recovery processes: market penetration of recovery technologies • Transfer coefficients: function of recovery technologies • Recovery system size: BAU - set by trends in BAU, CIR & REC - defined by model outcomes within constraints <p>Impact model parameters include:</p> <ul style="list-style-type: none"> • Foreground inventory: inputs and outputs of recovery system • Background inventory: energy mix, impact of primary production
2054
2055
2056
2057
2058
2059
2060

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".

2061 The following "external" elements are incorporated into the scenarios as background
2062 information but are not directly modelled. They are assumed to be constant across the
2063 three scenarios, but change over time.

- 2064 • Demographic change
2065 • Economic growth
2066 • Renewable energy transition

2067 The following "outside" elements are not incorporated into the scenarios, but are
2068 considered important and will be explored in sensitivity analysis and optimisation.

- 2069 • Resource supply constraints
2070 • International trade and co-operation
2071 • Re-industrialisation of EU
2072 • Resistance to recovery projects ("NIMBY")

2073 These elements are detailed in Table 4.1.

Table 4.1: List of external scenario elements

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

F

Back to ToC

4.3.2. Summary

REVIEW NOTICE

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

2075



2076

Demographic change

2078

INDEPENDENT VARIABLES

2079

- Population
- Median age
- Urbanisation

2081

DEPENDENT VARIABLES

2083

- Demand
- Waste generation
- Waste composition

2084

2086

Economic growth

2087

INDEPENDENT VARIABLES

2088

- GDP growth

2089

DEPENDENT VARIABLES

2090

- Demand
- Waste generation
- Waste composition

2091

2092

Renewable energy transition

2094

INDEPENDENT VARIABLES

2095

- Energy mix

2096

DEPENDENT VARIABLES

2097

- Demand
- Waste generation
- Waste composition
- Recovery impacts



2099

2100

2103

2104

INDEPENDENT VARIABLES

2105

- Resource availability

2106

DEPENDENT VARIABLES

2107

- Resource prices

2108

- Settings of the recovery system to counteract supply crunch

2109

- Waste composition (incorporating lag and substitution effects)

2110

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.

2111

2112

2113

INDEPENDENT VARIABLES

2114

- Raw material prices
- Secondary raw material prices

2116

DEPENDENT VARIABLES

2117

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

2121

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

Definition

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

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



Justification for setting as an external scenario factor

Demographics undoubtedly exert a significant influence on supply and demand patterns within any resource environment. [78] As such, demographic factors play a role in shaping the demand for CRMs and the efficiency of waste management systems. However, within the scope of FutuRaM's scenario modelling, these demographic elements are treated as background variables.

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

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

REVIEW NOTICE

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

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) [79–81].

It was decided to 're-model' this data, rather than extract it from the population figures in the SSP2 baseline scenario datasets [82, 83] to which the background of FutuRaM's scenarios are (broadly) aligned. This allows the use of the most up-to-date and 'raw' data possible.

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

EU27 + 4

Data source: [79]

POPULATION MODELLING RESULTS:

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

Normalised population forecasts for the EU27+4

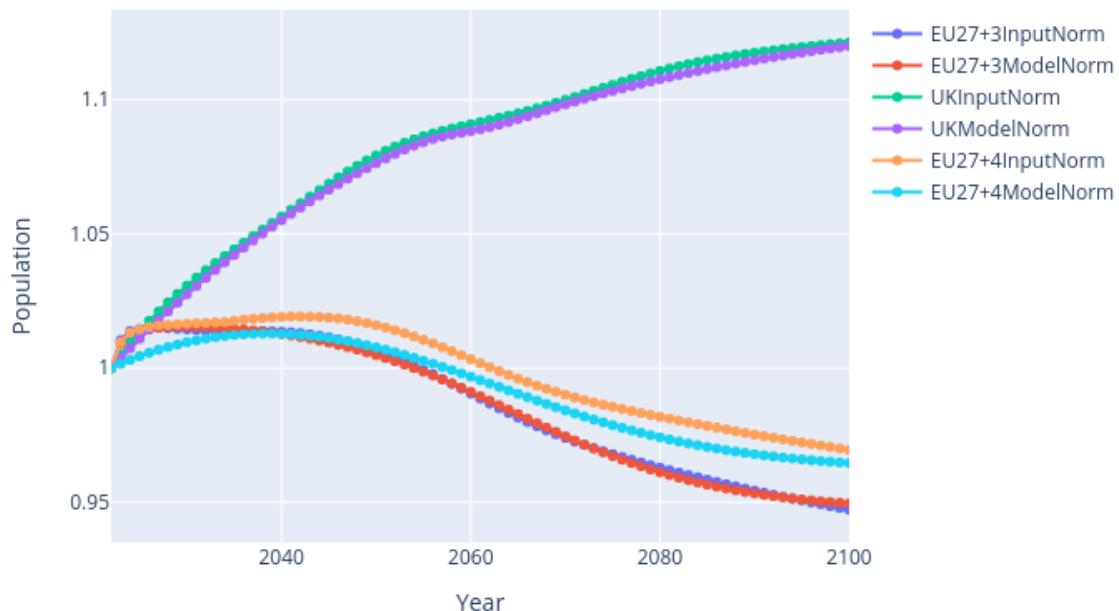


Figure 4.5: Population projections for the EU27+3 and the UK

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.

2192 It is projected by Eurostat that all EU Member States and the three EFTA countries
2193 will experience continued population ageing. The population in 2100 is predicted to be
2194 lower than in 2022, with a decline in the working-age demographic. There's an observed
2195 trend of ageing within the elderly demographic itself. Migration can both alleviate and
2196 accelerate the ageing process. It depends on whether there's an influx or outflow of the
2197 working-age population. For instance, the search for better job opportunities can lead
2198 to a considerable outflow. Consequently, age dependency ratios are set to rise, posing
2199 challenges for public expenditure on pensions, healthcare, and long-term care.

2200 **METHOD**

2201 Eurostat provides international projections for the European Union (EU) and the Eu-
2202 ropean Free Trade Association countries, which include Iceland, Liechtenstein, Norway,
2203 and Switzerland. Unlike the UN's projections, Eurostat's are deterministic in nature. Their
2204 most recent projection, dating from 2020, presents a base variant along with four other
2205 variants, starting with the baseline year 2019. In the base variant, it is forecasted that the
2206 EU-27 population will decline by nearly 7 percent or about 30 million people by 2100.
2207 However, in the medium term, the population is expected to grow until 2025, reaching
2208 about 449 million people, before reducing to 416 million by 2100. Country-specific, sex,
2209 and age data are available in Eurostat's database.

2210 The final projection starts with the 2022 population divided by sex and age. Mortality
2211 rates are applied to determine the number of deaths. Numbers for non-EU and EU
2212 immigrants are computed. For the years 2022 and 2023, refugees under TP are also
2213 included. Emigrants, including refugees under TP for the years 2024 to 3033, are then
2214 subtracted. Based on this, the end-of-year population and the working-age population
2215 are computed. Using these figures, additional non-EU immigrants are calculated, and the
2216 end-of-year population is re-assessed. This allows for the computation of live births, total
2217 deaths, immigration, and emigration for 2022.

2218 **SCENARIOS**

2219 Eurostat also considers five alternative scenarios besides the baseline for EUROPOP2023.
2220 These are: lower fertility, lower mortality, zero net migration, decreased non-EU immigra-
2221 tion, and increased non-EU immigration. For instance, the lower fertility scenario posits
2222 a total fertility rate that's 20% less than the baseline for each projection year (2023 –
2223 2100). This implies fewer live births yearly compared to the baseline. The lower mortality
2224 scenario suggests a life expectancy at birth in 2100 that's two years more than the baseline.
2225 Migration scenarios include zero net migration, 33% less non-EU immigration each year,
2226 and 33% more non-EU immigration every year throughout the projection horizon.

2227 UK

2228 Data source: [80]

- 2229 • New data will be released January 2024.
- 2230 • No scenarios were developed due to the additional uncertainty in the underly-
2231 ing data related to the CoViD-19 pandemic-related fluctuations.

2232 POPULATION MODELLING RESULTS:

2233 The full results of the population modelling are presented in Table 4.2.

2234 POPULATION PROJECTIONS

2235 The UK population in mid-2020 was estimated at 67.1 million. Over the decade to
2236 mid-2030, it's projected to rise by 2.1 million (3.2% increase), in comparison to a 6.9%
2237 increase between 2010 and 2020. Over the next 25 years, the projected growth is 3.9
2238 million (5.8%), less than the 15.6% growth between mid-1995 and mid-2020.

2239 In contrast to the EU27+3, the UK population is projected to continue to continue
2240 growing (slowly) until 2100, the end of the projection period, when it reaches 76 million.

ASSUMPTIONS:

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

METHODOLOGY

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

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.

2271 These projections are informed by the finite reserves of primary exhaustible resources
2272 and the ongoing trend of declining birth rates. These indications suggest a shift towards a
2273 new equilibrium state for the planet that aligns with heightened industrial and technological
2274 capacities and improved healthcare standards. By constructing logistic models that
2275 depict the growth dynamics of the global population and individual continents, we can
2276 forecast population sizes and their growth rates for the next two centuries. The insights
2277 garnered present opportunities for the regulation and optimal management of global
2278 demographic resources.

2279 ***Projection Methodology***

2280 **Methodology source:** [81]

2281 Population projections underpin many political and economic decisions at various
2282 levels. Often, the users lack the expertise to fully grasp the methods and limitations of
2283 the projections they rely on.

2284 Population development is contingent upon three primary factors: fertility, net migra-
2285 tion, and mortality. Usually, a projection starts with the age- and sex-specific numbers at
2286 a given time. Using estimates for the future development of the three determinants, the
2287 population is projected forward. Forecasts often refine mortality and migration by age
2288 and sex.

2289 Projection methodologies fall into deterministic and stochastic categories. Deterministic
2290 models, being the most widespread, set parameters in one or more scenarios. Their
2291 strengths lie in ease of use, adaptability to changes in parameters, and straightforwardness
2292 for non-experts. A prominent deterministic method is the cohort component method
2293 (CCM) which separately simulates fertility, migration, and mortality before integrating
2294 them into a projection. Given a population P_{t-1} at the end of period $t - 1$, the CCM
2295 updates this using births B_t , net migration M_t , and deaths D_t as:

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

2296 However, deterministic models face challenges. They:

- 2297 • Overlook the probabilistic nature of population processes.
- 2298 • Rely on rigid future assumptions with low individual probabilities of occur-
- 2299 rence.
- 2300 • Limit the number of considered scenarios, inadequately reflecting future risk.
- 2301 • Lack probabilistic quantification for identified futures.
- 2302 • May be biased by experts' subjective assessments.

2303 In contrast, stochastic models view parameters as random variables. While determin-
 2304 istic models might assume fixed values for determinants like G_t , M_t , and S_t in certain
 2305 scenarios, stochastic models see these as probabilistic, represented as:

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

2306 Yet, it's essential to understand that no forecast offers absolute truth. Their aim isn't pre-
 2307 dicting unexpected events, but extrapolating core demographic trends. Both deterministic
 2308 and stochastic methods exist to quantify forecast uncertainty.

2309 Applying these results in real-world scenarios warrants a cautious approach. Past
 2310 trends might not persist in the future. For instance, population growth isn't just about
 2311 demographics but also infrastructure. Can a housing market accommodate growth? Will
 2312 cities meet their limits? Projections inherently carry assumptions. For instance, regions
 2313 must meet housing demands, and urban challenges arise from positive population growth,
 2314 such as the need for expanded childcare or public transport infrastructure.

2315 Predicting and managing future global population growth stands as a paramount chal-
 2316 lenge for humanity. Most contemporary researchers believe there's a ceiling to the planet's
 2317 'carrying capacity'. Come 2022, Earth's population is anticipated to hit the eight billion
 2318 mark. UN predictions suggest that by 2100, this number will rise to ten billion. How-
 2319 ever, there's an observable trend towards smaller family sizes, with birth rates currently
 2320 hovering around the replacement rate of 2.1 children per woman. Should global fertility
 2321 rates align with family replacement levels (2.0) by 2100, Earth's population is projected
 2322 to stabilise between ten and eleven billion. The emergence of new statistical data ne-
 2323 cessitates updates to global population growth models. Where once the Verhulst logistic
 2324 model was deemed inadequate for characterising global population growth dynamics, the
 2325 tapering growth rate now reaffirms its applicability. Many recent studies have leveraged
 2326 the logistic growth model. Our analyses confirm that Earth's population growth rate aligns
 2327 closely with a quadratic function, mirroring the Verhulst equation (Fig. 4). All subsequent
 2328 computations will employ the Verhulst logistic model:

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

2329 The solution to equation (8) will be sought as a logistic function:

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

2330 Function $Y(t)$ parameters were ascertained using the least squares method, ensuring
 2331 maximal alignment between the function's value and the existing statistical data. The
 2332 parameter g was presumed equal to the initial population size at the start of observations
 2333 ($t_0 = 1900$).

2334 CURVE FITTING EXPLANATION

2335 Terms with subscript 1 describe the initial logistic component, charting population
 2336 growth from 2022 to 2042.

2337 Subscript 2 terms Correspond to the second logistic component, which outlines post-
 2338 2042 population decline.

- 2339 **b_1** Represents the initial population at the start of the observation period - Europe's
 2340 population in 1900 per the model's parameters.
- 2341 **b_1** Denotes the carrying capacity of population growth, effectively indicating the
 2342 population apex achievable via the first logistic function.
- 2343 **A_1** Influences the gradient of the first growth phase. Higher values result in steeper
 2344 population inclines.
- 2345 **a_1** Represents the growth rate of the initial logistic function, dictating how swiftly the
 2346 population nears the carrying capacity b_1 .
- 2347 **t_1** Marks the inflection point in the first logistic phase, signifying the period of maxi-
 2348 mum growth velocity.
- 2349 **b_2** Illustrates the decline's carrying capacity, indicating the population decrease as
 2350 projected by the second logistic function.
- 2351 **A_2** Determines the gradient of the decline phase, with larger values resulting in sharper
 2352 declines.
- 2353 **a_2** Represents the rate of decline in the latter logistic function, determining the speed
 2354 at which the population reaches the decline's carrying capacity b_2 .
- 2355 **t_2** Highlights the inflection point during the decline phase, marking the period where
 2356 the decrease is most rapid.

Table 4.2: Population projections for the EU27+4

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

2357
2358

Incorporation of demographic factors into individual waste stream models

2359

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

2360

2361



BATT (BATTERY WASTE)

- X

2362



CDW (CONSTRUCTION AND DEMOLITION WASTE)

- X

2363



ELV (END-OF-LIFE VEHICLES)

- X

2364



MIN (MINING WASTE)

- X

2365



SLASH (SLAGS AND ASHES)

- X

2366



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

- X

2367

Conclusion

2368

REVIEW NOTICE

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



2375

2376

2377



2378 4.3.4. Economic factors: *GDP growth*

2379 *Definitions*

2380 Gross Domestic Product (GDP) PPP

2381 A measure of a country's economic output that accounts for differences in price
 2382 levels between countries. By using PPPs and the common currency of international
 2383 dollars, GDP PPP is adjusted for price level differences across countries, providing a
 2384 more accurate measure of the economic output and living standards, as it reflects
 2385 the real purchasing power of the citizens.

2386 Purchasing Power Parity (PPP)

2387 An economic theory that allows the comparison of the purchasing power of various
 2388 world currencies to one another. It involves a comparison of the relative prices of a
 2389 standard set of goods and services in different countries, thus providing a measure
 2390 of the relative cost of living and enabling a more accurate comparison of economic
 2391 well-being.

SCENARIO TRENDS FOR: GDP growth



Scenario I – Business-as-usual:

Slow stable growth



Scenario II – Recovery:

Slow stable growth



Scenario III – Circularity:

Slow stable growth

2394 Sources of data

2395 The GDP projections for FutuRaM's future scenarios are based on economic data from the
 2396 OECD as well as population data from Eurostat and the UK's ONS [79, 80, 84]

2397 Results of projections

2398 As an 'external element', the GDP projections do not differ across the scenarios, only as a
 2399 function of time.

2400 The results of the projections are shown in Figure 4.6. An interactive figure can be
 2401 viewed here [🔗](#)



Figure 4.6: GDP projections for the EU27+4

Methodological Overview of OECD's GDP Projection Framework

[84–87]

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 [88, 89]. This convergence is modelled through an enriched version of the Solow growth model, factoring in a dual-sector configuration [90], which the OECD dubs the ENV-Growth model. Rather than focusing solely on convergence in income, the ENV-Growth model prioritises the growth factors that will drive GDP over time.

For GDP projections up to 2060, the OECD combines model-based assessments with expert evaluations, considering the economic dynamics of individual countries and the global market. These forecasts are denominated in the constant US dollars and PPPs of 2010, based on data from OECD and World Bank, which use the Atlas method for calculating PPPs [85, 91]. The data originate from the OECD Long-Term Baseline Scenario. This scenario, which is integral to the OECD Economic Outlook, serves as a comparative standard to gauge the possible effects of structural reforms, assuming a policy-neutral environment. Conversely, long-term projections diverge from the medium-term forecasting model, which is predominantly demand-driven, by focusing on a supply-side perspective that takes into account labour and capital availability and productivity growth rates.

Determinants of Long-term Growth

[85, 92]

2424 Recognizing the multifaceted nature of economic advancement, GDP growth pro-
2425 jections consider an array of influences such as demographics, educational attainment,
2426 technological progress, energy access, and capital flow patterns. The MaGE framework
2427 facilitates GDP estimation by charting dynamic paths that reflect the structural interplay
2428 defining the economic landscape until 2050 [92].

2429 The ENV-Growth model's projections span a century and include a wider selection
2430 of countries, enhancing the original methodologies developed by the OECD Economics
2431 Department [86, 87]. It introduces considerations for energy usage and resource revenue
2432 from oil and gas sectors, aligning with the enhanced sectoral approach for fossil fuels
2433 presented by [93].

2434 The model's foundation lies in its projection of the five pivotal elements driving eco-
2435 nomic growth:

- 2436 • Physical capital
- 2437 • Employment, shaped by population trends, age demographics, participation
2438 rates, and unemployment scenarios
- 2439 • Human capital, based on education and its consequential effect on labour
2440 productivity
- 2441 • Energy demand and resource extraction for exporting countries
- 2442 • Total factor productivity (TFP)

2443 The determinants of growth are not restricted to these factors; they also encompass a
2444 spectrum of social, economic, and institutional influences, including workforce education,
2445 trade openness, institutional integrity, fiscal strategies, regulatory frameworks, and de-
2446 mographic shifts. The underlying potential for economic catch-up through technology
2447 transfer and innovation is underscored by the differential in income between each country
2448 and the global technology frontrunner.

2449 In the context of employment, projections from IIASA inform the total employment
2450 figures, combining time-specific participation rates for different age cohorts with pro-
2451 jected unemployment trends. Education assumptions translate gender and age-specific
2452 educational projections into a human capital index, which then informs labour productivity
2453 enhancements.

2454 For physical capital, the model follows a standard capital accumulation methodology
2455 with a set depreciation rate, with the investment rate per unit of GDP edging towards a
2456 balanced growth path level determined by the production function's structural parameters.

2457 Energy and natural resources are integrated as productive components for consumers
 2458 and as extra income from specific oil and gas sectors for producer nations. The model
 2459 calibrates domestic energy productivity to historical improvement rates, progressing
 2460 towards an efficiency frontier indicative of cutting-edge energy appliances. The economic
 2461 contribution of energy resources to producer countries is extrapolated from resource
 2462 depletion models that describe the dynamics between reserves and resources and the
 2463 temporal evolution of marginal production costs.

2464 FutuRaM's economic forecasts, while not based directly on the SSP data, are consistent
 2465 with the SSP2 baseline derived from similar sources and models [82, 83, 94–97], offering
 2466 a comprehensive picture of potential economic trajectories.

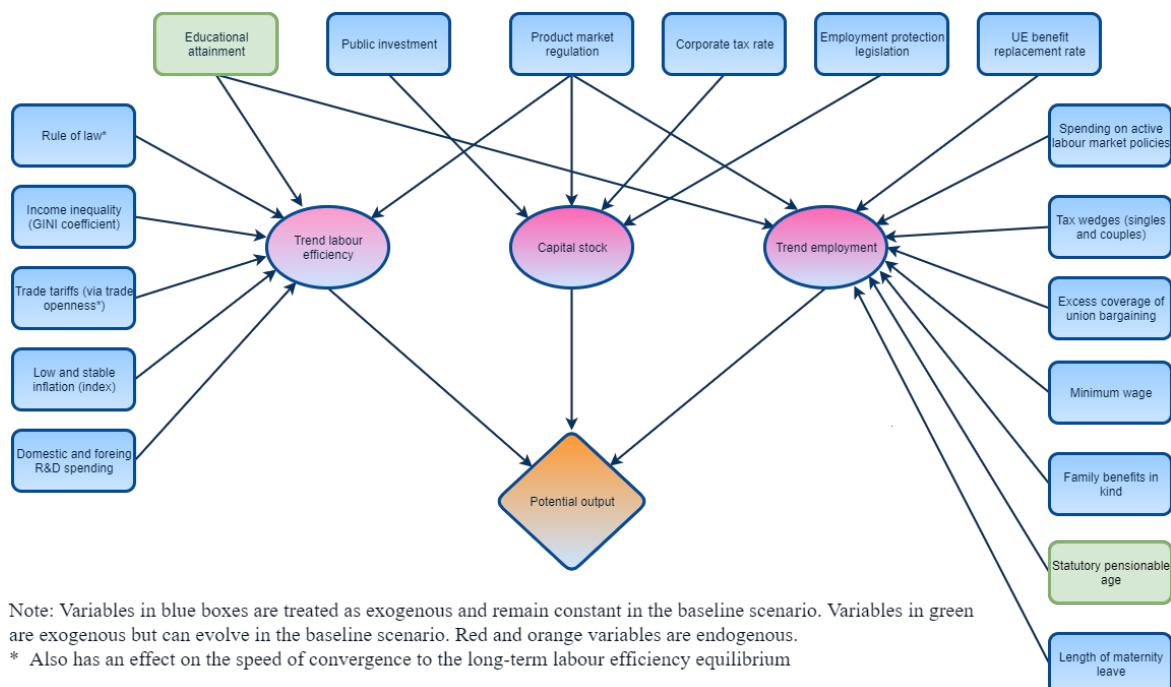


Figure 4.7: Factors incorporated in the long-term model [85]

2467 Implications of GDP Growth on FutuRaM's Waste Models

2468 GDP growth has significant implications for models concerning secondary raw material
 2469 recovery and waste generation. For example, increasing GDP tends to lead to higher
 2470 consumption levels, which can result in more waste generation across various streams.
 2471 However, higher income also provides greater resources for investment in recovery tech-
 2472 nologies and infrastructure. Below are some examples for each of the specified waste
 2473 streams.



BATT (BATTERY WASTE)

2475 As GDP grows, the demand for electronic devices and electric vehicles typically increases, leading to a higher turnover of batteries. This could necessitate advancements in
2476 recovery methods for battery components, such as lithium and cobalt, to reduce reliance
2477 on primary sources and mitigate environmental impact.
2478



CDW (CONSTRUCTION AND DEMOLITION WASTE)

2480 Economic growth often spurs construction activity, thereby increasing CDW. Increasing
2481 GDP as a ratio of waste generation could lead to enhanced recycling processes, promoting
2482 the circular economy by converting waste into secondary raw materials for new construc-
2483 tion projects.



ELV (END-OF-LIFE VEHICLES)

2485 The number of ELVs rises with economic prosperity, as people can afford newer vehicles
2486 more often. This creates opportunities to recover valuable materials and components,
2487 necessitating more efficient recycling processes.



MIN (MINING WASTE)

2489 As economies expand, so does the demand for minerals, potentially increasing mining
2490 waste. With increased GDP, there could be more investment in techniques to minimise
2491 waste generation and recover valuable materials from mining by-products.



SLASH (SLAGS AND ASHES)

2493 Higher GDP can correlate with increased industrial activity, producing more slags
2494 and ashes. Enhanced recovery techniques can transform these by-products into useful
2495 secondary raw materials, such as aggregates in construction.



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

2497 GDP growth can lead to shorter replacement cycles for electronic goods, increasing
2498 the amount of WEEE. There's a potential for improved recovery of precious metals and
2499 rare earth elements, driving innovation in e-waste recycling technologies.

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

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

BATT (BATTERY WASTE)

• X

CDW (CONSTRUCTION AND DEMOLITION WASTE)

• X

ELV (END-OF-LIFE VEHICLES)

• X

MIN (MINING WASTE)

• X

SLASH (SLAGS AND ASHES)

• X

WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

• X

Conclusion

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

REVIEW NOTICE

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

2520

2521

2522

2523

2524 4.3.5. The Renewable Energy Transition

2525 **Definition**

2526 The term "energy transition" refers to the current global shift from fossil fuels to renewable
 2527 energy sources to meet the urgent need to reduce greenhouse gas emissions, combat
 2528 climate change, and enhance energy security. This transition encompasses a fundamen-
 2529 tal transformation of energy supply and consumption patterns, including the increased
 2530 use of sustainable energy to achieve a low-carbon economy. Historical shifts in energy
 2531 sources—from biomass to coal, and later to oil and natural gas—reflect the ongoing evolu-
 2532 tion of energy use. The present focus is on scaling up renewables such as solar and wind,
 2533 which are becoming increasingly cost-competitive. Key aspects of the transition include
 2534 adopting electric vehicles, improving public transportation, advancing energy-efficient
 2535 technologies for building heating, and developing energy storage and grid solutions to
 2536 support the integration of variable renewable energy sources.

2537 **Future energy mix in the EU**

2538 The projected electricity mix for the EU is presented in Figure 4.8. An interactive figure
 2539 can be viewed here [🔗](#)

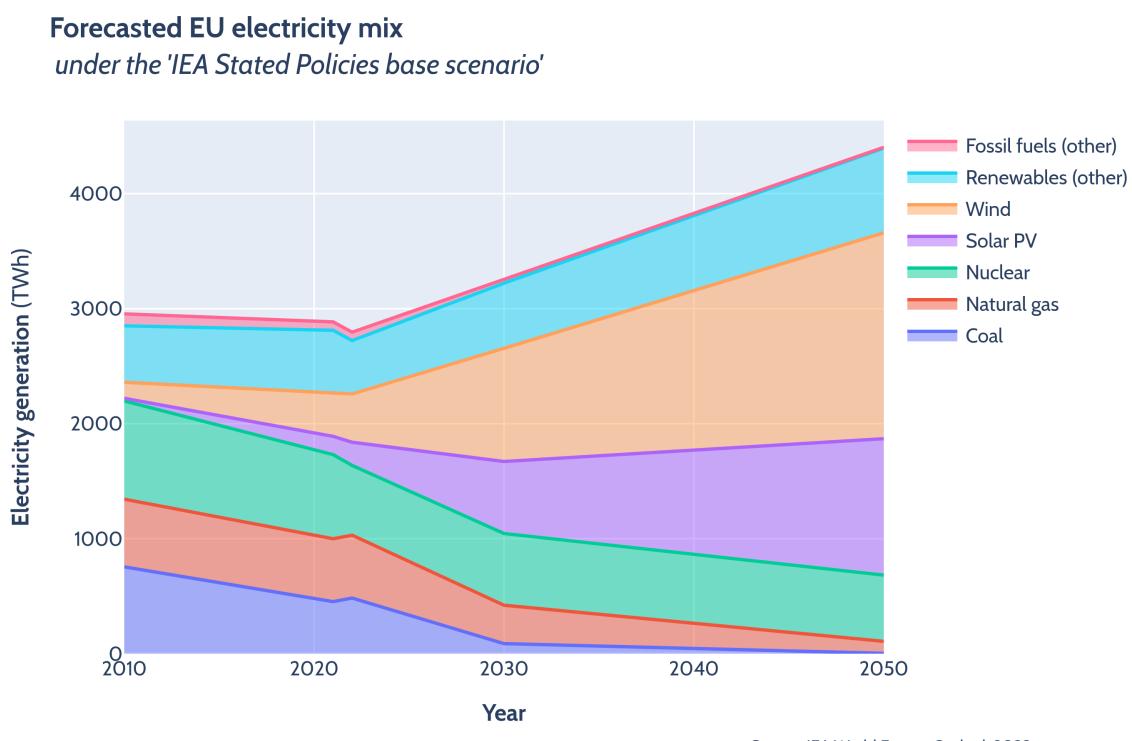


Figure 4.8: EU electricity mix forecast until 2050

2540 **Brief context of renewable energy in the EU**

2541 Renewable energy is integral to the EU's shift towards a low-carbon economy and reduc-
 2542 ing reliance on imported fossil fuels—a response accentuated by the urgency to curtail
 2543 dependence on Russian energy sources. The EU's strategic move is encapsulated in the
 2544 REPowerEU Plan of Action, introduced in May 2022, and agreed upon in 2023 which

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

Relevant technologies in the renewable energy sector

The cornerstone technologies in renewable energy—batteries, electrolyzers, wind turbines, heat pumps, and solar PV—play pivotal roles across various sectors (Figure 85). Heat pumps serve industrial processes, while solar PV and batteries support ICT, defence, and mobility with energy and uninterrupted power supplies, respectively [98].

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

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

Addressing the intermittency of wind and solar power necessitates adequate storage solutions and robust grid systems, with electrolyzers emerging as a crucial technology for renewable hydrogen production, forecasted to exceed 1 GW capacity by the end of 2022 [102].

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

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

Supply Chain bottlenecks in renewable energy

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

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

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

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

2619 Across all technologies analysed, a common pattern of heavy reliance on imports,
2620 particularly from China, is observed at different stages of the value chains. The EU's primary
2621 sourcing and processing capabilities for critical raw materials are notably low, creating
2622 dependencies at multiple levels. Despite a strong manufacturing capacity for wind turbine
2623 assembly, the EU is entirely reliant on imports for the value chain of rare-earth permanent
2624 magnets. Similarly, for solar PV, the dependence on imports is comprehensive. The recent
2625 surge in Chinese manufacturing market share for heat pumps and the developing value
2626 chain for batteries in the EU are also noteworthy.

2627 A breakdown of the materials required for each technology is given in Table 4.3.

Table 4.3: Raw materials essential to the renewable energy sector

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

Continued on next page

Table 4.3 – Continued from previous page

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

The integration of the energy transition has significant implications for the management of Critical Raw Materials (CRMs) across various waste streams due to changing material requirements and waste profiles [18, 98, 103, 104].

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.

SLASH (SLAGS AND ASHES)

- 2660
- The energy transition could increase the generation of certain industrial wastes such as slags, which may contain valuable CRMs.
- 2661

2662

Implementation in EU Law

2663

FIT FOR 55 PACKAGE (2021)

2664 The "Fit for 55" package is a collection of policy initiatives proposed by the European
2665 Commission in July 2021 aimed at revising and updating EU legislation to reflect the
2666 increased ambition of reducing net greenhouse gas emissions by at least 55% by 2030,
2667 compared to 1990 levels [105]. This target was a significant step up from the previous goal
2668 of a 40% reduction and is part of the European Union's plan to become climate-neutral
2669 by 2050 – an objective set out in the European Green Deal[31].

2670 The package includes proposals to revise the EU Emissions Trading System (ETS), to
2671 increase the use of renewable energy, to improve energy efficiency, and to implement
2672 carbon pricing mechanisms, among other measures. The intention is to align existing laws
2673 with the 2030 climate target and to set the legal foundation for Europe's transition to a
2674 green economy. This includes changes across various sectors including transportation,
2675 building, and energy production to reduce emissions and promote sustainable practices.

2676

REPOWEU PLAN (2022)

2677 The invasion of Ukraine by Russia has caused significant disruption to energy markets
2678 in Europe and globally. To eliminate reliance on an unreliable supplier, the European
2679 Commission has devised the REPowerEU plan [100]. This initiative focuses on energy
2680 conservation, the production of clean energy, and the diversification of energy sources,
2681 supported by financial and legal measures to develop Europe's necessary new energy
2682 infrastructure and systems.

2683 **Accelerating Clean Energy** Renewable energy sources, being both cost-effective and envi-
2684 ronmentally friendly, can be produced locally, thereby reducing dependency on imported
2685 energy. The REPowerEU plan aims to expedite the green transition and trigger substantial
2686 investments in renewable energy. It also seeks to facilitate the rapid transition of industry
2687 and transport from fossil fuels, reducing both emissions and dependency.

2688 This includes a variety of measures focused on renewable energy and energy efficiency,
2689 such as:

- 2690 • Increasing the EU's 2030 renewable energy target of the 'Fit for 55 package'
2691 from 40% to 45%.
- 2692 • Accelerating the deployment of photovoltaic (PV) energy.
- 2693 • Introducing the European Solar Rooftop Initiative.
- 2694 • Doubling the deployment rate of individual heat pumps.
- 2695 • Decarbonising the industry by promoting electrification and renewable hydro-
2696 gen.
- 2697 • Speeding up renewable energy project and grid infrastructure permit pro-
2698 cesses.
- 2699 • Increasing the EU's binding energy savings target for 2030 to 13%.

2700 The May 2022 REPowerEU plan by the European Commission, in response to the
2701 energy market disruptions due to Russia's invasion of Ukraine, is designed to rapidly cut
2702 down on the EU's reliance on Russian fossil fuels. It raises the renewable energy target of
2703 the Fit for 55 package from 40% to 45%.

2704 This ambitious goal for renewable energy use, coupled with REPowerEU's strategies to
2705 reduce energy demand, necessitates substantial increases in renewable capacity across
2706 the electricity, transport, and heating and cooling sectors. The Commission forecasts that
2707 to meet the 2030 objectives, renewable electricity should reach 69%, 32% in transport,
2708 and a yearly growth of at least 2.3 percentage points in heating and cooling.

2709 RENEWABLES ENERGY DIRECTIVE (2023)

2710 The recent legislation strengthening the EU Renewable Energy Directive marks an
2711 advancement towards the European Green Deal and REPowerEU ambitions. With the
2712 provisional agreement, the EU's binding renewable energy target for 2030 is now at least
2713 42.5%, aiming potentially to reach 45%. This target significantly surpasses the previous
2714 goal of 32% and is nearly double the present proportion of EU renewable energy.

2715 A distinct enhancement over the REPowerEU plan is the establishment of definitive
2716 binding targets for renewable energy. The legislation optimises permitting procedures,
2717 acknowledges renewable energy as an overriding public interest, and designates acceleration
2718 zones for expedited development in strategically identified regions.

2719 The directive also introduces specific directives across various sectors:

- 2720 • In heating and cooling, it sets forth progressive annual renewable targets and a
2721 49% renewable energy consumption benchmark in buildings by 2030.
- 2722 • It for the first time includes the industrial sector under its ambit, establishing
2723 indicative and binding targets for the use of renewable energy and renewable
2724 hydrogen, respectively.
- 2725 • For the transport sector, it specifies a reduction in greenhouse gas intensity
2726 and sets sub-targets for advanced biofuels and renewable fuels of non-biological
2727 origin, underpinning the EU's renewable hydrogen objectives.
- 2728 • It further enhances the "guarantees of origin" system to improve consumer in-
2729 formation and supports the integration of the energy system through electrifi-
2730 cation and waste heat capture.

2731 In summary, the agreement accelerates the EU's strides towards energy autonomy,
2732 promises to reduce energy costs over time, and decreases dependence on imported fossil
2733 fuels. It intensifies the EU's pledge to a decarbonised economy and aligns with REPower-
2734 erEU's broader goals but with specific, more ambitious targets and refined processes for
2735 rapid renewable energy adoption.

2736 While the reinforced EU Renewable Energy Directive is a pivotal step towards the EU's
2737 "Fit for 55" framework and the overarching European Green Deal goals, it has not been
2738 without its critics. The Directive's ambitious targets for 2030 have spurred a range of
2739 responses from member states and institutions, with concerns centered around feasibility,
2740 economic impact, and the varying capabilities of nations to meet these objectives [106].

The following is a summary of the key points raised by member states and the European Commission in their statements on the directive [106]:

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

Challenges to the expansion of renewable energy in the EU

In addition to the internal conflict among member states [106], a recent IEA analysis concluded that EU's renewable energy expansion is constrained by inadequate policy support, complex permitting, and grid upgrades' pace. [102]

2775 Current forecasts indicate that the solar PV and wind capacity expansions fall short of
2776 the REPowerEU plan's renewable electricity targets for 2030. The European Commission
2777 Staff Working Document states that achieving a 69% share of renewable electricity
2778 requires 592 GW of solar PV and 510 GW of wind by 2030, translating to annual additions
2779 of 48 GW for solar PV and 36 GW for wind [107]. These figures significantly exceed the IEA's
2780 main case projections of 39 GW for solar PV and 17 GW for wind between 2022 and 2027,
2781 resulting in a renewable generation share of 54% in the electricity sector—15 percentage
2782 points below the desired 69% by 2030. Therefore, to fulfill the necessary installed
2783 capacity for generating 69% of electricity from renewables by 2030, the annual net
2784 additions for solar PV need to increase by 22%, and for wind, more than double [108]. The
2785 EU estimates that the total amount required for these investments will exceed €360bn
2786 before 2030 [107].

2787 **Policy Support:**

2788 Uncertainty from infrequent auctions and limited visibility hampers utility-scale
2789 solar PV and distributed PV projects, with issues in current auction designs and
2790 support scheme extensions affecting growth and profitability.

2791 **Permitting:**

2792 A primary bottleneck due to complex regulations, land restrictions, social opposition,
2793 and permitting office inefficiencies increases costs and extends project lead times.

2794 **Grid Congestion:**

2795 Insufficient grid capacity and upgrade challenges caused by permitting hurdles,
2796 labour shortages, and opposition slow the integration of new renewable plants.

2797 The IEA analysis states that improvements addressing these issues could boost solar
2798 and wind deployment by 30% by 2027. An accelerated case requires increased policy
2799 support, regulatory reforms, and quicker infrastructure development [108].

2800 For utility-scale solar PV, competitive auctions must be introduced or extended, with
2801 revised auction designs to reflect current market conditions. Distributed PV could see
2802 growth with better support and remuneration for self-consumption.

2803 Despite potential policy and regulatory advances, wind energy, particularly onshore,
2804 faces persistent permitting difficulties, and offshore wind is bogged down by grid connec-
2805 tion delays.

2806 Finally, market interventions and the energy crisis debate could influence renewable
2807 investments, stressing the need for careful reform processes involving all stakeholders to
2808 maintain investor confidence.

2809

Incorporation of the energy transition into the *FutuRaM* scenarios

REVIEW NOTICE

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

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

There are alternatives, such as the EU reference scenario [109] and the POTEEnCIA central scenario, which is similar, although somewhat outdated [110]

2810

2811

2812 In light of the information presented above, as well as the nature of the three scenarios,
 2813 *FutuRaM* will use a moderate growth scenario for the energy transition. The data for this
 2814 is sourced from the projections of the International Energy Agency (IEA) using the "base
 2815 case" of their "Stated Policies (STEP)" scenario [111].

2816 The IEA's World Energy Outlook 2023 presents a range of scenarios, including the
 2817 Stated Policies (STEP) scenario, the Sustainable Development Scenario (SDS) — which is
 2818 the IEA's pathway to achieving the Paris Agreement goals — and the Net Zero Emissions
 2819 scenario. Full details of the scenarios are available in the documentation of the IEA's Global
 2820 Energy and Climate (GEC) Model [112].

2821 A comparison of the IEA's projections for the renewable energy transition in the EU
 2822 under the STEP and APS scenarios is presented in Table 4.4.

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

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

2823

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

2824

THE STATED POLICIES SCENARIO (STEP)

2825 The Stated Policies Scenario (STEPS) is an energy model that offers a conservative
 2826 projection based on existing and developing energy policies, without assuming full achieve-
 2827 ment of governments' announced goals. It undertakes a detailed, sector-by-sector assess-
 2828 ment including a variety of factors such as pricing, efficiency standards, and infrastructure
 2829 projects as of the end of August 2023. Although it incorporates far-reaching governmental
 2830 targets, such as net zero emissions and complete energy access, these are not presumed
 2831 to be fully implemented without evaluating the regulatory, financial, and infrastructural
 2832 context of each country.

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

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

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.

2841

THE FUTURE ENERGY MIX IN THE EU

In a global sense, the energy transition manifests in FutuRaM's forecasts by way of the background energy mix. In Figure 4.8 is the IEA's projection of the energy mix in the EU for the Stated Policies scenario. Additional forecasts for rare earth elements (REEs) supply and demand related to wind energy and e-mobility are offered by the JRC [103].

2842

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 Ws

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.

2843

2844

2845

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

2846

2847

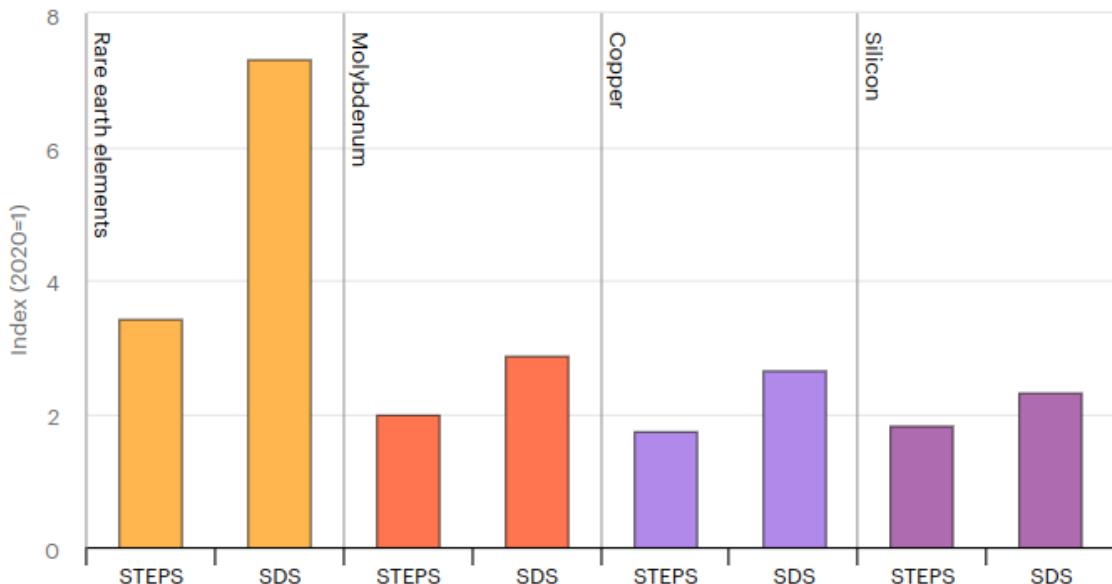


Figure 4.9: Change in demand for selected elements

2848

2849

2850

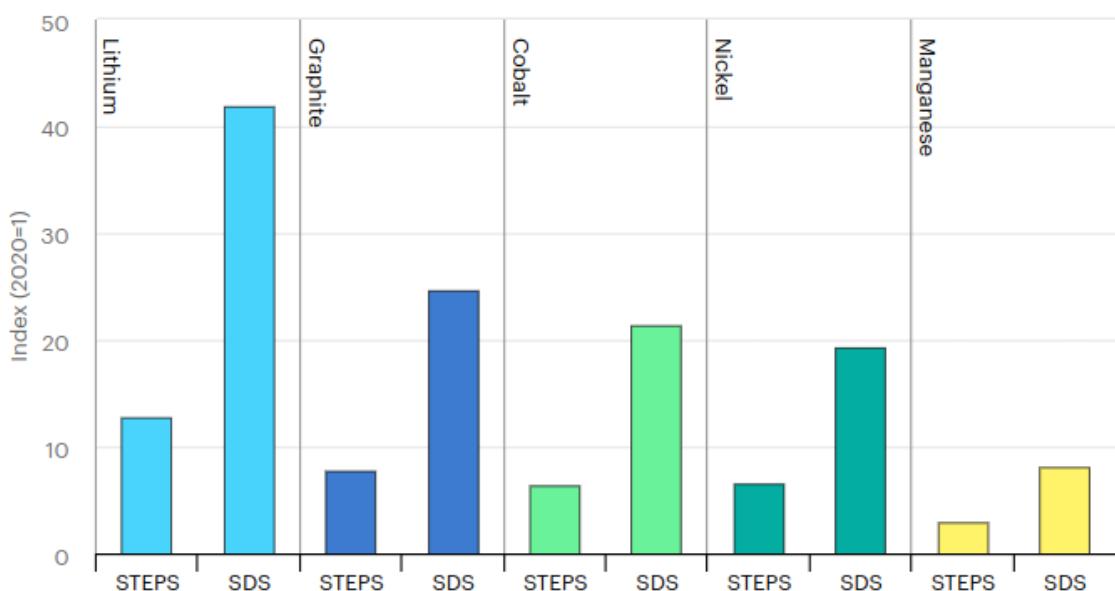


Figure 4.10: Change in demand for battery relevant elements

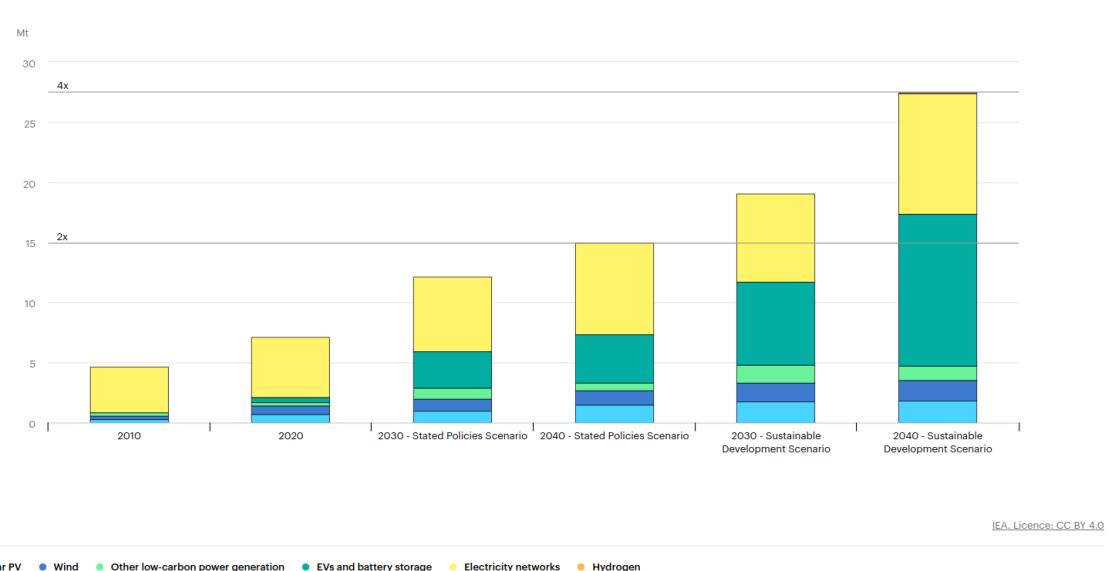


Figure 4.11: Global mineral demand (total) under various scenarios

2852
2853

Incorporation of the energy transition into individual waste stream models

2854

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

2855

2856

BATT (BATTERY WASTE)

- 2857
- X

2858

CDW (CONSTRUCTION AND DEMOLITION WASTE)

- 2859
- X

2860

ELV (END-OF-LIFE VEHICLES)

- 2861
- X

2862

MIN (MINING WASTE)

- 2863
- X

2864

SLASH (SLAGS AND ASHES)

- 2865
- X

2866

WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

- 2867
- X

4.3.6. Supply constraints and market dynamics

REVIEW NOTICE

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

Introduction

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

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

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

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

Impacts of supply constraints and market dynamics

IMPACT ON WASTE GENERATION

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

IMPACT ON COLLECTION AND RECOVERY SYSTEMS

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

LAG TIMES TO RECOVERY

2899
2900 The scarcity of materials can extend the time products remain in use before entering the waste stream, affecting the timing and efficiency of waste recovery systems.

2901 **Economic Factors Influencing Waste Management**

2902 Economic aspects like prices, subsidies, and taxation play a crucial role in waste management, especially in the context of supply constraints.
2903

2904 **INFLUENCE OF RAW MATERIAL PRICES**

2905 High prices for primary raw materials can incentivize the recycling of secondary materials. This economic motivation can lead to advancements in recycling technology and
2906 increased recycling efforts.
2907

2908 **SECONDARY RAW MATERIAL PRICING**

2909 The pricing of secondary raw materials, often influenced by the availability and price
2910 of primary materials, affects their attractiveness for recycling. Competitive pricing of
2911 secondary materials can promote their use over primary materials.

2912 **GOVERNMENTAL POLICIES: SUBSIDIES AND TAXATION**

2913 Policies involving subsidies for recycling activities or taxation on primary raw materials
2914 can shape the waste management landscape. These fiscal tools can encourage or
2915 discourage recycling based on their design and application.

2916 **MARKET DYNAMICS AND POLICY INTERVENTIONS**

2917 Market dynamics, influenced by policy interventions, can also impact waste management.
2918 For example, a policy promoting the use of recycled materials can alter market
2919 preferences and boost recycling efforts.

2920 ***Incorporation of supply constraints and market dynamics into the model***

2921 **SENSITIVITY ANALYSIS**

2922 Sensitivity analysis is an instrumental approach in modelling to ascertain the impact
2923 of supply constraints and market dynamics on the waste management system. This
2924 technique involves systematically varying parameters within the model and observing the
2925 resultant effects on the output. It is particularly beneficial in identifying which variables
2926 have the most significant influence on the system's behaviour.

2927 Global Sensitivity Analysis, an extension of this concept, examines the entire parameter
2928 space, offering a comprehensive view of potential model responses to changes in input
2929 factors. This method is crucial in revealing the relative importance of different variables
2930 and can highlight areas where the system is most susceptible to economic fluctuations.

2931 By utilising sensitivity analysis, decision-makers can better understand the robustness
2932 of their systems and formulate strategies that are resilient to economic uncertainties.

EXAMPLE

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

Scenario:

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

Analysis:

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

Outcome:

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

EXAMPLE

Reduction of a Valuable Material in the Waste Stream:

Scenario:

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

Analysis:

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

Outcome:

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

OPTIMISATION

2938 Optimisation techniques are employed to identify the most efficient operational settings for the waste management system under diverse economic conditions. By modelling
2939 various local scenarios that encapsulate different economic realities — such as varying
2940 levels of resource scarcity, price dynamics of primary versus secondary materials, and the
2941 impact of subsidies or taxes — the model aims to find the optimal balance. This balance
2942 could be in terms of cost-effectiveness, resource utilization, environmental impact, or a
2943 combination of these factors. Optimization provides a framework to make data-driven
2944 decisions that can enhance the efficiency and sustainability of the waste management
2945 system.

2946 Multi-Objective Optimisation is a key aspect of this process, where multiple conflicting
2947 objectives are considered simultaneously. This approach is essential in waste management
2948 systems, where there is often a need to balance economic goals with environmental
2949 sustainability.

2951 By employing optimisation techniques, particularly Multi-Objective Optimisation, the model can provide insights into the trade-offs and synergies between different objectives, thereby facilitating more informed and balanced decision-making in waste management policies and operations.

EXAMPLE

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

Scenario:

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

Analysis:

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

Outcome:

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

EXAMPLE

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

Scenario:

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

Analysis:

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

Outcome:

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

2960
2961

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

2962

BATT (BATTERY WASTE)

- 2963
2964
2965
2966
2967
- Fluctuating availability and prices of lithium and cobalt can significantly impact the recycling value and processes for batteries.
 - Governmental policies on battery disposal and recycling can alter the landscape of battery waste management, influencing recycling rates and methodologies.

2968

CDW (CONSTRUCTION AND DEMOLITION WASTE)

- 2969
2970
2971
2972
- Variations in the construction market and raw material prices can influence the generation and composition of construction and demolition waste.
 - Economic incentives and regulatory frameworks for sustainable construction practices can drive the recycling and reuse rates of CDW.

2973

ELV (END-OF-LIFE VEHICLES)

- 2974
2975
2976
2977
- Changes in the metal market, particularly for steel and aluminium, can impact the profitability of recycling ELVs.
 - Environmental regulations on vehicle disposal and recycling can shape the recovery strategies for ELV waste.

2978

MIN (MINING WASTE)

- 2979
2980
2981
2982
- Market demand for specific minerals can influence the focus and intensity of recovery efforts from mining residues.
 - Policy changes regarding mine waste management can lead to shifts in recovery and disposal practices for mining residues.

2983

SLASH (SLAGS AND ASHES)

- 2984
2985
2986
2987
2988
2989
- The variability in the composition of slags and ashes due to different industrial processes and raw materials can significantly influence recovery and recycling strategies.
 - Market conditions for secondary raw materials derived from slags and ashes, such as metals, can greatly affect the economic viability of their recovery and recycling processes.

2990

WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

2991

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

2992

2993

2994

2995

2996
2997

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

2998

3000

3001

3002

3003

3004

3005

3006

3007

3008

3009

3010

3011

3012

WASTE STREAM NOTICE

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

 **BATT (BATTERY WASTE)**

- X

 **CDW (CONSTRUCTION AND DEMOLITION WASTE)**

- X

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

- X

 **MIN (MINING WASTE)**

- X

 **SLASH (SLAGS AND ASHES)**

- X

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

- X

3013

4.3.7. Conclusion

REVIEW NOTICE

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

3014

3015

3016

4.4. INTERNAL ELEMENTS — TECHNOLOGICAL CHANGE

3017

4.4.1. Introduction

Technological Change

Scenario elements

- Product technology (composition)
- Recovery technology
- Recovery system development

Waste model parameters include:

- **Lifetimes:**
function of product technology
- **Composition:**
function of product composition,
durability, design-for-repair, etc.

Recovery model parameters include:

- **Recovery processes:**
market penetration of recovery technologies
- **Transfer coefficients:**
function of recovery technologies
- **Recovery system size:**
BAU - set by trends in BAU, CIR & REC - defined by model outcomes within constraints

3018

3019

3020

3021

3022

3023

Product technology and recovery technology development will differ across scenarios and across product groups in each waste stream. These differences must be integrated into individual stock-flow models through interpretations of the scenarios and the conversion of these into estimations of the changes.

3024 recognising the need for assumptions about technological advancements in products
3025 and recovery processes. The document stresses the importance of addressing product
3026 technology development until 2050, as this will vary in importance across different waste
3027 streams.

3028 4.4.2. Methodology

3029 1. Scenario Analysis:

3030 Different future scenarios are explored to understand how technological develop-
3031 ment might unfold. This includes examining existing and new technologies, their
3032 properties over time, and how they are diffused into the market.

3033 2. Waste Stream Focus:

3034 The approach varies in importance across different waste streams like EEE, ELV, BATT,
3035 CDW, and SLASH. For each stream, specific assumptions and approaches need to
3036 be tailored.

3037 3. Data Collection:

3038 Gathering data from various sources, including patents, scientific publications, busi-
3039 ness reports, and expert opinions, to inform assumptions about technology devel-
3040 opment.

3041 4. Modelling Approach:

3042 Utilizing dynamic Material Flow Analysis (dMFA) for modelling, covering a timeline
3043 from 2000 to 2050. This includes historical data analysis and future projections
3044 based on assumptions.

3045 5. Technology Diffusion:

3046 Understanding the rate and manner in which technologies gain market share, de-
3047 picted through S-curves. This involves considering factors like price, legislation, and
3048 organizational support.

3049 6. Assumptions on Technology Development:

3050 Outlining specific assumptions at the level of each waste stream and aligning these
3051 assumptions across streams where possible.

3052 7. Integration into SF Models:

3053 Incorporating the assumptions about product and recovery technology development
3054 into SF models to reflect the scenario-based variations.

3055 8. Transparency and Communication:

3056 Ensuring that the chosen approaches and assumptions are clearly stated for trans-
3057 parency and ease of understanding.

3058 The methodology is designed to provide a comprehensive understanding of how
3059 future technology developments can impact various aspects of waste management and
3060 resource recovery in a circular economy context.

3061

4.4.3. Summary

REVIEW NOTICE

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

3062

3063

4.4.4. Future product and waste composition: *Description*

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

Task 2.2 and 2.3

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

Definition

SCENARIO TRENDS FOR: Future product and waste composition



Scenario I — Business-as-usual:

Stable



Scenario II — Recovery:

Strong shift toward design for recycling, remanufacturing, recovery



Scenario III — Circularity:

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

Context

International and European Trends

Implementation in EU Law

Development of a metric for XXX

Benefits and risks

ENVIRONMENTAL BENEFITS AND RISKS

MANUFACTURERS' PERSPECTIVE

3082

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

3083

Relevance of XXX to Critical Raw Materials in Waste Streams

3084

3085

3086

3087

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).

3088

BATTERIES (BATT)

3089

- X

3090

END-OF-LIFE VEHICLES (ELV)

3091

- X

3092

WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

3093

- X

3094

CONSTRUCTION AND DEMOLITION WASTE (CDW)

3095

-

3096

3097

3098

4.4.5. Future product and waste composition: *Scenarios*

3099

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

3100

3101

Summary

3102

REVIEW NOTICE

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

3103

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

3104

X

3105

**BATT (BATTERY WASTE)**

3106

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3107

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

3108

**MIN (MINING WASTE)**

3109

**SLASH (SLAGS AND ASHES)**

3110

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

3111





Scenario II: Recovery

3113

X

3114

**BATT (BATTERY WASTE)**

3115

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3116

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

3117

**MIN (MINING WASTE)**

3118

**SLASH (SLAGS AND ASHES)**

3119

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

3120

3121



3122



Scenario III: Circularity

3123

X

3124

**BATT (BATTERY WASTE)**

3125

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3126

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

3127

**MIN (MINING WASTE)**

3128

**SLASH (SLAGS AND ASHES)**

3129

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

3130



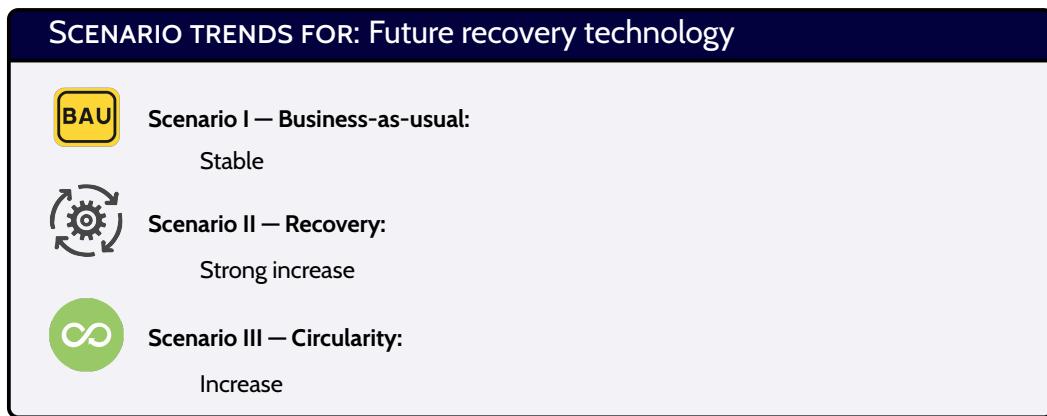
3131



4.4.6. Future recovery technology: *Description*

Definition

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



Context

Ultimately, resource efficiency is determined by how well the links among products, EOL processing, recyclate quality, recycling, and metallurgical technology are understood and optimized and, thence, how much material eventually lands in landfill because its complex composition eliminates its economic value. Poor material stewardship occurs and ultimately landfills exist because of a failure to create economically viable recyclates. Although the second law of thermodynamics imposes limits on recyclability, such failures also result from avoidable mistakes such as inadequate product design, collection systems, and process optimization.

Ensuring continued resource availability and material flow into sustainable products requires well-designed systems that capture these resources from end-of-life (EOL) products and recycle them into new applications. Understanding the impact of product design and recycling system performance on this closure of material cycles requires comprehensive approaches consistent with basic principles, as presented in this article.

To inform policy and design resource supply and recycling systems, one must have detailed knowledge and understanding of recycling and high-temperature processing technology, as well as the effects of product design and possible changes in products and consumer behavior. A robust system design will help maximize resource efficiency, for example, reducing landfill usage, while securing the long-term supply of metals for products in the renewable-energy and other sustainability sectors.

3161 Ultimately, resource efficiency is determined by how well the links among products,
3162 EOL processing, recyclate quality, recycling, and metallurgical technology are understood
3163 and optimized and, thence, how much material eventually lands in landfill because its
3164 complex composition eliminates its economic value. Poor material stewardship occurs
3165 and ultimately landfills exist because of a failure to create economically viable recyclates.
3166 Although the second law of thermodynamics imposes limits on recyclability, such failures
3167 also result from avoidable mistakes such as inadequate product design, collection systems,
3168 and process optimization.

3169 Our research and development provides a theoretical basis for understanding the
3170 minimization of waste creation and hence the environmental burden of product and metal
3171 usage. It underpins resource efficiency with a theoretical basis, which is an important
3172 tool to help maintain and safeguard resources used in manufactured products, including
3173 scarce critical elements.

3174 [113]

3175 ***International and European Trends***

3176 ***Implementation in EU Law***

3177 ***Development of a metric for XXX***

3178 ***Benefits and risks***

3179 **ENVIRONMENTAL BENEFITS AND RISKS**

3180 **MANUFACTURERS' PERSPECTIVE**

3181

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

3182

Relevance of XXX to Critical Raw Materials in Waste Streams

3183

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).

3184

3185

3186

3187



BATT (Battery waste)

3188

3189



ELV (End-of-Life Vehicles)

3190

3191



WEEE (Waste Electrical and Electronic Equipment)

3192

3193



CDW (Construction and Demolition Waste)

3194

3195



MIN (Mining Waste)

3196

3197



SLASH (Slags and Ashes)

3198

3199

3200



3201

4.4.7. Future recovery technology: Scenarios

WASTE STREAM NOTICE

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

3202

3203

3204

Summary

REVIEW NOTICE

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

3205

3206



Scenario I: Business-as-usual

3207

X

3208

**BATT (BATTERY WASTE)**

3209

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3210

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

3211

**MIN (MINING WASTE)**

3212

**SLASH (SLAGS AND ASHES)**

3213

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

3214



3216



Scenario II: Recovery

3217

X

3218

**BATT (BATTERY WASTE)**

3219

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3220

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

3221

**MIN (MINING WASTE)**

3222

**SLASH (SLAGS AND ASHES)**

3223

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

3224



3225



Scenario III: Circularity

3226

X

3227

**BATT (BATTERY WASTE)**

3228

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3229

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

3230

**MIN (MINING WASTE)**

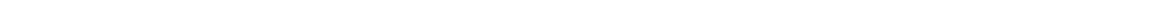
3231

**SLASH (SLAGS AND ASHES)**

3232

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

3233



3234

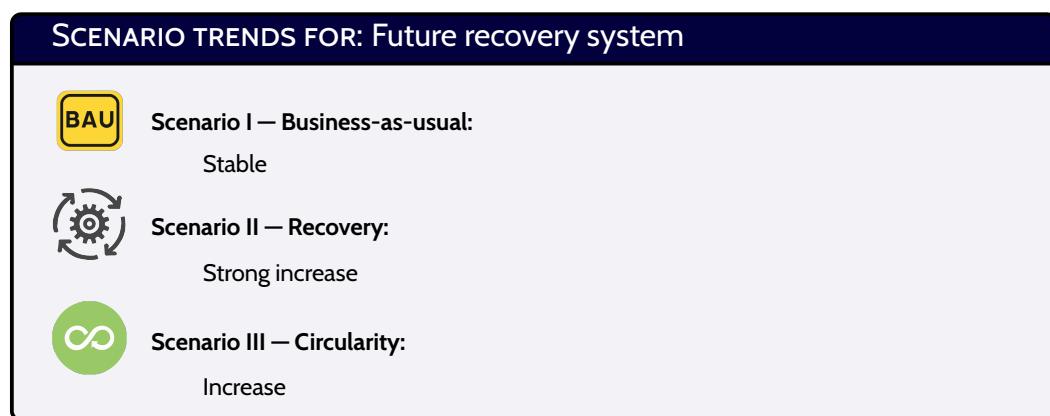


3235

4.4.8. Future recovery system: *Description*

3236

Definition



3237

3238

3239

Context

3240

International and European Trends

3241

Implementation in EU Law

3242

Development of a metric for XXX

3243

Benefits and risks

3244

ENVIRONMENTAL BENEFITS AND RISKS

3245

MANUFACTURERS' PERSPECTIVE

3246

BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

3247

Relevance of XXX to Critical Raw Materials in Waste Streams

3248

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).

3249

3250

3251

3252

BATT (Battery waste)

3253



3254

ELV (End-of-Life Vehicles)

3255



3256

WEEE (Waste Electrical and Electronic Equipment)

3257



3258

CDW (Construction and Demolition Waste)

3259



3260

MIN (Mining Waste)

3261



3262

SLASH (Slags and Ashes)

3263



3264



3265



3266

4.4.9. Future recovery system: *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

3267

3268

3269

Summary

REVIEW NOTICE

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

3270

3271



Scenario I: Business-as-usual

3272

X

3273

**BATT (BATTERY WASTE)**

3274

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3275

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

3276

**MIN (MINING WASTE)**

3277

**SLASH (SLAGS AND ASHES)**

3278

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

3279



3281



Scenario II: Recovery

3282

X

3283

**BATT (BATTERY WASTE)**

3284

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3285

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

3286

**MIN (MINING WASTE)**

3287

**SLASH (SLAGS AND ASHES)**

3288

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

3289



3290



Scenario III: Circularity

3291

**BATT (BATTERY WASTE)**

3292

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3293

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

3294

**MIN (MINING WASTE)**

3295

**SLASH (SLAGS AND ASHES)**

3296

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

3297



3298



Conclusion

REVIEW NOTICE

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

3299

3300

3301

3302

3303

3304

4.5. INTERNAL ELEMENTS — THE CIRCULAR ECONOMY

3305

4.5.1. Introduction

3306

Main sources: [16, 71, 114–122]

Circular Strategies
<p>Scenario elements</p> <ul style="list-style-type: none">• R0-2: Refuse, Reduce, Reuse (including 'sharing economy')• R3: Repair• R4-5: Refurbish and Remanufacture
<p>Waste model parameters include:</p> <ul style="list-style-type: none">• Put-on-market: function of consumer behaviour (internal)• Lifetimes: function of repair rate, durability, design-for-repair• Waste composition: function of product composition, durability (weight), design-for-repair, etc.• Collection rate: function of consumer engagement in re-X strategies, collection infrastructure, legislation, export rate
<p>Recovery model parameters include:</p> <ul style="list-style-type: none">• Transfer coefficients: function of design-for-(re-X) strategies, recovery technology (internal)• Recovery system size: function of collection rate

3307

3308

3309 **The Circular Economy and its re-X strategies**

3310 The re-X strategies underpin the circular economy, embodying a range of actions and
3311 approaches. These strategies are conceptualised in various ways, depending on the
3312 focus and perspective of different authors. The description that follows is based on the
3313 framework provided by [122], with a detailed mapping of these strategies illustrated in
3314 Figure 4.12.

3315 **R0: Refuse**

3316 — This concept is applied both in consumer and producer contexts. For consumers,
3317 it means choosing not to buy or use products or services that are not needed or
3318 are unsustainable, thereby preventing waste creation. For producers, it involves
3319 refusing the use of specific hazardous materials and designing production processes
3320 to avoid waste. This approach is integral to shifting towards a more post-material
3321 lifestyle and reducing packaging waste.

3322 **R1: Reduce**

3323 — Reduce is used in a consumer-oriented, producer-oriented, and generic sense.
3324 It encompasses using products less frequently, with more care, and for longer,
3325 and making repairs for life extension. For producers, it involves using less material
3326 per unit of production, a concept known as dematerialization. It also includes
3327 participation in the sharing economy through pooling and sharing products.

3328 **R2: Resell/Reuse**

3329 — Resell and Reuse involve bringing products back into the economy after initial
3330 use, either by reselling or reusing them for the same or a different purpose. This
3331 concept includes direct reuse of products such as second-hand sales and reuse
3332 in fabrication like refurbishment and remanufacturing. Quality inspections, minor
3333 repairs, and online consumer-to-consumer auctions are part of this strategy.

3334 **R3: Repair**

3335 — Repair aims to extend the product's lifespan by bringing it back to working order,
3336 fixing minor defects, or replacing broken parts. It can be performed by various actors,
3337 including the customer, repair companies, or through non-commercial peer-to-peer
3338 repair workshops. Planned repairs and ad-hoc repairs are both included under this
3339 concept.

3340 **R4: Refurbish**

3341 — Refurbishing typically applies to large multi-component products where many
3342 components are replaced or repaired, resulting in an overall upgrade of the product.
3343 This process brings the product up to a state-of-the-art level using newer, more
3344 advanced components, and is often seen in industries like aviation and construction.

3345 **R5: Remanufacture**

3346 — Remanufacture involves disassembling, checking, cleaning, and replacing or re-
3347 pairing the full structure of a product in an industrial process. It is distinguished from
3348 refurbishing by the extent of disassembly and replacement of components, often
3349 resulting in a product that is like new but with a shorter expected lifespan due to
3350 the use of recycled components.

3351 **R6: Repurpose**

3352 — Repurposing involves adapting discarded goods or components for another func-
3353 tion, giving the material a distinct new lifecycle. This can result in both low and
3354 high-value end-products and is popular in industrial design and art communities. Ex-
3355 amples include transforming defective microchips into jewellery or plastic sheeting
3356 into handbags.

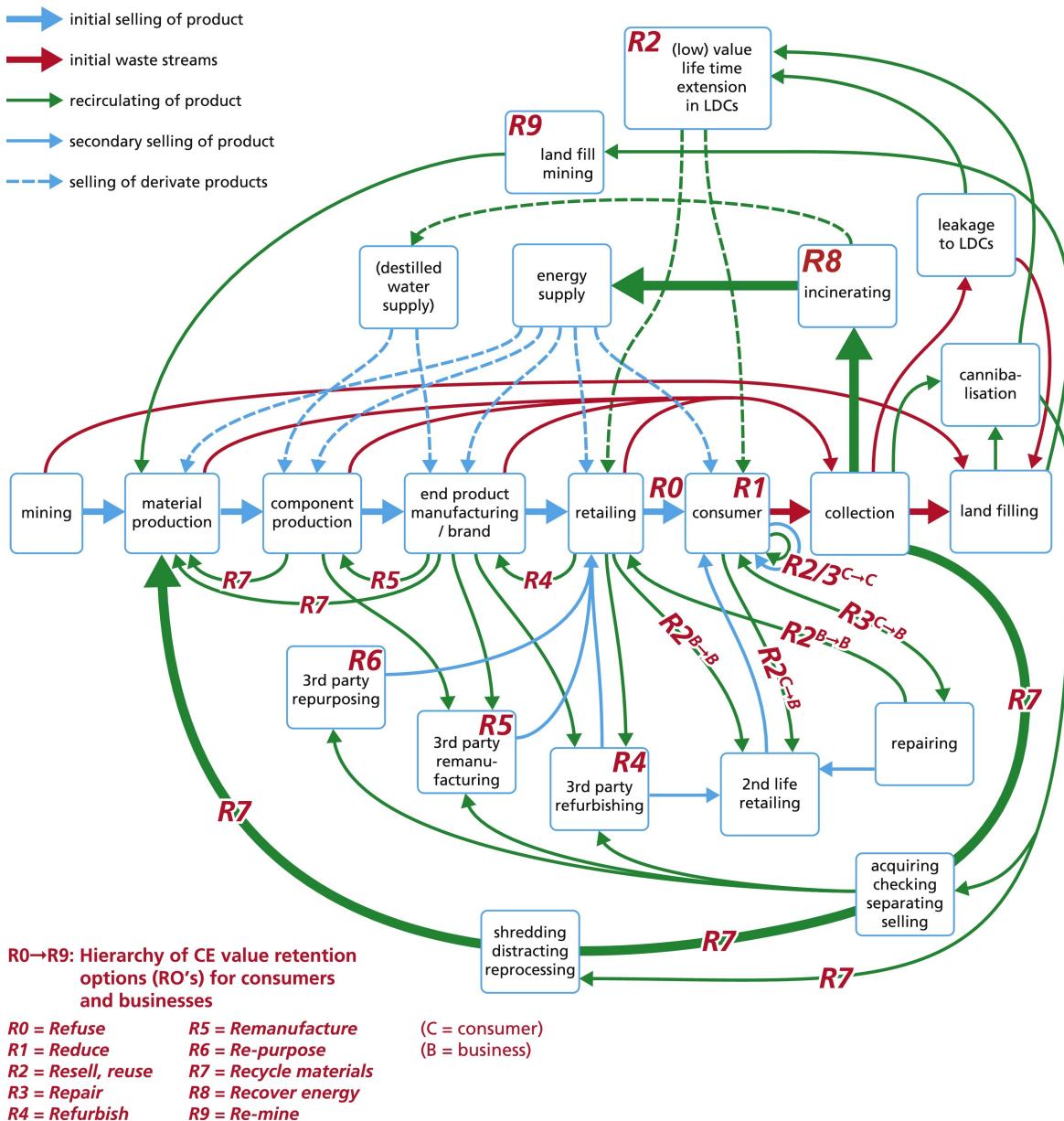


Figure 4.12: A detailed mapping of the re-X strategies in the circular economy [122]

EU CIRCULAR ECONOMY INDICATORS (CEIs)

See the EU working documents [116] and [123] for more detailed assessment of progress relating to the CEIs. Table 4.6 presents an overview of the EU's CEIs including their target for 2023.

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

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

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

Table 4.6: EU Circular Economy Indicators (CEIs) and their targets for 2023 [123]

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

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

3382 Figure 4.13 depicts the CEIs, their trends from 2000-2022, and their linear forecasts
3383 until 2050. An interactive figure can be viewed here [8](#). Note that the linear trends are
3384 not deemed to be representative of the actual future values, but are used to illustrate the
3385 trends and the magnitude of the changes. There will be constraints defined to limit and
3386 shape the growth of the CEIs in each of the scenarios. The settings for this will be
3387 determined from the waste stream quantification and the scenario storylines.

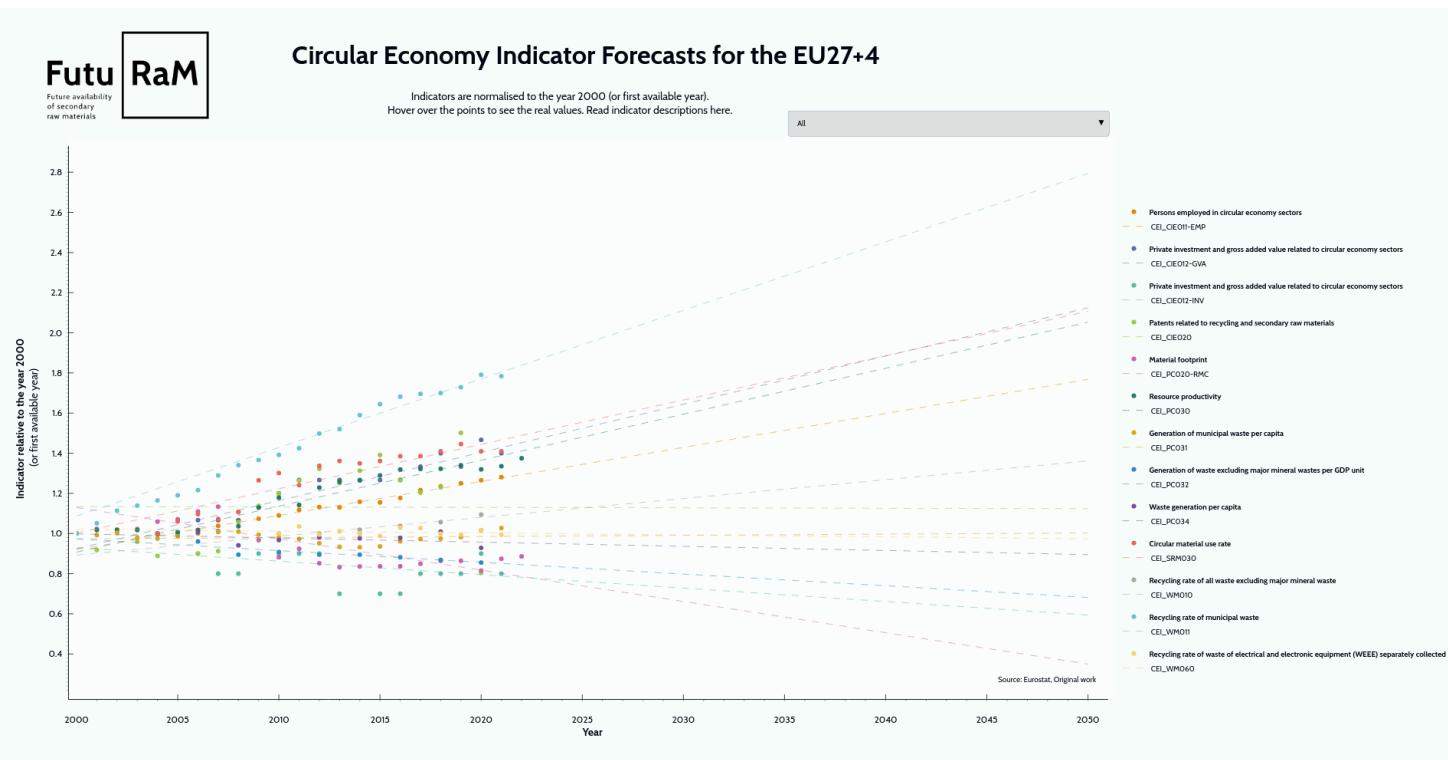


Figure 4.13: EU Circular Economy Indicators (CEIs) - trends from 2000-2022 and linear forecasts.

4.5.2. Summary

REVIEW NOTICE

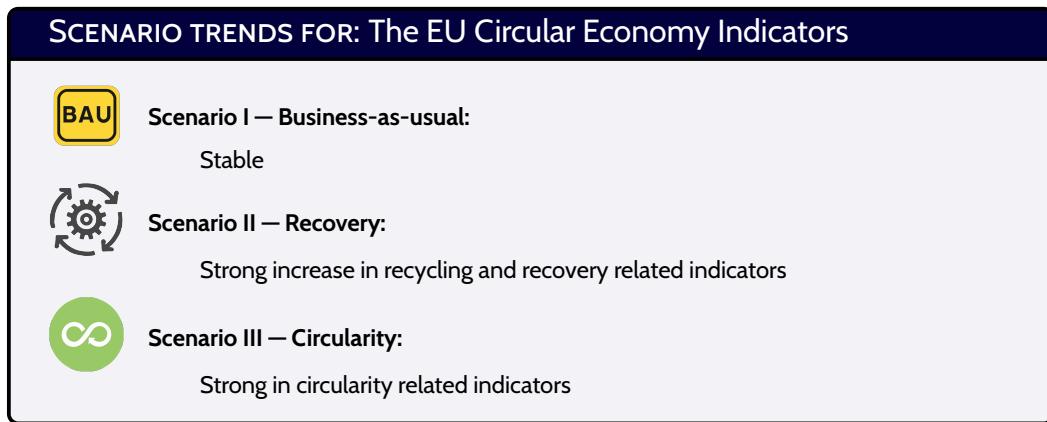
This section will be compiled once the individual waste stream sections for each parameter are complete.

The environmental and socio-economic impacts of raw material use are most effectively addressed at the product group level. Examining a product group as a whole, rather than focusing on individual resources or materials, allows for a comprehensive understanding and management of its utilization and the environmental impacts across the production chain and product lifecycle [121]. Additionally, setting impact targets for product groups aligns more closely with the capacity of stakeholders within the chain to modify resource usage or mitigate related environmental impacts.

Although the nature and magnitude of raw material use impacts can differ significantly among product groups, necessitating tailored impact targets, there is also a need for simplicity in target setting. A manageable and communicable approach for governments is to aim for a significant reduction, such as halving the environmental impact at the product group level. The benefit of establishing more general effect targets lies in the flexibility it offers for varying focuses across different product groups. A target set at the product group level is not only clear and easily communicable but also acknowledges the complexity and diversity inherent in a circular economy.

4.5.3. The EU Circular Economy Indicators: *Description*

[116, 123, 124]



Economic Indicators

**CEI_CIEO11: PERSONS EMPLOYED IN CIRCULAR ECONOMY SECTORS &
CEI_CIEO12: 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, Prodcom 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_PCO20: MATERIAL FOOTPRINT****Indicator metadata:** **Context:**

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

Indicator Description:

This indicator assesses the global demand for material extraction driven by EU consumption and investment. The Material Footprint provides insight into the environmental burden shifted to other regions due to the EU's consumption patterns. It is expressed through the Raw Material Consumption (RMC) metric, indicating the material extraction required for goods consumed within the EU.

Unit:

The unit of measure is tonnes per capita.

Source Data:

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

CEI_PCO31: 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_SRMO30: 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. [60]

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 [33, 34]. The indicator's transition from 'Recycling rate of e-waste' to its current form is to align more closely with the CE monitoring framework revisions.

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

- Applicable up to the year 2018 for EEE classified under 10 product categories as outlined in Annex I of the Directive, with Annex II providing a corresponding indicative product list.
- Applicable from the year 2019 forward, where all EEE will be classified within 6 product categories as delineated in Annex III.

Unit:

The percentage serves as the unit of measure

Source Data:

Data procurement is executed by the ESS and supplied by Eurostat. The indicator's underlying data stems from:

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

3640

3641



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

3643

3644

Summary

REVIEW NOTICE

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

3646

3647



Scenario I: Business-as-usual

3648

XX

3650

3651

**BATT (BATTERY WASTE)**

3652

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3653

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

3654

**MIN (MINING WASTE)**

3655

**SLASH (SLAGS AND ASHES)**

3656

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

3657





Scenario II: Recovery

3658

XX

3660

3661

**BATT (BATTERY WASTE)**

3662

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3663

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

3664

**MIN (MINING WASTE)**

3665

**SLASH (SLAGS AND ASHES)**

3666

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

3667

3668



Scenario III: Circularity

3669

XX

3670

3671

**BATT (BATTERY WASTE)**

3672

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3673

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

3674

**MIN (MINING WASTE)**

3675

**SLASH (SLAGS AND ASHES)**

3676

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

3677

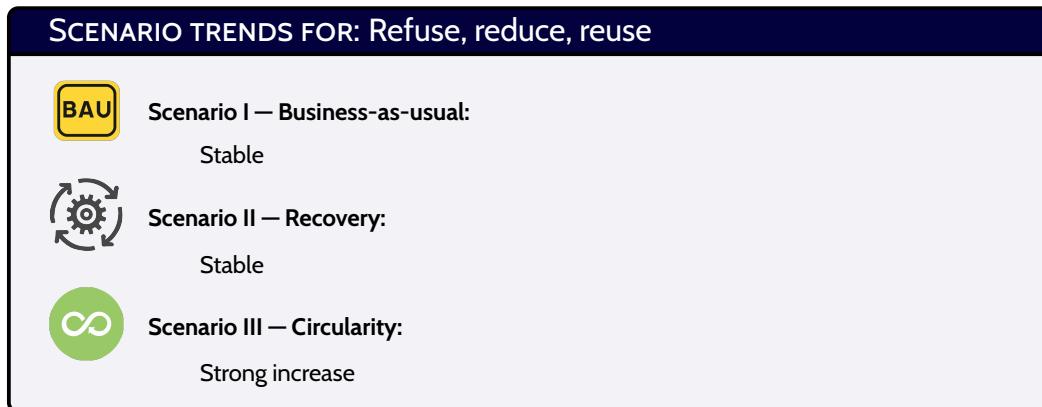


3678



4.5.5. Refuse, Reduce, Reuse: *Description*

Refuse, Reduce, and Reuse are the first three short loops (R0-2) in the circular economy scheme. They exist close to the consumer and can be linked to commercial or non-commercial actors engaged in extending the product's lifespan [125].



These strategies are pivotal in the circular economy, effectively reducing the environmental impact of products or services.

- R0: Refuse: Choosing not to purchase products or services that are unnecessary or unsustainable.
- R1: Reduce: Decreasing the quantity of products or services used or needed.
- R2: Reuse: Utilising products or services again for the same or a different purpose.

These strategies will be incorporated into FutuRaM's modelling framework through:

- Waste volume reduction from:
 - Reduction in overall demand, that is, the put on market (POM) of a product or service.
 - Reduction in the amount of material used in a product or service (efficiency).
 - Extension of the lifetime of products from reuse.
- Changes in the composition of waste, as some products are more amenable to being refused or reused than others.

Definitions

REFUSE

Refuse encompasses consumer and producer decisions aimed at minimising waste creation and reducing environmental impact. For consumers, it involves choosing not to purchase products that are not environmentally friendly and reducing overall consumption. In the production context, it signifies the deliberate avoidance of certain materials or processes to enhance circularity, such as eschewing hazardous substances or designing to minimise waste. Refuse, as a concept, prioritises waste prevention at the source and is integral to fostering a more circular economy [122].

REDUCE

Reduce refers to strategies aimed at minimising the use of natural resources, including energy, raw materials, and thereby reducing waste generation. This concept is multi-faceted:

- For consumers, it involves using products less frequently, caring for and repairing products to extend their life, and participating in the sharing economy.
- For producers, it focuses on using less material per production unit, often referred to as 'dematerialisation', and incorporating these principles early in the Concept and Design Life Cycle.

Reduction is also linked to the notion of Reuse, as decreasing the quantity of products (like cars) can incentivise their reuse. Policy measures to enforce reduction, such as banning single-use plastics or imposing environmental taxes, are essential for effective implementation [126].

Reuse Reuse is about extending the life of products in their original form for as long as possible, thus conserving resources and energy. It involves maintaining and repairing products to keep them in use and developing business models that support these practices. Examples include:

- Reusable packaging initiatives in various industries.
- Encouraging the reuse of items like clothing, furniture, and electronics.
- Deposit-refund systems that incentivise product return and reuse.

Reuse strategies are vital for reducing the consumption of new products and avoiding the dichotomy of 'new for the rich, reused for the poor', promoting equitable and sustainable consumption patterns [115].

4.5.6. Refuse, Reduce, Reuse: Scenarios

WASTE STREAM NOTICE

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

3736

3737

3738

REVIEW NOTICE

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

3739

3740



Scenario I: Business-as-usual

3741

XX

3743

3744

**BATT (BATTERY WASTE)**

3745

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3746

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

3747

**MIN (MINING WASTE)**

3748

**SLASH (SLAGS AND ASHES)**

3749

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

3750



3751



Scenario II: Recovery

3752

XX

3753

3754

**BATT (BATTERY WASTE)**

3755

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3756

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

3757

**MIN (MINING WASTE)**

3758

**SLASH (SLAGS AND ASHES)**

3759

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

3760



3761



Scenario III: Circularity

3762

XX

3763

3764

**BATT (BATTERY WASTE)**

3765

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

3766

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

3767

**MIN (MINING WASTE)**

3768

**SLASH (SLAGS AND ASHES)**

3769

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

3770

3771



4.5.7. Repair: Description

[127–131]

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.

SCENARIO TRENDS FOR: Repair



Scenario I – Business-as-usual:

Stable



Scenario II – Recovery:

Stable



Scenario III – Circularity:

Strong increase

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 [132]

3793 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.

3794
3795
3796
3797
3798
3799 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.

3800
3801
3802
3803
3804 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.

3805
3806
3807
3808
3809 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

[129–131]

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

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

- **Legal Guarantees:**

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

- **Design Requirements:**

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

- **Financial Incentives:**

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

- **Copyright Law Exemptions:**

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

- **Consumer Information:**

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

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

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

- **Communication and Awareness:**

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

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.

Further measures considered include:

- Amending Directive 2005/29/EC to prohibit presenting products as allowing repair when such repair is not possible, as well as omitting to inform consumers that it is not possible to repair goods in accordance with legal requirements.
- Amending Directive 2005/29/EC to prohibit omitting to inform the consumer that the good is designed to limit its functionality when using consumables, spare parts, or accessories that are not provided by the original producer.
- Traders to provide, before the conclusion of the contract, for all types of goods, where applicable, the reparability score of the good as provided by the producer in accordance with Union law, to allow consumers to make an informed transactional decision and choose goods that are easier to repair.
- Ensuring information such as on the availability of spare parts and a repair manual, should no reparability score be available at the Union level.

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

In addition, as part of the implementation of the EU Circular Economy Action Plan [15], the European Commission has carried out a study for the analysis and development of a possible scoring system to inform about the ability to repair and upgrade products [131] and has an ongoing project in the Product Bureau to develop and propose new metrics [134, 135].

Development of a metric for repairability

[131–138]

The trend in consumer goods towards reduced durability and repairability has been contributing to an increase in waste electronic and electrical equipment (WEEE). The Organization for Economic Co-operation and Development has suggested that extending product lifetimes through enhanced durability and repairability is a viable solution to this growing issue. The European Commission's Circular Economy Action Plan reinforces this viewpoint, advocating for maintaining the value in products for as long as possible by imposing durability and repairability requirements. In response, several scoring systems for repairability have been developed to guide standardization efforts, aid market surveillance authorities, and inform consumer decision-making.

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

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

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

In 2021, France took a pioneering step by integrating the reparability index into national legislation. [139] 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 repairability index marks an assertive step towards the broader adoption of such measures. Looking ahead, enhancements like a durability index may offer greater insights into the long-term usability of products.

In parallel, organizations such as TÜV SÜD are actively supporting the repairability testing landscape, aligning with standards like the French Repairability Scoring Index to ensure products fulfil specified repairability criteria [140]. Their approach factors in documentation, disassembly, and the availability of spare parts and repair services, highlighting a practical, though less detailed, framework compared to France's comprehensive index.

Benefits and risks

ENVIRONMENTAL BENEFITS AND RISKS

[131, 141]

The implementation of the right to repair holds considerable promise for the reduction of environmental impacts if applied appropriately. It must be recognized that electronic equipment replacement often occurs not solely due to product failure. Influencing factors such as perceived obsolescence contribute significantly, as evidenced by a study in Austria revealing only 30% of replacements were attributable to malfunctioning products [128].

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

Moreover, the environmental benefit of repair is contingent not only on the increased product lifespan post-repair but also on the environmental footprint of the spare parts required for repair. Circuit boards, for example, carry substantial environmental impacts, and their replacement could still result in significant environmental costs. Common repairs typically involve less impactful components such as screens, casings, batteries, or software [127].

Cordella et al. [127] report that compared to the baseline of replacing smartphones every two years, extending the device's life through repair can substantially diminish the carbon footprint. A one-year extension, with a battery change, can reduce greenhouse gas (GHG) emissions by 29%, and by 44% with a two-year extension.

With 472 million Europeans owning a mobile phone, there are 8.11 Mt CO₂-eq. in annual emissions solely from phones. Extending the life of a mobile phone by just one year, including component replacements, could reduce emissions to 6.23 Mt CO₂-eq. annually [132]. 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.

3972 Nevertheless, these potential reductions should be interpreted with caution as they
3973 are based on estimations and may not account for potential rebound effects. For instance,
3974 economic savings from prolonged use of electronic devices could lead to rebound ef-
3975 fects where savings are offset by additional consumption stemming from the economic
3976 savings [142].

3977 Finally, repair activities offer a more energy-efficient alternative within the Circular
3978 Economy compared to recycling and remanufacturing, which demand extensive energy
3979 input and high material throughput. When feasible, repair should be prioritized over other
3980 circular economy strategies [131].

3981 MANUFACTURERS' PERSPECTIVE

- 3982 • Compliance with eco-design standards could reduce profit margins.
- 3983 • Risk of increased liability and the need to ensure long-term availability of spare
3984 parts.
- 3985 • Potential decrease in turnover due to extended product lifecycles.
- 3986 • Reduction in EU imports could foster the EU's technological independence, as
3987 per the EU Chips Act.
- 3988 • Loss in turnover potentially offset by repair services and spare parts supply.

3989 BROADER ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

- 3990 • Right to Repair could enhance competitiveness by increasing product longevity
3991 and added value.
- 3992 • Positive impact on professional repair services, spare parts provision, and tool
3993 providers.
- 3994 • SMEs and local repair shops likely to benefit significantly.
- 3995 • Potential for the development of new European leaders in repair services.
- 3996 • A more repairable design could improve recycling processes and increase com-
3997 ponent harvesting.

3998 ***Relevance of Repairability to Critical Raw Materials in Waste Streams***

3999 The integration of the 'Right to Repair' ethos and the promotion of repairability has
4000 implications for the management of Critical Raw Materials (CRMs) across various waste
4001 streams, such as BATT (waste batteries), ELV (end-of-life vehicles), WEEE (waste electrical
4002 and electronic equipment), and CDW (construction and demolition waste).

4003 **BATTERIES (BATT)**

4004
4005
Batteries are a crucial repository of CRMs like lithium, cobalt, and nickel. Enhancing their repairability can lead to:

- 4006
4007
4008
4009
- Refurbishing batteries for second-life applications.
 - Design modifications for easier replacement of battery cells.
 - Reduced extraction of new raw materials, mitigating the environmental footprint.

4010 END-OF-LIFE VEHICLES (ELV)

4011
4012
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:

- 4013
4014
- Influence design changes for modularity and ease of part replacement.
 - Prolong the utility of CRMs and lessen new resource extraction.

4015 WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

4016
4017
The WEEE stream contains valuable CRMs like gold, silver, and rare earth elements. Promoting repairability results in:

- 4018
4019
4020
- 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.

4021 CONSTRUCTION AND DEMOLITION WASTE (CDW)

4022
4023
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:

- 4024
- Lead to buildings designed for deconstruction, not demolition.

4025
4026
4027
4028
4029

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.

4.5.8. Repair: Scenarios

WASTE STREAM NOTICE

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

4032

4033

4034

4035

Summary

REVIEW NOTICE

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

4036

4037



Scenario I: Business-as-usual

4038

XX

4040

4041

**BATT (BATTERY WASTE)**

4042

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4043

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

4044

**MIN (MINING WASTE)**

4045

**SLASH (SLAGS AND ASHES)**

4046

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

4047





Scenario II: Recovery

4048

XX

4050

4051

**BATT (BATTERY WASTE)**

4052

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4053

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

4054

**MIN (MINING WASTE)**

4055

**SLASH (SLAGS AND ASHES)**

4056

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

4057





Scenario III: Circularity

4058

XX

4060

4061

**BATT (BATTERY WASTE)**

4062

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4063

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

4064

**MIN (MINING WASTE)**

4065

**SLASH (SLAGS AND ASHES)**

4066

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

4067



4068



4.5.9. Remanufacturing and Refurbishing: *Description*

Definition

Remanufacturing involves disassembling the full structure of a multi-component product, inspecting, cleaning, repairing, or replacing necessary parts, and reassembling it to its original state or better. This process can include both reused and new components, aiming to achieve a quality level that meets or exceeds the new product [122, 143, 144].

Refurbishing, often confused with remanufacturing, is the process where the overall structure of a large multi-component product remains intact, while components are replaced or repaired, resulting in an overall 'upgrade' of the product. It aims to bring the product up to a specified quality, possibly incorporating newer, more advanced components [122].

SCENARIO TRENDS FOR: Remanufacturing and Refurbishing



Scenario I — Business-as-usual:

Stable



Scenario II — Recovery:

Stable



Scenario III — Circularity:

Strong increase

4081

4082 **Context**

4083 Remanufacturing and refurbishing are essential strategies in the circular economy, aimed
4084 at extending product lifecycles and reducing waste. They are particularly relevant in the
4085 medium long loops (R4-R6) of product recovery, where they serve as business activities
4086 indirectly linked to the consumer [145].

4087 ***International and European Trends***

4088 Remanufacturing is gaining momentum globally, particularly in the U.S. and Europe.
4089 Governments are legislating manufacturers to assume responsibility for their products
4090 post-use, emphasizing recyclability and waste reduction. The market for environmen-
4091 tally friendly products, valued at over USD 200 billion, is driving corporations to adopt
4092 remanufacturing and other green practices [146, 147].

4093 ***Implementation in EU Law***

4094 EU laws increasingly mandate manufacturers to engage in product recovery, including
4095 remanufacturing. This aligns with the EU's broader goals of sustainable development,
4096 resource efficiency, and transitioning to a circular economy [31, 145].

4097 ***Economic Scale and Regional Focus in Europe***

4098 The remanufacturing industry in Europe generates around €30bn in turnover and employs
4099 about 190,000 people. Key regions like Germany, the UK, Ireland, France, and Italy
4100 have significant remanufacturing activities. Germany leads in remanufacturing turnover,
4101 particularly in aerospace, automotive, and heavy-duty off-road (HDOR) sectors [145].

4102 ***Benefits and Risks***

4103 **Environmental Benefits and Risks:**

4104 Remanufacturing significantly reduces environmental impact by conserving raw
4105 materials and energy, while risks may include the potential for resource-intensive
4106 processes if not efficiently managed.

4107 **Manufacturers' Perspective:**

4108 For manufacturers, remanufacturing offers economic benefits, with costs typically
4109 40–60% lower than manufacturing new products. It also enhances corporate image
4110 and competitive advantage in a market increasingly sensitive to environmental
4111 concerns [146].

4112 **Broader Economic and Environmental Implications:**

4113 Remanufacturing contributes to a sustainable economy, offering a less resource-
4114 intensive alternative to new production. It supports employment, innovation, and
4115 reduces dependency on raw material extraction.

4116

Benefits and Risks

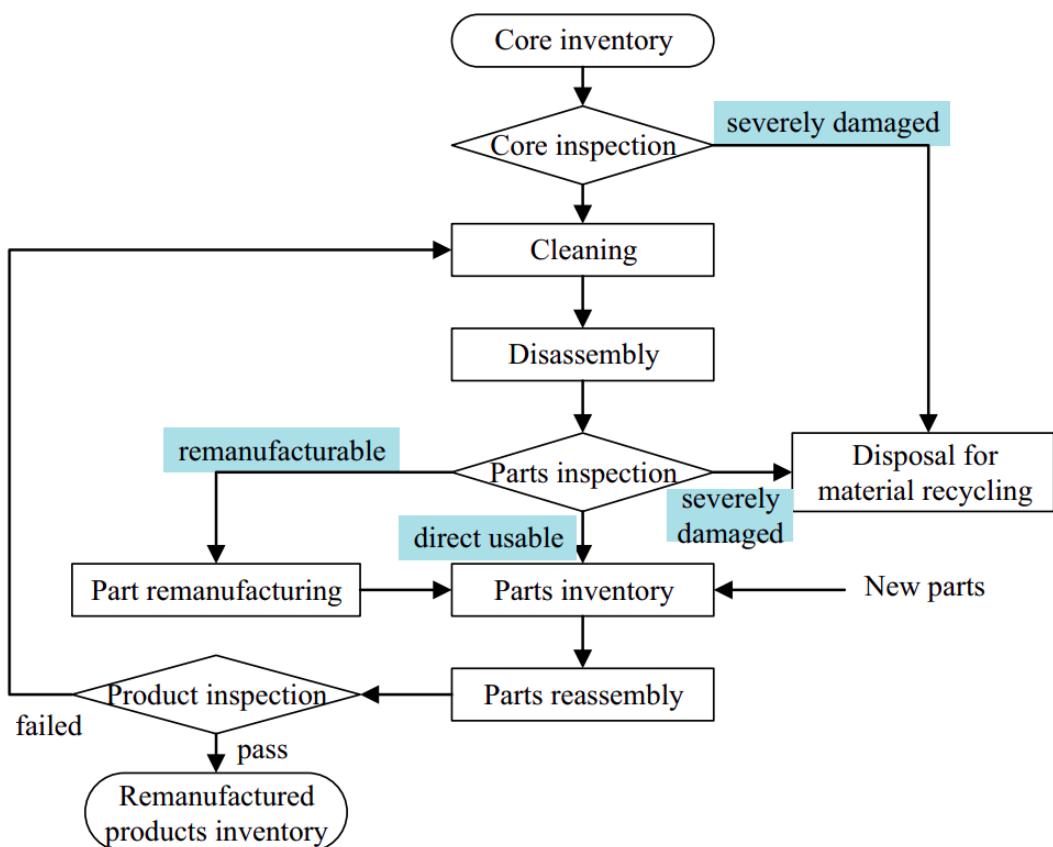


Figure 4.14: An example of a generic remanufacturing process for vehicle components [149]

4149

4150



4151
4152

Relevance of Remanufacturing and Refurbishing in FutuRaM's Waste Streams



BATT (Battery waste)

- 4154
4155
4156
4157
4158
- Electric Vehicle Batteries: Remanufacturing can involve replacing degraded cells or modules to extend their lifespan, thereby conserving lithium and cobalt.
 - Laptop Batteries: Through remanufacturing, individual cells within the battery pack can be replaced or upgraded, enhancing the overall battery life and efficiency.



ELV (End-of-Life Vehicles)

- 4160
4161
4162
4163
- Automotive Engines: Remanufacturing can include refurbishing engine components, such as pistons and bearings, to restore performance and efficiency.
 - Transmission Systems: Rebuilding transmission systems with replaced or refurbished gears and bearings can significantly extend the life of the vehicle.



WEEE (Waste Electrical and Electronic Equipment)

- 4165
4166
4167
4168
- Smartphones: Remanufacturing can involve replacing batteries, screens, and other components to restore them to like-new condition.
 - Printers and Copiers: Components such as toner cartridges, drums, and fusers can be remanufactured to extend their service life and improve functionality.



CDW (Construction and Demolition Waste)

- 4170
4171
4172
4173
4174
- Structural Steel Elements: In construction and demolition, steel beams and columns can be refurbished and reused in new construction projects.
 - Wooden Beams and Flooring: Wooden elements can be remanufactured through processes like sanding, treating, and reinforcing for reuse in construction.

4177

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

4178

4179

4180

Global trends

4181

Summary

REVIEW NOTICE

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

4182

4183



Scenario I: Business-as-usual

4185 XX

4186

4187

**BATT (BATTERY WASTE)**

4188

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4189

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

4190

**MIN (MINING WASTE)**

4191

**SLASH (SLAGS AND ASHES)**

4192

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

4193





Scenario II: Recovery

4194

XX

4196

4197

**BATT (BATTERY WASTE)**

4198

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4199

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

4200

**MIN (MINING WASTE)**

4201

**SLASH (SLAGS AND ASHES)**

4202

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

4203



Scenario III: Circularity

4204

4205 XX

4206

4207

**BATT (BATTERY WASTE)**

4208

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4209

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

4210

**MIN (MINING WASTE)**

4211

**SLASH (SLAGS AND ASHES)**

4212

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

4213



4214

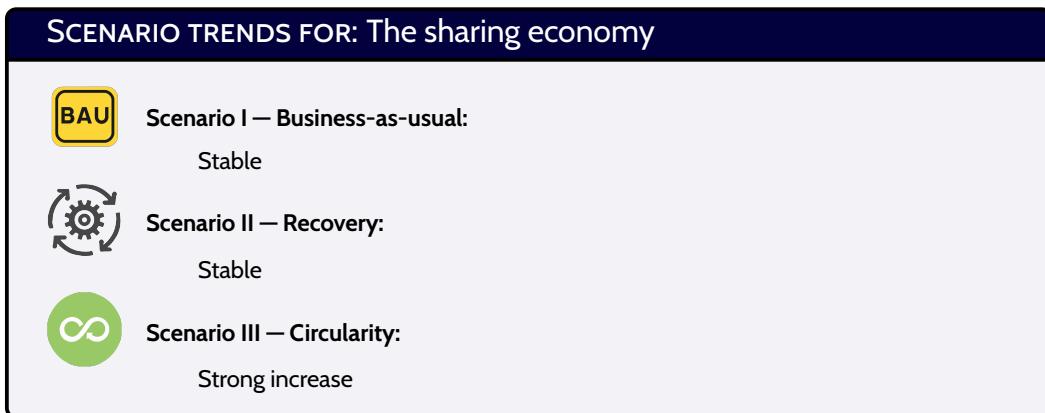


4.5.11. The Sharing Economy: *Description*

[150–155]

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[155]. 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 [151]. This figure is expected to grow, indicating the sharing economy's increasing importance within the EU's economic structure.

Environmental Prospects

[150, 151, 153]

See [155] 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.

4275 Eco-efficiency is enhanced when environmental resources are utilised more effectively,
4276 leading to an increased use of products with minimal environmental burden. This is
4277 exemplified in collaborative fashion consumption, which could reduce the prevalent
4278 overconsumption in the fashion industry. By facilitating the exchange of underused
4279 clothing, the sharing economy can increase the lifecycle of garments and encourage the
4280 production of more durable products.

4281 Beyond the realm of fashion, car sharing and shared accommodation are other aspects
4282 of the sharing economy with notable environmental benefits. Car sharing can significantly
4283 reduce the number of vehicles needed, thereby lowering exhaust emissions. Similarly,
4284 shared accommodations have been associated with significantly lower carbon dioxide
4285 emissions compared to conventional hotel stays.

4286 However, the question of whether the sharing economy indeed delivers environmental
4287 benefits remains contested. [155, 156] Detractors highlight the potential for an increase in
4288 environmental burdens, particularly if the heightened usability of shared goods escalates
4289 greenhouse gas emissions. The environmental and socio-economic impacts engendered
4290 by the collaborative economy are intricate and highly variable across different business
4291 models. Generally speaking, collaborative consumption models that optimise the use
4292 of existing assets tend to exhibit a lower environmental footprint compared to their
4293 traditional counterparts. Nevertheless, there is a risk that the financial savings afforded by
4294 collaborative consumption could spur additional spending and consumption, which might
4295 negate the direct environmental savings. Despite such reservations, the prevailing view is
4296 that the sharing economy, by transforming consumption from ownership to communal
4297 use, can yield considerable environmental advantages.

4298 **Implications for Waste Streams**

4299 The adoption of sharing economy principles can influence various waste streams, includ-
4300 ing:

- 4301 • **BATT (Waste Batteries):** As devices are shared and utilized more efficiently,
4302 the frequency of battery disposal could decline, mitigating the waste battery
4303 stream.
- 4304 • **CDW (Construction and Demolition Waste):** The sharing of construction
4305 equipment and machinery could potentially slow down the turnover rate of
4306 these items, reducing associated waste.
- 4307 • **WEEE (Waste Electrical and Electronic Equipment):** Sharing electronic de-
4308 vices extends their lifecycle and reduces the rate at which they are discarded,
4309 thereby impacting electronic waste volumes.
- 4310 • **ELV (End-of-Life Vehicles):** A shift towards car-sharing services could reduce
4311 the demand for manufacturing new vehicles, potentially leading to a downturn
4312 in the generation of automotive waste.

4313 The trajectory of the sharing economy indicates a shift towards collective usage pat-
4314 terns. Its continuing evolution could play a critical role in the future of critical raw material
4315 recovery systems by affecting demand and the lifecycle of products, which, in turn, in-
4316 fluences waste stream outputs. The broader implications for the raw materials sector
4317 are significant, suggesting a possible recalibration of recovery strategies for critical raw
4318 materials in light of emerging consumption patterns.

4319 **Challenges in Measuring Sharing Economy Growth**

4320 Identifying a universal metric for the growth of the sharing economy is challenging due to
4321 its diverse and dynamic nature. Current measures, such as STOXX Global sharing economy
4322 indices, Solactive Sharing Economy Index and the INDXX US Sharing Economy Index,
4323 largely revolve around the market sizes of prominent sharing economy companies, such
4324 as Uber and Airbnb. These indices, while useful, predominantly reflect the scalability of
4325 these businesses rather than the sharing economy's broader impacts on production and
4326 waste reduction.

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

4327

4328

4329

4330

4331

4332

4333

4334

4335

4.5.12. The Sharing Economy: Scenarios

WASTE STREAM NOTICE

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

4336

4337

4338

Summary

REVIEW NOTICE

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

4339

4340



Scenario I: Business-as-usual

4341

XX

4343

4344

**BATT (BATTERY WASTE)**

4345

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4346

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

4347

**MIN (MINING WASTE)**

4348

**SLASH (SLAGS AND ASHES)**

4349

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

4350



4351



Scenario II: Recovery

4352

XX

4353

4354



BATT (BATTERY WASTE)

4355



CDW (CONSTRUCTION AND DEMOLITION WASTE)

4356



ELV (END-OF-LIFE VEHICLES)

4357



MIN (MINING WASTE)

4358



SLASH (SLAGS AND ASHES)

4359



WEEE (WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT)

4360



4361



Scenario III: Circularity

4362

XX

4363

4364

**BATT (BATTERY WASTE)**

4365

**CDW (CONSTRUCTION AND DEMOLITION WASTE)**

4366

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

4367

**MIN (MINING WASTE)**

4368

**SLASH (SLAGS AND ASHES)**

4369

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

4370

4371



Conclusion

REVIEW NOTICE

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

4373

4374

4375

4376

4.6. CONCLUSION

REVIEW NOTICE

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

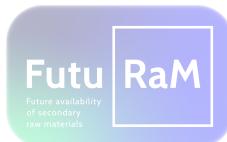
4377

4379

4380

4381

4382





4383

4384

Interpretation

4385

CHAPTER CONTENTS

4386	5.1 Introduction	202
4387	5.2 Conclusion	203



5.1. INTRODUCTION

REVIEW NOTICE

This section will be constructed at a later stage of the project.

4389

4390



5.2. CONCLUSION

REVIEW NOTICE

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

4391

4393

4394



4395

4396

4397



4398

Modelling — Waste generation

4399

4400

CHAPTER CONTENTS

6.1 Introduction	205
----------------------------	-----



4402

6.1. INTRODUCTION

4403

Development of the codebase for the waste generation models is ongoing.

REVIEW NOTICE

This section will be constructed at a later stage of the project.

4404

4405

4406



4407



4408

4409



4410

Modelling — Recovery system

4411

4412

CHAPTER CONTENTS

7.1	Introduction	208
-----	------------------------	-----



7.1. INTRODUCTION

4414

Development of the codebase for the recovery model is ongoing.

4415

REVIEW NOTICE

This section will be constructed at a later stage of the project.

4416

4417

4418



4419



4420

4421



4422

Modelling — Integration

4423

CHAPTER CONTENTS

8.1 Introduction	211
----------------------------	-----

4424



8.1. INTRODUCTION

REVIEW NOTICE

This section will be constructed at a later stage of the project.

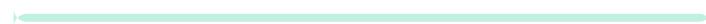
4426

4427

4428



4429



4430

4431



4432

Impacts

4433

CHAPTER CONTENTS

4434

9.1 Introduction	214
----------------------------	-----

9.1. INTRODUCTION

Task 2.4

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

4435

4437

REVIEW NOTICE

This section will be constructed at a later stage of the project.

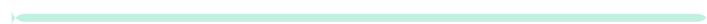
4438

4439

4440



4441



4442



4443

Bottlenecks

4444

CHAPTER CONTENTS

4445

10.1 Introduction	217
-----------------------------	-----

4446



10.1. INTRODUCTION

Task 2.5

Assess the environmental and socioeconomic impacts and bottlenecks of future SRM recovery (ULEI, TUB, Empa, UNITAR, Chalmers, UNITAR, WEEECycle) (M37-M47)

This task will develop a report based on an assessment on the pressures and bottlenecks associated with environmental and socioeconomic issues related to each waste sector, including the associated changes and impacts on imports and of primary raw materials production (D2.1).

4448

4449

REVIEW NOTICE

This section will be constructed at a later stage of the project.

4450

4451

4452



4453



4454



4455

Conclusion

4456

CHAPTER CONTENTS

4457



REVIEW NOTICE

This section will be constructed at a later stage of the project.

4458

4459

4460



4461

4462



4463

References

4464

4465 Literature referred to in section 13.4 is excluded from the following lists of references,
4466 except for those titles cited elsewhere in the report.

4467

CHAPTER CONTENTS

4468	12.1 Legislation and Government Documents	222
4469	12.2 Reports	224
4470	12.3 Datasets	227
4471	12.4 Books	228
4472	12.5 Book Chapters	228
4473	12.6 Articles	229
4474	12.7 Online Sources	235
4475	12.8 Miscellaneous	235



12.1. LEGISLATION AND GOVERNMENT DOCUMENTS

- [2] European Commission. *European Critical Raw Materials Act*. European Commission, 2023. URL: https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en (cit. on pp. vii, 6, 7).
- [15] European Commission. *A New Circular Economy Action Plan For a Cleaner and More Competitive Europe*. European Commission, 2020. DOI: 10.2779/05068. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN> (cit. on pp. xvii, 6, 172).
- [31] European Commission. *The European Green Deal*. European Commission, 2019. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN> (cit. on pp. 6, 101, 182).
- [32] European Commission. *Directive 2002/96/EC Of The European Parliament and of The Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)*. European Commission, 2003. URL: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0024:0038:en:PDF> (cit. on p. 6).
- [33] European Commission. *Directive 2012/19/EU of the European Parliament and of the council of 4 July 2012 on waste electrical and electronic equipment (WEEE) text with EEA relevance*. European Commission, 2012. URL: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:197:0038:0071:EN:PDF> (cit. on pp. 6, 33, 42, 52, 157).
- [34] European Commission. *Directive 2012/19/EU of the European Parliament and of the council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast)*. European Commission, 2012. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019> (cit. on pp. 6, 33, 42, 52, 157).
- [36] European Commission. *Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC*. European Commission, 2023. URL: <https://eur-lex.europa.eu/eli/reg/2023/1542/oj> (cit. on pp. 6, 32, 40, 51).
- [37] European Commission. *Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU) No 2019/1020*. European Commission, 2020. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020PC0798> (cit. on pp. 6, 8, 32, 40, 51).
- [50] Government of the Netherlands. *A Circular Economy in the Netherlands by 2050*. 2016. URL: https://circulareconomy.europa.eu/platform/sites/default/files/17037circulaireconomie_en.pdf (cit. on pp. 30, 38, 48).
- [60] European Commission. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)*. European Commission, 2008. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098> (cit. on pp. 34, 43, 54, 156).
- [71] Government of the Netherlands. *National Circular Economy Programme 2023-2030*. 2023. URL: <https://www.government.nl/binaries/government/documenten/reports/2023/09/27/national-circular-economy-programme-2023-2030/NPCE+Circulaire+Economie+rapport+Engels.pdf> (cit. on pp. 46, 142).
- [74] United Nations General Assembly. *Transforming our world: the 2030 Agenda for Sustainable Development*. 2015. URL: <https://www.refworld.org/docid/57b6e3e44.html> (cit. on p. 50).
- [75] European Commission. *Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC*. European Commission, 2023. URL: <http://data.europa.eu/eli/dir/2014/53/2023-10-01> (cit. on p. 53).
- [99] European Parliament and Council of the European Union. *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation*

- 4524
4525
4526
4527
(EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. Directive. European Parliament and Council of the European Union, 31st Oct. 2023. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413 (cit. on p. 94).
- 4528 [100] European Commission. *Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: REPowerEU Plan*. Communication. European Commission, 2022. URL: https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF (cit. on pp. 94, 101).
- 4530
4531
4532
4533 [105] European Commission. *Fit for 55 - The EU's plan for a green transition - Consilium*. 2021. URL: <https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/#package> (cit. on p. 101).
- 4534
4535
4536 [106] European Parliament and Council of the European Union. *Draft Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 (first reading) - Interinstitutional File: 2021/0218(COD)*. Interinstitutional File. European Parliament and Council of the European Union, 6th Oct. 2023. URL: <https://data.consilium.europa.eu/doc/document/ST-13188-2023-ADD-1-REV-3/en/pdf> (cit. on pp. 103, 104).
- 4537
4538
4539
4540
4541
4542 [116] European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a Monitoring Framework for the Circular Economy*. COM (2018) 29 Final. 2018. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:29:FIN> (visited on 02/11/2018) (cit. on pp. 142, 144, 151).
- 4543
4544
4545
4546
4547 [123] European Commission. *Commission Staff Working Document: Measuring Progress towards Circular Economy in the European Union – Key Indicators for a Revised Monitoring Framework Accompanying the Document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a Revised Monitoring Framework for the Circular Economy*. Staff Working Document. SWD/2023/306 final. 2023. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023SC0306> (cit. on pp. 144, 145, 151).
- 4548
4549
4550
4551
4552
4553
4554 [133] Directorate-General for Justice European Commission and Consumers. *Proposal for a Directive of the European Parliament and of the Council on Common Rules Promoting the Repair of Goods and Amending Regulation (EU) 2017/2394, Directives (EU) 2019/771 and (EU) 2020/1828*. Directive Proposal. 2023. URL: https://eur-lex.europa.eu/resource.html?uri=cellar:cdbeaa83-c94e-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF (cit. on pp. 171, 172).
- 4555
4556
4557
4558
4559
4560
4561
4562 [139] Ministère de la transition écologique. *Décret n°2020-1757 du 29 décembre 2020 relatif à l'indice de réparabilité des équipements électriques et électroniques [Decree No. 2020-1757 of 29 December 2020 on the repairability index of electrical and electronic equipment]*. Légifrance. NOR: TRED2023604D, ELI: <https://www.legifrance.gouv.fr/eli/decret/2020/12/29/TRED2023604D/jo/>

4563
4564 texte, Aliases: <https://www.legifrance.gouv.fr/eli/decret/2020/12/29/2020-1757/jo/texte>, JORF n°0316 of 31 December 2020, Text n°5. Paris, 2020 (cit. on p. 173).

4565 12.2. REPORTS

- 4566 [3] European Commission et al. *Study on the critical raw materials for the EU 2023 — Final report*. 2023.
4567 DOI: 10.2873/725585. URL: <https://data.europa.eu/doi/10.2873/725585> (cit. on p. vii).
- 4568 [6] Lena Börjeson et al. *Towards a user's guide to scenarios - a report on scenario types and scenario*
4569 *techniques*. 2005. URL: <https://www.osti.gov/etdeweb/biblio/20688312> (cit. on pp. xvi, 3,
4570 12, 14).
- 4571 [13] Vivienne Halleux. *New EU regulatory framework for batteries: Setting sustainability requirements*. 2021.
4572 URL: [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2021\)689337](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)689337)
4573 (cit. on pp. xvii, 32, 40, 51).
- 4574 [18] International Energy Agency (IEA). *Critical Minerals Market Review 2023*. 2023. URL: <https://www.iea.org/reports/critical-minerals-market-review-2023> (cit. on pp. xviii, 100, 108).
- 4575 [19] Lucia Mancini, Camillo De Camillis and David Pennington. *Security of supply and scarcity of raw*
4576 *materials: Towards a methodological framework for sustainability assessment*. 2013. DOI: 10.2788/94926.
4577 URL: <https://eplca.jrc.ec.europa.eu/uploads/RawMat-scarcity-of-raw-materials.pdf> (cit. on p. xviii).
- 4578 [38] Marcin Szczepański. *Resilience of global supply chains: Challenges and solutions*. 2021. URL: [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2021\)698815](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)698815) (cit. on p. 9).
- 4579 [49] International Energy Agency (IEA). *World Energy Outlook 2022*. 2022. URL: <https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf> (cit. on p. 29).
- 4580 [51] Hoesung Lee, Katherine Calvin, Dipak Dasgupta et al. *Climate Change 2023 Synthesis Report Summary*
4581 *for Policymakers*. 2024. URL: <https://www.ipcc.ch/report/ar6/syr/> (cit. on p. 30).
- 4582 [52] A. Løvik, C. Marmy, M. Ljunggren et al. *Material composition trends in vehicles: critical raw materials and*
4583 *other relevant metals*. Eur 30916 En. 2021. DOI: 10.2760/351825. URL: <https://publications.europa.eu/en/publication/30916>.
- 4584

- 4589 jrc.ec.europa.eu/repository/bitstream/JRC126564/JRC126564_01.pdf (cit. on pp. 32,
4590 41, 51).
- 4591 [53] N. Tazi et al. *Initial analysis of selected measures to improve the circularity of critical raw materials and*
4592 *other materials in vehicles*. 2023. DOI: 10.2760/207541. URL: <https://publications.jrc.ec.europa.eu/repository/handle/JRC132821> (cit. on pp. 32, 41, 51).
- 4593 [54] L. Ljunggren, A. Løvik, D. Kushnir et al. *RMIS – Raw materials in vehicles*. 2022. URL: <https://rmis.jrc.ec.europa.eu/veh%5C#/p/intro> (cit. on pp. 32, 41, 51).
- 4594 [55] International Energy Agency (IEA). *Global EV Outlook 2023*. 2022. URL: <https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEV02023.pdf> (cit. on
4595 pp. 32, 41, 51).
- 4596 [56] K. Parajuly, R. Kuehr, A. K. Awasthi et al. *Future E-waste Scenarios*. StEP Initiative, UNU ViE-SCYCLE,
4597 UNEP IETC, 2019. URL: <https://www.unep.org/ietc/resources/publication/future-e-waste-scenarios> (cit. on pp. 33, 42, 52).
- 4598 [57] United Nations Institute for Training United Nations Environment Programme and Research. *Electronic and Electrical Waste Outlook in West Asia*. 2023. URL: <https://wedocs.unep.org/20.500.11822/42147> (cit. on pp. 33, 42, 52).
- 4599 [58] Vanessa Forti, Cornelis P Balde, Ruediger Kuehr et al. *The Global E-waste Monitor 2020: Quantities,*
4600 *flows and the circular economy potential*. 2020. URL: https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf (cit. on pp. 33, 42, 52).
- 4601 [59] Jaco Huisman et al. *Countering WEEE Illegal Trade (CWIT) Summary Report, Market Assessment, Legal*
4602 *Analysis, Crime Analysis and Recommendations Roadmap*. 2015. DOI: 10.13140/rg.2.1.4864.2328.
4603 URL: <http://i.unu.edu/media/ias.unu.edu-en/news/10221/CWIT-Final-Summary1.pdf> (cit. on p. 42).
- 4604 [60] Ellen MacArthur. *Towards a circular economy: Business rationale for an accelerated transition*. 2015.
4605 URL: https://emf.thirdlight.com/file/24/_A-BkCs_h7gfln_Am1g_JKe2t9/Towards%20a%20circular%20economy%3A%20Business%20rationale%20for%20an%20accelerated%20transition.pdf (cit. on pp. 46, 47).
- 4606 [61] B. Oberle et al. *Global Resources Outlook 2019: Natural Resources for the Future We Want*. Tech. rep.
4607 Nairobi, Kenya: United Nations Environment Programme, 2019. URL: <https://www.resourcepanel.org/reports/global-resources-outlook> (cit. on p. 74).
- 4608 [62] Robert J. Barro. *Determinants of Economic Growth in a Panel of Countries*. CEMA Working Papers.
4609 China Economics, Management Academy, Central University of Finance and Economics, 2003.
4610 URL: http://www.clmeconomia.jccm.es/pdfclm/barro_i.pdf (cit. on p. 87).
- 4611 [63] Stefano Carrara et al. *Supply chain analysis and material demand forecast in strategic technologies and*
4612 *sectors in the EU – A foresight study*. JRC132889. Luxembourg: Publications Office of the European
4613 Union, 2023. DOI: 10.2760/334074. URL: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC132889/JRC132889_01.pdf (cit. on pp. 94, 95, 100).
- 4614 [64] Keramidas K et al. *Global Energy and Climate Outlook 2022: Energy trade in a decarbonised world*.
4615 Policy assessment. 2022. DOI: 10.2760/863694(online) (cit. on p. 94).
- 4616 [65] International Energy Agency (IEA). *Renewables 2022*. 2022. URL: <https://www.iea.org/reports/renewables-2022> (cit. on pp. 96, 104).
- 4617 [66] International Energy Agency (IEA). *Energy Technology Perspectives 2023*. 2023. DOI: 10.1787/7c6b23db-en.
4618 URL: <https://www.oecd-ilibrary.org/content/publication/7c6b23db-en> (cit. on p. 100).
- 4619 [67] European Commission. *Commission Staff Working Document Implementing the REPowerEU Action*
4620 *Plan: Investment Needs, Hydrogen Accelerator and Achieving the Bio-methane Targets Accompanying the*
4621 *document Communication from the Commission to the European Parliament, the European Council, the*
4622 *Council, the European Economic and Social Committee and the Committee of the Regions REPowerEU*
4623 *Plan COM(2022) 230 final*. Commission Staff Working Document SWD(2022) 230 final. European
4624

- Commission, 18th May 2022. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN> (cit. on p. 105).

[109] European Commission et al. *EU reference scenario 2020 – Energy, transport and GHG emissions – Trends to 2050*. 2021. DOI: doi/10.2833/35750. URL: <https://op.europa.eu/o/opportal-service/download-handler?identifier=96c2ca82-e85e-11eb-93a8-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=> (cit. on p. 106).

[110] Mantzos L et al. *The POTEnCIA Central scenario: an EU energy outlook to 2050*. 2021. DOI: 10.2760/32835. URL: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118353/potencia_central_scenario_online.pdf (cit. on p. 106).

[114] R. Pardo and J.P. Schweitzer. *A Long-term Strategy for a European Circular Economy – Setting the Course for Success*. Policy Paper. Produced for the Think2030 project. Brussels: Think2030, 2018 (cit. on p. 142).

[118] OECD. *Material Resources, Productivity and the Environment*. 2015, p. 172. DOI: <https://doi.org/https://doi.org/10.1787/9789264190504-en>. URL: <https://www.oecd-ilibrary.org/content/publication/9789264190504-en> (cit. on p. 142).

[121] Aldert Hanemaaijer et al. *Possible Objectives for a Circular Economy: Summary of the Dutch policy brief 'Mogelijke doelen voor een Circulaire Economie'*. 4685. The Hague: PBL Netherlands Environmental Assessment Agency, 2021. URL: <https://www.pbl.nl/sites/default/files/downloads/pbl-2021-possible-objectives-for-a-circular-economy-4685.pdf> (cit. on pp. 142, 150).

[131] M. Cordella, F. Alfieri and J. Sanfelix Forner. *Analysis and development of a scoring system for repair and upgrade of products*. 29711 En. Jrc114337. Luxembourg: Publications Office of the European Union, 2019. DOI: 10.2760/725068 (cit. on pp. 169, 171, 172, 174, 175).

[132] M. Moeslinger et al. *Towards an Effective Right to Repair for Electronics*. JRC Technical Reports Jrc129957. Luxembourg: Publications Office of the European Union, 2022. DOI: 10.2760/42722. URL: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC129957/JRC129957_01.pdf (cit. on pp. 169, 171, 172, 174).

[135] Christoforos Spiliotopoulos et al. *Product reparability scoring system: Specific application to smart-phones and slate tablets*. 2022 (cit. on p. 172).

[147] Nabil Nasr et al. *Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy*. Tech. rep. Nairobi, Kenya: United Nations Environment Programme, 2018. URL: <https://www.resourcepanel.org/file/1105/download?token=LPqPM9Bo> (cit. on p. 182).

[151] Robert Vaughan and Raphael Daverio. *PWC report for DG-Grow: Analytical paper on the economic scale and growth of the collaborative economy*. 2016. URL: <https://ec.europa.eu/docsroom/documents/16954/attachments/1/translations/en/renditions/native> (cit. on pp. 190, 191).

[152] European Commission et al. *Study to monitor the economic development of the collaborative economy at sector level in the 28 EU Member States – Final report*. 2018. DOI: doi/10.2873/83555. URL: <https://op.europa.eu/o/opportal-service/download-handler?identifier=0cc9aab6-7501-11e8-9483-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=> (cit. on p. 190).

[153] European Commission et al. *Environmental potential of the collaborative economy – Final report and annexes*. 2018. DOI: doi/10.2779/518554. URL: <https://op.europa.eu/o/opportal-service/download-handler?identifier=8e18cbf3-2283-11e8-ac73-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=> (cit. on pp. 190, 191).

[154] Alberta Andreotti et al. *Participation in the Sharing Economy: Report from the EU H2020 Research Project Ps2Share: Participation, Privacy, and Power in the Sharing Economy*. 2017. DOI: 10.5167/uzh-

- 4685 149823. URL: <https://www.bi.edu/globalassets/forskning/h2020/participation-working-paper.pdf> (cit. on p. 190).
- 4686
- 4687 [160] Intergovernmental Panel on Climate Change (IPCC). *Climate Change and Land*. 2022. doi: 10.1017/9781009157988. URL: <https://doi.org/10.1017/9781009157988> (cit. on p. 240).
- 4688

4689 12.3. DATASETS

- 4690 [79] Eurostat and European Commission. *Population projections - Population and demography - Eurostat*.
4691 2023. URL: <https://ec.europa.eu/eurostat/web/population-demography/population-projections> (cit. on pp. 75, 86).
- 4692
- 4693 [80] Office for National Statistics — ONS. *2020-based interim national population projections: year ending June 2022 estimated international migration variant*. (Accessed on 10/30/2023). 2023. URL: <https://www.ons.gov.uk/file?uri=/peoplepopulationandcommunity/populationandmigration/>
- 4694
- 4695

- 4696 populationprojections/datasets/2020basedinterimnationalpopulationprojectionsyearendingjune2020
4697 ukpopulationxmlopenData/ukppvopendata2020.xls (cit. on pp. 75, 78, 86).
- [84] OECD. *Long-term baseline projections, No. 109 (Edition 2021)*. Accessed on 01 November 2023. 2021. DOI: 10.1787/cbdb49e6-en. URL: <https://www.oecd-ilibrary.org/content/data/cbdb49e6-en> (cit. on pp. 86, 87).
- [91] *Databank / The World Bank*. The World Bank. 2011. URL: <https://databank.worldbank.org/> (cit. on p. 87).
- [103] European Commission, Joint Research Centre. *Forecast of Rare Earths Supply and Demand - Wind Energy and E-Mobility*. Updated 2020-12-17, Accessed 2023-11-13. 2020. URL: <http://data.europa.eu/89h/aa1fc9e1-360d-478e-a6da-51b092f30d32> (cit. on pp. 100, 108).
- [111] International Energy Agency (IEA). *World Energy Outlook 2022*. International Energy Agency (IEA). 2022. URL: <https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf> (cit. on p. 106).
- [124] Eurostat. *Database - Eurostat*. 2023. URL: <https://ec.europa.eu/eurostat/data/database> (cit. on p. 151).

4711 12.4. BOOKS

- 4712 [43] Julian Lincoln Simon. *The ultimate resource 2*. Princeton, NJ: Princeton University Press, 1998 (cit. on p. 29).
- 4713 [44] Julian Lincoln Simon. *The ultimate resource*. Princeton, NJ: Princeton University Press, 1983 (cit. on p. 29).
- 4714 [46] Paul R Ehrlich, Anne H Ehrlich and John P Holdren. *Ecoscience: population, resources, environment*. 3rd ed. New York, NY: W.H. Freeman, 1978 (cit. on p. 29).
- 4715 [47] Paul R Ehrlich. *The Population Bomb*. New York, NY: Random House, 1986 (cit. on p. 29).
- 4716 [89] Robert J. Barro and Xavier Sala-i-Martin. *Economic growth*. 2nd ed. Cambridge, Massachusetts: The MIT Press, 2004 (cit. on p. 87).
- 4717 [120] Walter Stahel. *The Circular Economy - a user's guide*. 2019. ISBN: 978-0-367-20014-5 (cit. on p. 142).

4722 12.5. BOOK CHAPTERS

- 4723 [9] Saskia Sardesai, Markus Stute and Josef Kamphues. "A Methodology for Future Scenario Planning". In: *Next Generation Supply Chains: A Roadmap for Research and Innovation*. Ed. by Rosanna Fornasiero et al. Springer International Publishing, 2021. ISBN: 978-3-030-63505-3. DOI: 10.1007/978-3-030-63505-3_2. URL: https://link.springer.com/chapter/10.1007/978-3-030-63505-3_2 (cit. on pp. xvi, 3).
- 4724 [59] Isabel Narbón-Perpiñá and Diego Prior. "Management of Waste Electrical and Electronic Equipment in European Union Countries: A Comparison". In: *E-waste Recycling and Management: Present Scenarios and Environmental Issues*. Ed. by Anish Khan, Inamuddin and Abdullah M. Asiri. Springer International Publishing, 2020. ISBN: 978-3-030-14184-4. DOI: 10.1007/978-3-030-14184-4_7. URL: https://doi.org/10.1007/978-3-030-14184-4_7 (cit. on pp. 33, 42, 52).
- 4725 [161] Warren E. Walker, Robert J. Lempert and Jan H. Kwakkel. "Deep Uncertainty". In: *Encyclopedia of Operations Research and Management Science*. Ed. by Saul I. Gass and Michael C. Fu. Springer US,

4735
4736 2013, pp. 395–402. ISBN: 978-1-4419-1153-7. DOI: 10.1007/978-1-4419-1153-7_1140. URL:
https://doi.org/10.1007/978-1-4419-1153-7_1140 (cit. on p. 240).

4737 12.6. ARTICLES

- 4738 [1] T. E. Graedel, E. M. Harper, N. T. Nassar et al. "On the materials basis of modern society". In:
4739 *Proceedings of the National Academy of Sciences* (2015). ISSN: 0027-8424. DOI: 10.1073/pnas.
4740 1312752110. URL: <https://doi.org/10.1073/pnas.1312752110> (cit. on p. vii).
- 4741 [5] Karl H Dreborg. "Essence of backcasting". In: *Futures* 9 (1996). ISSN: 0016-3287. DOI: 10.1016/
4742 s0016-3287(96)00044-4. URL: <https://www.sciencedirect.com/science/article/pii/S0016328796000444> (cit. on pp. xvi, 3).
- 4743 [7] Lena Börjeson et al. "Scenario types and techniques: Towards a user's guide". In: *Futures* (2006).
4744 ISSN: 0016-3287. DOI: 10.1016/j.futures.2005.12.002. URL: <https://www.sciencedirect.com/science/article/pii/S0016328705002132> (cit. on pp. xvi, 3, 12, 14).
- 4745 [8] Muhammad Amer, Tugrul U. Daim and Antonie Jetter. "A review of scenario planning". In: *Fu-*
4746 *tures* (2013). ISSN: 0016-3287. DOI: 10.1016/j.futures.2012.10.003. URL: <https://www.sciencedirect.com/science/article/pii/S0016328712001978> (cit. on pp. xvi, 3, 6, 12).
- 4747 [10] Elisabeth A Lloyd and Vanessa J Schweizer. "Objectivity and a comparison of methodological
4748 scenario approaches for climate change research". In: *Synthese* (2014). DOI: 10.1007/s11229-013-
4749 0353-6. URL: <https://doi.org/10.1007/s11229-013-0353-6> (cit. on p. xvi).
- 4750 [11] Fulvio Ardente and Fabrice Mathieu. "Environmental assessment of the durability of energy-using
4751 products: method and application". In: *Journal of Cleaner Production* (2014). ISSN: 0959-6526. DOI:
4752 10.1016/j.jclepro.2014.03.049. URL: <https://www.sciencedirect.com/science/article/pii/S0959652614002807> (cit. on p. xvi).
- 4753 [14] Harald Helander and Maria Ljunggren. "Battery as a service: Analysing multiple reuse and recy-
4754 clining loops". In: *Resources, Conservation and Recycling* (2023). ISSN: 0921-3449. DOI: 10.1016/j.
4755 resconrec.2023.107091. URL: <https://www.sciencedirect.com/science/article/pii/S0921344923002276> (cit. on pp. xvii, 32, 40, 41, 51).
- 4756 [16] Julian Kirchherr, Denise Reike and Marko Hekkert. "Conceptualizing the circular economy: An analysis
4757 of 114 definitions". In: *Resources, Conservation and Recycling* (2017). ISSN: 0921-3449. DOI: 10.1016/
4758
- 4759 [16] Julian Kirchherr, Denise Reike and Marko Hekkert. "Conceptualizing the circular economy: An analysis
4760 of 114 definitions". In: *Resources, Conservation and Recycling* (2017). ISSN: 0921-3449. DOI: 10.1016/
4761
- 4762

- 4763 j .resconrec .2017 .09 .005. URL: <https://www.sciencedirect.com/science/article/pii/S0921344917302835> (cit. on pp. xvii, 142).
- 4764
- 4765 [17] Teresa Domenech and Bettina Bahn-Walkowiak. "Transition towards a resource efficient circular economy in Europe: policy lessons from the EU and the member states". In: *Ecological Economics* (2019) (cit. on p. xvii).
- 4766
- 4767 [20] Martin Geissdoerfer, Marina P.P. Pieroni, Daniela C.A. Pigozzo et al. "Circular business models: A review". In: *Journal of Cleaner Production* (2020). ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2020.123741. URL: <https://doi.org/10.1016/j.jclepro.2020.123741> (cit. on pp. xxi, 53).
- 4768
- 4769 [25] Peter Bishop, Andy Hines and Terry Collins. "The current state of scenario development: An overview of techniques". In: *Foresight - The journal of future studies* (2007). DOI: 10.1108/14636680710727516 (cit. on pp. 3, 12).
- 4770
- 4771 [26] Kathya Cordova-Pozo and Etiënne A.J.A. Rouwette. "Types of scenario planning and their effectiveness: A review of reviews". In: *Futures* (2023). ISSN: 0016-3287. DOI: 10.1016/j.futures.2023.103153 (cit. on pp. 3, 12).
- 4772
- 4773 [27] Jim Skea, Renée van Diemen, Joana Portugal-Pereira et al. "Outlooks, explorations and normative scenarios: Approaches to global energy futures compared". In: *Technological Forecasting and Social Change* (2021) (cit. on pp. 3, 12, 238–240).
- 4774
- 4775 [28] Philip W.F van Notten, Jan Rotmans, Marjolein B.A van Asselt et al. "An updated scenario typology". In: *Futures* (2003). ISSN: 0016-3287. DOI: 10.1016/s0016-3287(02)00090-3. URL: <https://www.sciencedirect.com/science/article/pii/S0016328702000903> (cit. on p. 3).
- 4776
- 4777 [29] Matthew Spaniol and Nicholas Rowland. "The scenario planning paradox". In: *Futures* (2017). DOI: 10.1016/j.futures.2017.09.006. URL: <https://doi.org/10.1016/j.futures.2017.09.006> (cit. on p. 6).
- 4778
- 4779 [30] Herman Kahn and Anthony J. Wiener. "The Next Thirty-Three Years: A Framework for Speculation". In: *Daedalus* (1967). ISSN: 00115266. URL: <http://www.jstor.org/stable/20027066> (cit. on p. 6).
- 4780
- 4781 [39] Bernhard Steubing, Christopher Mutel, Florian Suter et al. "Streamlining scenario analysis and optimization of key choices in value chains using a modular LCA approach". In: *The International Journal of Life Cycle Assessment* (2016) (cit. on p. 11).
- 4782
- 4783 [40] Chia-Chien Hsu and Brian A. Sandford. "The Delphi Technique: Making Sense of Consensus". In: *Practical Assessment, Research, and Evaluation* (2019). ISSN: 1531-7714. DOI: 10.7275/pdz9-th90. URL: <https://scholarworks.umass.edu/pare/vol12/iss1/10> (cit. on p. 12).
- 4784
- 4785 [41] Konstantinos Kokkinos, Vayos Karayannis, Nicholas Samaras et al. "Multi-scenario analysis on hydrogen production development using PESTEL and FCM models". In: *Journal of Cleaner Production* (2023). ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2023.138251. URL: <https://www.sciencedirect.com/science/article/pii/S0959652623024095> (cit. on p. 19).
- 4786
- 4787 [42] Manel Sansa, Ahmed Badreddine and Taieb Ben Romdhane. "Sustainable design based on LCA and operations management methods: SWOT, PESTEL, and 7S". In: (2021). DOI: 10.1016/b978-0-12-823987-2.00019-2. URL: <https://doi.org/10.1016/B978-0-12-823987-2.00019-2> (cit. on p. 19).
- 4788
- 4789 [48] Paul R Ehrlich and Anne H Ehrlich. "The population bomb revisited". In: *The electronic journal of sustainable development* (2009). URL: http://www.ejsd.org/docs/The_Population_Bomb_Revisited.pdf (cit. on p. 29).
- 4790
- 4791 [61] Julia Moschen-Schimek, Thomas Kasper and Marion Huber-Humer. "Critical review of the recovery rates of construction and demolition waste in the European Union — An analysis of influencing factors in selected EU countries". In: *Waste Management* (2023). ISSN: 0956-053x. DOI: 10.1016/j.wasman.2023.05.020. URL: <https://www.sciencedirect.com/science/article/pii/S0956053X23003616> (cit. on p. 34).
- 4792
- 4793 [64] Valentin Vogl, Max Åhman and Lars J. Nilsson. "The making of green steel in the EU: a policy evaluation for the early commercialization phase". In: *Climate Policy* 21.1 (Aug. 2020), pp. 78–92.
- 4794
- 4795
- 4796
- 4797
- 4798
- 4799
- 4800
- 4801
- 4802
- 4803
- 4804
- 4805
- 4806
- 4807
- 4808
- 4809
- 4810
- 4811
- 4812

- 4813 ISSN: 1752-7457. DOI: 10.1080/14693062.2020.1803040. URL: <http://dx.doi.org/10.1080/14693062.2020.1803040> (cit. on pp. 35, 44, 54).
- 4814 [66] C. Asquer et al. "Biomass ash characterisation for reuse as additive in composting process". In: *Biomass and Bioenergy* 123 (Apr. 2019), pp. 186–194. ISSN: 0961-9534. DOI: 10.1016/j.biombioe.2019.03.001. URL: <http://dx.doi.org/10.1016/j.biombioe.2019.03.001> (cit. on pp. 35, 44, 54).
- 4815 [67] Robert U Ayres. "Metals recycling: economic and environmental implications". In: *Resources, Conservation and Recycling* 21.3 (Nov. 1997), pp. 145–173. ISSN: 0921-3449. DOI: 10.1016/S0921-3449(97)00033-5. URL: [http://dx.doi.org/10.1016/S0921-3449\(97\)00033-5](http://dx.doi.org/10.1016/S0921-3449(97)00033-5) (cit. on p. 37).
- 4816 [73] Mario Giampietro and Silvio O. Funtowicz. "From elite folk science to the policy legend of the circular economy". In: *Environmental Science & Policy* (2020). DOI: 10.1016/j.envsci.2020.04.012. URL: <https://doi.org/10.1016/j.envsci.2020.04.012> (cit. on p. 47).
- 4817 [81] Patrizio Vanella, Philipp Deschermeier and Christina B. Wilke. "An Overview of Population Projections–Methodological Concepts, International Data Availability, and Use Cases". In: *Forecasting* (2020), pp. 346–363. ISSN: 2571-9394. DOI: 10.3390/forecast2030019. URL: <https://www.mdpi.com/2571-9394/2/3/19> (cit. on pp. 75, 80).
- 4818 [82] Detlef P. van Vuuren et al. "The Shared Socio-economic Pathways: Trajectories for human development and global environmental change". In: *Global Environmental Change* 42 (2017), pp. 148–
- 4819
4820
4821
4822
4823
4824
4825
4826
4827
4828
4829
4830
4831

- 4832 152. ISSN: 0959-3780. DOI: 10.1016/j.gloenvcha.2016.10.009. URL: <https://www.sciencedirect.com/science/article/pii/S0959378016301790> (cit. on pp. 75, 89).
- 4833
- 4834 [83] Samir KC and Wolfgang Lutz. "The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100". In: *Global Environmental Change* (2017). DOI: 10.1016/j.gloenvcha.2014.06.004 (cit. on pp. 75, 89).
- 4835
- 4836
- 4837 [85] Yvan Guillemette and David Turner. "The long game: Fiscal outlooks to 2060 underline need for structural reform". In: 29 (2021). DOI: 10.1787/a112307e-en. URL: <https://www.oecd-ilibrary.org/content/paper/a112307e-en> (cit. on pp. 87, 89).
- 4838
- 4839
- 4840 [86] Romain Duval and Christine de la Maisonneuve. "Long-run GDP growth framework and scenarios for the world economy". In: *Journal of Policy Modeling* (2010). Also published as OECD Economics Department Working Papers 663 (cit. on pp. 87, 88).
- 4841
- 4842
- 4843 [87] OECD. "Long-term growth scenarios". In: (2012) (cit. on pp. 87, 88).
- 4844
- 4845 [90] N. Gregory Mankiw, David Romer and David N. Weil. "A contribution to the empirics of economic growth". In: *Quarterly Journal of Economics* 107 (1992), pp. 407–437 (cit. on p. 87).
- 4846
- 4847 [92] Lionel Fontagné, Erica Perego and Gianluca Santoni. "MaGE 3.1: Long-term macroeconomic projections of the World economy". In: *International Economics* 172 (2022). URL: http://www.cepii.fr/PDF_PUB/wp/2021/wp2021-12.pdf (cit. on pp. 87, 88).
- 4848
- 4849 [93] Jean Chateau et al. "Long-term economic growth and environmental pressure: reference scenarios for future global projections". In: (2012). OECD Environment Directorate Working Papers, forthcoming (cit. on p. 88).
- 4850
- 4851
- 4852 [94] Leiwen Jiang and Brian C. O'Neill. "Global urbanization projections for the Shared Socioeconomic Pathways". In: *Global Environmental Change* (2017). DOI: 10.1016/j.gloenvcha.2015.03.008 (cit. on p. 89).
- 4853
- 4854
- 4855 [95] Marian Leimbach et al. "Future growth patterns of world regions – A GDP scenario approach". In: *Global Environmental Change* 42 (2017), pp. 215–225. DOI: 10.1016/j.gloenvcha.2015.02.005 (cit. on p. 89).
- 4856
- 4857
- 4858 [96] Jesús Crespo Cuaresma. "Income projections for climate change research: A framework based on human capital dynamics". In: *Global Environmental Change* 42 (2017), pp. 226–236. DOI: 10.1016/j.gloenvcha.2015.02.012 (cit. on p. 89).
- 4859
- 4860
- 4861 [97] Rob Dellink et al. "Long-term economic growth projections in the Shared Socioeconomic Pathways". In: *Global Environmental Change* 42 (2017), pp. 200–214. DOI: 10.1016/j.gloenvcha.2015.06.004 (cit. on p. 89).
- 4862
- 4863
- 4864 [113] Markus Reuter and Antoinette van Schaik. "Opportunities and limits of recycling: A dynamic-model-based analysis". In: 37 (2012). ISSN: 1938-1425. DOI: 10.1557/mrs.2012.57. URL: <http://dx.doi.org/10.1557/mrs.2012.57> (cit. on p. 129).
- 4865
- 4866
- 4867 [115] Piero Morseletto. "Targets for a circular economy". In: *Resources, Conservation and Recycling* 153 (2020), p. 104553. ISSN: 0921-3449. DOI: 10.1016/j.resconrec.2019.104553. URL: <https://www.sciencedirect.com/science/article/pii/S0921344919304598> (cit. on pp. 142, 164).
- 4868
- 4869
- 4870 [117] Alfonso Marino and Paolo Pariso. "Comparing European countries' performances in the transition towards the Circular Economy". In: *Science of The Total Environment* 729 (2020), p. 138142. ISSN: 0048-9697. DOI: 10.1016/j.scitotenv.2020.138142. URL: <https://www.sciencedirect.com/science/article/pii/S0048969720316557> (cit. on p. 142).
- 4871
- 4872
- 4873
- 4874 [119] Martin Calisto Friant, Walter J.V. Vermeulen and Roberta Salomone. "Analysing European Union circular economy policies: words versus actions". In: *Sustainable Production and Consumption* 27 (2021), pp. 337–353. ISSN: 2352-5509. DOI: <https://doi.org/10.1016/j.spc.2020.11.001>. URL: <https://www.sciencedirect.com/science/article/pii/S2352550920313750> (cit. on p. 142).
- 4875
- 4876
- 4877
- 4878
- 4879 [122] Denise Reike, Walter J.V. Vermeulen and Sjors Witjes. "The circular economy: New or Refurbished as CE 3.0? – Exploring Controversies in the Conceptualization of the Circular Economy through a
- 4880

- 4881 Focus on History and Resource Value Retention Options". In: *Resources, Conservation and Recycling*
4882 135 (2018). Sustainable Resource Management and the Circular Economy, pp. 246–264. ISSN:
4883 0921-3449. DOI: <https://doi.org/10.1016/j.resconrec.2017.08.027>. URL: <https://www.sciencedirect.com/science/article/pii/S0921344917302756> (cit. on pp. 142–144,
4884 164, 181).
- 4885 [125] Walter Vermeulen, Denise Reike and Sjors Witjes. "Circular Economy 3.0 - Solving confusion
4886 around new conceptions of circularity by synthesising and re-organising the 3R's concept into a 10R
4887 hierarchy". In: *Renewable Matter* 2019 (June 2019). URL: https://www.ru.nl/publish/pages/940104/renewable_matters_tt_vermeulen.pdf (cit. on p. 163).
- 4888 [126] Eléonore Maitre-Ekern and Carl Dalhammar. "Towards a hierarchy of consumption behaviour in the
4889 circular economy". In: *Maastricht Journal of European and Comparative Law* (2019). DOI: 10.1177/
4890 1023263X19840943. URL: <https://doi.org/10.1177/1023263X19840943> (cit. on p. 164).
- 4893 [127] Mauro Cordella, Felice Alfieri and Javier Sanfelix. "Reducing the carbon footprint of ICT products
4894 through material efficiency strategies: A life cycle analysis of smartphones". In: *Journal of Industrial
4895 Ecology* (2021). DOI: <https://doi.org/10.1111/jiec.13119>. URL: <https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.13119> (cit. on pp. 169, 174).
- 4897 [128] H. Wieser and N. Tröger. "Exploring the inner loops of the circular economy: Replacement, repair,
4898 and reuse of mobile phones in Austria". In: *Journal of Cleaner Production* 172 (2018). DOI: 10.1016/
4899 j.jclepro.2017.11.10. URL: <https://doi.org/10.1016/j.jclepro.2017.11.10> (cit. on
4900 pp. 169, 174).
- 4901 [129] S. Svensson et al. "The Emerging 'Right to Repair' legislation in the EU and the U.S." In: (2018).
4902 Paper presented at Going Green CARE INNOVATION 2018 (cit. on pp. 169, 171).
- 4903 [130] Ricardo J Hernandez, Constanza Miranda and Julian Goñi. "Empowering sustainable consumption by
4904 giving back to consumers the 'right to repair'". In: *Sustainability* 12.3 (2020), p. 850 (cit. on pp. 169,
4905 171).
- 4906 [136] Laura Ruiz-Pastor and Jaime A. Mesa. "Proposing an integrated indicator to measure product
4907 reparability". In: *Journal of Cleaner Production* (2023). DOI: <https://doi.org/10.1016/j.jclepro.2023.136434>. URL: <https://www.sciencedirect.com/science/article/pii/S0959652623005929> (cit. on p. 172).
- 4910 [137] Mário Barros and Eric Dimla. "Smartphone reparability indexes in practice: Linking repair scores
4911 to industrial design features". In: *Journal of Industrial Ecology* (2023). DOI: 10.1111/jiec.13398
4912 (cit. on p. 172).
- 4913 [138] Sagar Dangal, Jeremy Faludi and Ruud Balkenende. "Design Aspects in Repairability Scoring Systems:
4914 Comparing Their Objectivity and Completeness". In: *Sustainability* (2022). ISSN: 2071-1050. DOI:
4915 10.3390/su14148634. URL: <https://www.mdpi.com/2071-1050/14/14/8634> (cit. on p. 172).
- 4916 [141] Stephanie Boulos et al. "The durability of products: standard assessment for the circular economy
4917 under the Eco-Innovation Action Plan". In: *Report for European Commission, DG Environment* (2015)
4918 (cit. on p. 174).
- 4919 [142] Tamar Makov and David Font Vivanco. "Does the circular economy grow the pie? The case of
4920 rebound effects from smartphone reuse". In: *Frontiers in Energy Research* (2018). DOI: 10.3389/

- fenrg. 2018. 00039. URL: <https://www.frontiersin.org/articles/10.3389/fenrg.2018.00039/full> (cit. on p. 175).
- [143] Siru Sihvonen and Tuomas Ritola. "Conceptualizing ReX for Aggregating End-of-life Strategies in Product Development". In: *Procedia CIRP* 29 (2015), pp. 639–644. DOI: 10.1016/j.procir.2015.01.026. URL: <https://doi.org/10.1016%2Fj.procir.2015.01.026> (cit. on p. 181).
- [144] Monsuru O. Ramoni and Hong-chao Zhang. "An entropy-based metric for product remanufacturability". In: *Journal of Remanufacturing* 2 (2012), pp. 1–8. ISSN: 2210-4690. DOI: 10.1186/2210-4690-2-2. URL: <https://doi.org/10.1186/2210-4690-2-2> (cit. on p. 181).
- [145] David Parker et al. "Remanufacturing market study". In: (2015). URL: <https://www.remanufacturing.eu/assets/pdfs/remanufacturing-market-study.pdf> (cit. on p. 182).
- [146] Subrata Mitra. "Revenue management for remanufactured products". In: *Omega* (2007). ISSN: 0305-0483. DOI: <https://doi.org/10.1016/j.omega.2005.10.003>. URL: <https://www.sciencedirect.com/science/article/pii/S030504830500157X> (cit. on p. 182).
- [148] Deepak Singhal, Sushanta Tripathy and Sarat Kumar Jena. "Remanufacturing for the circular economy: Study and evaluation of critical factors". In: *Resources, Conservation and Recycling* 156 (2020), p. 104681. ISSN: 0921-3449. DOI: <https://doi.org/10.1016/j.resconrec.2020.104681>. URL: <https://www.sciencedirect.com/science/article/pii/S0921344920300033> (cit. on p. 182).
- [149] Jiali Zhao et al. "An energy and time prediction model for remanufacturing process using graphical evaluation and review technique (GERT) with multivariant uncertainties". In: *Environmental Science and Pollution Research* (Apr. 2021), pp. 1–13. DOI: 10.1007/s11356-021-13438-z (cit. on pp. 182, 183).
- [150] Amal Dabbous and Abbas Tarhini. "Does sharing economy promote sustainable economic development and energy efficiency? Evidence from OECD countries". In: *Journal of Innovation & Knowledge* (2021). DOI: 10.1016/j.jik.2020.11.001. URL: <https://www.sciencedirect.com/science/article/pii/S2444569X20300500> (cit. on pp. 190, 191).
- [155] Xiaoxi Zhu and Kai Liu. "A systematic review and future directions of the sharing economy: business models, operational insights and environment-based utilities". In: *Journal of Cleaner Production* (2021). ISSN: 0959-6526. DOI: <https://doi.org/10.1016/j.jclepro.2020.125209>. URL: <https://www.sciencedirect.com/science/article/pii/S0959652620352537> (cit. on pp. 190, 191, 193).
- [156] Andrea Geissinger et al. "How sustainable is the sharing economy? On the sustainability connotations of sharing economy platforms". In: *Journal of Cleaner Production* (2019). ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2018.09.196. URL: <https://www.sciencedirect.com/science/article/pii/S0959652618329299> (cit. on p. 193).
- [158] Mohammed Mahmoud et al. "A formal framework for scenario development in support of environmental decision-making". In: *Environmental Modelling & Software* (2009). ISSN: 1364-8152. DOI: 10.1016/j.envsoft.2008.11.010. URL: <https://doi.org/10.1016/j.envsoft.2008.11.010> (cit. on p. 239).
- [159] Eva Wollenberg, David Edmunds and Louise Buck. "Using scenarios to make decisions about the future: anticipatory learning for the adaptive co-management of community forests". In: *Landscape*

4962
4963
and Urban Planning (2000). ISSN: 0169-2046. DOI: 10.1016/s0169-2046(99)00071-7. URL:
[https://doi.org/10.1016/S0169-2046\(99\)00071-7](https://doi.org/10.1016/S0169-2046(99)00071-7) (cit. on p. 239).

4964 12.7. ONLINE SOURCES

- 4965 [4] European Commission. *Questions and Answers: The European Critical Raw Materials Act*. European
4966 Commission. 2023. URL: https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_1662 (cit. on p. vii).
- 4968 [35] European Commission. *End-of-life vehicles Regulation*. European Commission. 2023. URL: https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles/end-life-vehicles-regulation_en (cit. on pp. 6, 32, 41, 51).
- 4970 [62] European Steel Association (Eurofer). *European Steel in Figures*. Accessed: 15 November 2023.
4971 2023. URL: <https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures> (cit. on pp. 35, 44, 54).
- 4972 [63] European Aluminium. *Aluminium Industry*. Accessed: 15 November 2023. 2023. URL: <https://european-aluminium.eu/about-aluminium/aluminium-industry/> (cit. on pp. 35, 44, 54).
- 4974 [65] Visual Capitalist. *Visualizing 50 Years of Global Steel Production*. Accessed: 15 November 2023. 2023.
4975 URL: <https://www.visualcapitalist.com/visualizing-50-years-of-global-steel-production/> (cit. on pp. 35, 44, 54).
- 4976 [72] CBS - Statistics Netherlands. *Circularity of the Dutch economy has barely increased*. 2023. URL:
4977 <https://www.cbs.nl/en-gb/news/2023/04/circularity-of-the-dutch-economy-has-barely-increased> (cit. on p. 46).
- 4978 [76] European Parliament. *Long-awaited common charger for mobile devices will be a reality in 2024*.
4979 European Commission. 2023. URL: <https://www.europarl.europa.eu/news/en/press-room/20220930IPR41928/long-awaited-common-charger-for-mobile-devices-will-be-a-reality-in-2024> (cit. on p. 53).
- 4980 [140] TÜV SÜD. *Repairability Testing / TÜV SÜD*. 2023. URL: <https://www.tuvsud.com/en/services/testing/repairability-testing> (cit. on p. 174).
- 4981 [157] Center for Climate Adaptation Science and Solutions at the University of Arizona. *Glossary - Scenario
4982 Planning for the Institute of the Environment*. 2023. URL: <https://www.adaptationscenarios.org/glossary> (cit. on pp. 238–240).
- 4983
4984
4985
4986
4987
4988
4989
4990

4991 12.8. MISCELLANEOUS

- 4992 [12] United Nations Economic Commission for Europe (UNECE). *United Nations Framework Classification
4993 for Resources (UNFC)*. United Nations Economic Commission for Europe (UNECE), 2023. URL:

- 4994 https://unece.org/sustainable-energy/sustainable-resource-management/united-
4995 nations-framework-classification (cit. on pp. xvi, 3).
- 4996 [21] FutuRaM consortium European Commission. *Grant Agreement – Project 101058522 – FutuRaM*.
4997 2023. DOI: 10.3030/101058522. URL: <https://cordis.europa.eu/project/id/101058522>
4998 (cit. on pp. xxvi, xxviii, xxxii, 264).
- 4999 [22] FutuRaM consortium. *Consortium Agreement – Project 101058522 – FutuRaM*. 2022 (cit. on p. xxvi).
- 5000 [23] Kees Baldé James Horne. *Project Management Plan – Project 101058522 – FutuRaM*. 2023 (cit. on
5001 pp. xxvi, 264).
- 5002 [24] Kirsten Remmen et al. *FutuRaM conceptual and methodological framework (M6 report) – Project*
5003 *101058522 – FutuRaM*. 2023 (cit. on p. xxvi).
- 5004 [45] Damian Carrington. *Interview with Paul Ehrlich: 'Collapse of civilisation is a near certainty within*
5005 *decades'*. 2018. URL: <https://www.theguardian.com/cities/2018/mar/22/collapse-civilisation-near-certain-decades-population-bomb-paul-ehrlich> (cit. on p. 29).
- 5007 [68] Aurubis. *ReShape The Future Magazine – Aurubis annual report 2018/19*. 2019. URL: https://annualreport2018-19.aurubis.com/fileadmin/user_upload/AUR_AR2018-19_Magazine-_Reshape_the_future.pdf (cit. on p. 37).
- 5010 [77] Randall Munroe. *xkcd: Sustainable*. 2012. URL: <https://xkcd.com/1007/> (cit. on p. 66).
- 5011 [108] International Energy Agency (IEA). *Is the European Union on track to meet its REPowerEU goals?*
5012 International Energy Agency (IEA), 2022. URL: <https://www.iea.org/reports/is-the-european-union-on-track-to-meet-its-repowereu-goals> (cit. on p. 105).
- 5014 [112] International Energy Agency (IEA). *Global Energy and Climate Model*. International Energy Agency
5015 (IEA), 2023. URL: <https://www.iea.org/reports/global-energy-and-climate-model>
5016 (cit. on p. 106).
- 5017 [134] European Commission. *Product Bureau | Circular Economy: Environmental and Waste Management*.
5018 2023. URL: <https://susproc.jrc.ec.europa.eu/product-bureau//product-groups/447/home> (cit. on p. 172).
- 5019





5023

5024

Appendices

5025

CHAPTER CONTENTS

5026	13.1 Terminology	238
5027	13.2 List of relevant policy actions	241
5028	13.3 Scenario development methods	243
5029	13.4 Marker scenario mapping	246
5030	13.5 Drivers and factors identified in the initial collection phase	251
5031	13.6 Drivers and factors identified in the screening phase	255
5032	13.7 Drivers and factors after categorisation	258
5033	13.8 Drivers and factors for quantification	261
5034	13.9 Work breakdown structure for WP2	264



5035 13.1. TERMINOLOGY

5036 The following is a suggested terminology for use in our discussions and reports related to
5037 scenarios.

5038 This glossary is modelled on that used by [27]. Some additional definitions were
5039 sourced from [157].

Table 13.1: Terminology

TERM	DEFINITION	LEVEL/CONTEXT	ALSO CALLED	SOURCE
Normative scenario	Goal-oriented scenario: identify decisions and investments that must be made to achieve desired future outcomes. Example: Constraining cumulative emissions	Scenario type	Backcasting	[27]
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	[27]
Outlook	To provide a most likely estimate of future trends as a guide for decision-making	Scenario type	Forecast, projection	[27]
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	[27]
Scenario scale	Description of the spatial extent or temporal extent of a scenario. For us, mostly EU toward 2050.	Scenario component		[157]
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		[157]
Scenario literature	Journal articles, grey literature, etc., from which data is sourced that can be used to justify decisions in scenario development	Scenario component		[27]
Scenario logics	Methods for structuring the relationships between different drivers and assumptions in scenarios	Scenario component		[157]
Time horizon	End date of the scenario's forecast	Scenario attribute		[27]
Snapshot	The position of scenario/s at a particular point of time	Scenario attribute		[27]
Storyline and simulation	Combination of qualitative narrative development and quantitative modelling	Scenario component		[158, 159], in [157]
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	[27]

Continued on next page

Table 13.1 – 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		[160]
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	[161], in [157]
Factors	Causes of system change that are internal from the system of analysis. Can be (hopefully) quantified, or at least estimated	Scenario component (internal)		[27]
Factor variables	Discrete elements which are subject to change and have effects on one or more factors	Factor component		[27]
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		[27]
Trends	An inclination in a particular direction	Attribute of drivers or factors	System development	[27]
Likelihood	The likelihood of an occurrence, an outcome, or a result, where this can be estimated probabilistically	Attribute of drivers or factors	Probability	[157]

5040

13.2. LIST OF RELEVANT POLICY ACTIONS

5041
5042 The following table contains a description of policy actions that are relevant to the future of secondary raw material supply in the EU.

Table 13.2: List of relevant policy actions

POLICY	STATE	YEAR	STATUS	JURISDICTION	LINK
European Institute of Innovation and Technology: Raw Materials Project Call	European Union	2023	Announced	International	🔗
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	🔗
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	🔗

13.3. SCENARIO DEVELOPMENT METHODS

Table 13.3 provides an overview of the methods and tools considered, along with a brief description of each and its relevance to the specific context and objectives of the FutuRaM scenario development process.

Table 13.3: Scenario development methods

METHOD	DESCRIPTION	KEY CHARACTERISTICS	LIMITATIONS	APPLICATION
Delphi	Structured expert consultation to gather and distil knowledge and judgments	Iterative rounds of surveys/questionnaires, Expert consensus building	Time-consuming process, May be influenced by dominant opinions or group dynamics	Policy development, Technology foresight, Long-term planning
MCA	Decision-support technique to evaluate and rank scenarios based on criteria	Consideration of multiple dimensions in quantifying qualitative factors	Policy assessment, Project evaluation, Strategic planning	
Forecasting	Use of historical data and statistical methods to predict future trends	Reliance on quantitative models, Time series analysis	Assumption of future patterns based on past data, Sensitivity to data quality and accuracy	Economic forecasting, Demand/supply projections, Financial planning
Backcasting	Working backward from a desired future vision to identify necessary steps	Focus on desired outcomes and future targets, Identification of necessary actions	Uncertainty in future outcomes, Difficulty in determining feasible pathways	Sustainable development planning, Policy design, Long-term goal setting
Scenario Planning	Development of multiple future scenarios to understand the range of possibilities	Identification of key drivers and uncertainties, Narrative construction for each scenario	Subjectivity in scenario construction, Lack of predictive accuracy	Strategic management, Risk assessment, Policy analysis
Morphological Analysis	Exploration of different combinations of variables/factors	Matrix-based exploration of variables and combinations	Complexity in analysing a large number of variables and combinations	Technology assessment, Innovation analysis, System design
Cross-Impact Analysis	Analysis of interdependencies and interactions between variables/factors	Identification of relationships and cross-impacts	Assumptions about causal relationships, Difficulty in capturing complex dynamics	Policy analysis, Risk assessment, System modelling
Morphological Box	Systematic exploration of the potential combinations of different components	Identification of component options and combinations	Complexity in analysing a large number of components and combinations	Technology assessment, Innovation analysis, Decision-making
Gausemeier approach	Scenario development method involving the identification of future developments, evaluation of influencing factors, and determination of desired and undesired developments	Systematic analysis of future developments and factors	Relies on expert judgment and subjective assessments	Strategic planning, Innovation management

Continued on next page

Table 13.3 – Continued from previous page

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

13.4. MARKER SCENARIO MAPPING

5048 Table 13.4 below presents an overview of the marker scenarios that were considered in
5049 the scenario development phase of the FutuRaM project. The table is not intended to be
5050 exhaustive, but rather to provide an overview of the different scenarios that have been
5051 developed in the field of waste management, resource recovery, and circular economy.

Table 13.4: Overview of marker scenarios

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview	Academic	All (narratives)	Scenario to 2100	Global	5 SSPs	🔗
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)	🔗
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	🔗
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	🔗

Continued on next page

Table 13.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Scenarios for the Return of Lithium-ion Batteries out of Electric Cars for Recycling	Academic	ELV, Battery	Scenario to 2050	Global	2	🔗
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	🔗
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	🔗
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)	🔗

Continued on next page

Table 13.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
Environmental Implications of Future Demand Scenarios for Metals: Methodology and Application to the Case of Seven Major Metals	Academic	Various	Scenario to 2050	Global	4 (UN GEO-4)	🔗
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)	🔗
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	🔗
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	🔗

Continued on next page

Table 13.4 – Continued from previous page

LITERATURE	TYPE	WASTE STREAM	TEMPORAL COVERAGE	LOCATION	NUMBER OF SCENARIOS	LINK
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	
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	

13.5. DRIVERS AND FACTORS IDENTIFIED IN THE INITIAL COLLECTION PHASE

Table 13.5 lists the elements that were identified in the initial phase of driver/factor collection.

Table 13.5: Drivers and factors identified in the initial collection phase

METHOD	DESCRIPTION
Stricter environmental regulations	Increased regulations and policies aimed at reducing environmental impact
Inflation	Increase in the general price level of goods and services over time
Employment rates	Percentage of the working-age population that is employed
Exchange rates	Value of one currency relative to another currency
Interest rates	Cost of borrowing money or the return on investment
Gasoline price	Cost of gasoline for vehicles
Electricity price	Cost of electricity for consumers or businesses
Raw material prices	Prices of primary materials used in production processes
CO2 market	Trading system for carbon emissions permits or credits
Education level	Level of education attained by individuals or the overall population
Volunteering	Engagement in unpaid activities for the benefit of others
Transparency	Openness, accountability, and information accessibility
Compliance with rules	Adherence to regulations, guidelines, or standards
Cultural values / Consciousness	Beliefs, attitudes, and awareness of individuals and society
Accessibility	Ease of access to goods, services, or infrastructure
Land rights	Legal rights to ownership, use, or access to land
Work-life balance	Equilibrium between work and personal life
Urbanisation	Increase in the population living in urban areas
Water supply constraints	Limitations on the availability or access to freshwater resources
Increased intrinsic drive for env. protection	Growing internal motivation to protect and conserve the environment
NIMBY to projects	Not-In-My-Backyard opposition to the location of certain projects
Climate change impacts (flooding, etc.)	Consequences of climate change, such as increased flooding or extreme events
Climate change mitigation efforts	Actions taken to reduce greenhouse gas emissions and combat climate change
Redundancy	Availability of backup systems or alternative options
Material efficiency	Effective use and management of materials to minimize waste and loss

Continued on next page

Table 13.5 – Continued from previous page

METHOD	DESCRIPTION
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
GDP/PPP	Gross Domestic Product (GDP) adjusted for purchasing power parity (PPP)
Improved repairability	Enhanced ability to repair and maintain products or equipment
Target enforcement	Implementation and enforcement of specific targets or goals
Data protection	Safeguarding personal data and ensuring privacy
Infrastructure	Physical structures and facilities necessary for the functioning of society
Intellectual property issues	Legal rights and protections for intellectual creations and innovations
Population	Total number of people in a given area or region
Resource shortage	Insufficient availability or scarcity of natural resources
Treatment cost	Cost of waste treatment, disposal, or recycling processes
Digital product passports	Digital documentation providing information about a product's lifecycle
Obsolescence	State of being outdated or no longer in use or demand
Digitalization	Integration and adoption of digital technologies and processes
SRM prices	Prices of secondary raw materials or recycled materials
Product prices	Prices of goods or products in the market
Recyclability mandates	Requirements or regulations promoting the recyclability of products
Conflict in supply chain	Disputes or conflicts within the supply chain of raw materials or products
Obligatory recycling standards for treatment facilities	Mandatory standards for recycling processes in treatment facilities
Improved durability	Enhanced longevity and resistance of products or materials
Composition change	Alteration or modification of the composition of materials or products
Subsidies	Financial support or incentives provided by governments or organizations
Availability of recovery technologies	Existence and accessibility of technologies for material recovery
Taxation (raw materials, landfill)	Imposition of taxes on raw materials or landfill activities
Obligatory removal of CRMs from waste	Required removal or extraction of critical raw materials from waste streams
Corruption	Dishonest or unethical behaviour, typically involving misuse of power

Continued on next page

Table 13.5 – Continued from previous page

METHOD	DESCRIPTION
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
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

5056 **13.6. DRIVERS AND FACTORS IDENTIFIED IN THE SCREENING PHASE**

5057

5058 The following table lists the scenario elements that were identified in the screening phase
5059 of driver/factor collection.

Table 13.6: List of drivers and factors identified in the screening phase

DOMAIN	DRIVER/FACTOR	DEFINITION	BAU	REC	CIR
Economic	CO2 market price	Price of carbon dioxide (CO2) emissions in carbon markets	I	I	I
Economic	Economic growth	Rate of economic growth	I	I	I
Economic	Energy prices	Prices of energy resources	I	I	I
Economic	Market saturation	Level of saturation reached in the market for certain products or services	I	I	II
Economic	Raw material vs SRM prices	Price comparison between raw materials and Secondary Raw Materials (SRMs)	I	I	I
Economic	Re-industrialisation of EU	Process of revitalizing industrial activities in the European Union	I	I	I
Environmental	Climate change impacts (flooding, etc.)	Impacts of climate change such as flooding and other related events	I	I	I
Environmental	Climate change mitigation efforts	Efforts made to mitigate the effects of climate change	I	I	I
Environmental	Increased drive for env. protection	Growing motivation and drive to protect the environment	I	III	III
Environmental	Resource shortage	Shortage of natural resources	I	I	I
Legal/Political	Ecodesign/re-X mandates	Establishment of ecodesign requirements for specific product groups to improve circularity, energy performance, and other environmental sustainability aspects	I	II	III
Legal/Political	Governance: corruption vs compliance	Contrasting levels of corruption and compliance within governance systems	I	I	I
Legal/Political	International trade and co-operation (vs. autarky)	Level of international trade and cooperation versus self-sufficiency	I	I	I
Legal/Political	Product information transparency	Provision of transparent product information to consumers, manufacturers, importers, repairers, recyclers, or national authorities	I	III	III
Legal/Political	Progress toward renewable energy targets	Progress made in achieving renewable energy targets	I	I	I
Legal/Political	Stricter environmental regulations	Implementation of more stringent rules and regulations for environmental protection	I	III	III
Legal/Political	Subsidies/taxation to promote circularity	Provision of subsidies or implementation of taxation policies to incentivize circularity	I	I	I
Legal/Political	Supply chain due diligence laws	Implementation and enforcement of laws requiring companies to address negative human rights and environmental impacts in their value chains	I	II	III
Social	Hoarding	The act of stockpiling and keeping excessive amounts of products	III	II	II
Social	NIMBY to projects	Opposition of local communities to the location of new projects, such as mining, in their vicinity	I	I	I
Social	Participation in re-X activities	"Involvement in activities related to the ""re-"" concepts, including refusing, reducing, repairing, and reusing products"	I	II	III

Continued on next page

Table 13.6 – Continued from previous page

DOMAIN	DRIVER/FACTOR	DEFINITION	BAU	REC	CIR
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

13.7. DRIVERS AND FACTORS AFTER CATEGORISATION

5060 The 21 elements that were identified in this stage are listed in Table 13.7.

5061 Note that CIR and REC are very similar for many scenario elements, the main difference
5062 being the way in which the targets are achieved. That is, for CIR, re-X strategies are
5063 promoted, whereas, for REC, the focus is on technological advancements in the recovery
5064 system.

5065 This distinction will have a significant impact on how the scenarios are quantitatively
5066 modelled and on the subsequent outcomes of these models.
5067

Table 13.7: List of drivers and factors identified in the screening phase

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

Continued on next page

DOMAIN	DRIVER/FACTOR	DEFINITION	INTERNAL	BAU	REC	CIR
SOC	Population and urbanisation	Growth and urban development of population	FALSE	n/a	n/a	n/a
ECO	CO2 market price	Price and market dynamics of carbon emissions	FALSE	n/a	n/a	n/a

5068

13.8. DRIVERS AND FACTORS FOR QUANTIFICATION

5069 The following Table 13.8 lists the categorised scenario elements that were quantified and
5070 incorporated into the modelling.

Table 13.8: List of scenario elements categorised for quantification. The roman numerals in the columns BAU, REC, and CIR represent the magnitude of the future trend for the element in the scenario. Internal, external, and outside refer to the classification type of the scenario element

DOMAIN	ELEMENT	INTERNAL	EXTERNAL	OUTSIDE	BAU	REC	CIR	PARAMETERS AFFECTED
ECO	Subsidies and taxation to promote circular strategies	✓			I	I	III	demand, waste generation, lifetimes, sharing, collection,
POL	Targets and enforcement to promote circular strategies	✓			I	I	III	demand, waste generation, lifetimes, sharing, collection
SOC	Participation in re-X activities	✓			I	I	III	demand, waste generation, lifetimes, sharing, collection,
ECO	Subsidies and taxation to promote recovery strategies	✓			I	III	I	recycling rates, recovery capacity, recovery impacts, collection
POL	Targets and enforcement to promote recovery strategies	✓			I	III	I	recycling rates, recovery rates, capacity
POL	Supply chain due diligence laws	✓			I	III	III	composition, export
POL	Stricter environmental regulations	✓			I	III	III	composition, waste generation, lifetimes, export, recovery rates, recovery capacity, recovery impacts
POL	Stricter waste management regulations	✓			I	III	III	composition, waste generation, lifetimes, export, recovery rates, recovery capacity, recovery impacts
TECH	Product technology	✓			I	III	III	lifetimes, recovery rates, recovery impacts
TECH	Recovery technology	✓			I	III	III	recovery rates, recovery capacity, recovery impacts
TECH	Integration of SRM recovery system across Europe	✓			I	III	III	recycling rates, recovery rates, recovery capacity, recovery impacts
ECO	Progress toward renewable energy targets		✓		-	-	-	composition, demand, waste generation, recovery impacts
ECO	Economic growth		✓		-	-	-	composition, demand, waste generation
SOC	Population		✓		-	-	-	demand, waste generation

Continued on next page

Table 13.8 – Continued from previous page

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

13.9. WORK BREAKDOWN STRUCTURE FOR WP2

5071
5072
5073
5074
Table 13.9 lists tasks and subtasks for work package two, along with the responsible partner and the planned start and end dates for each task. This table was sourced from the FuTuRaM project management plan [23].

5075
5076
Table 13.10 shows the Gaant chart for the entire FuTuRaM project. This chart was sourced from the FuTuRaM grant agreement, page 37 [21].

WP	Task	SubTask	SubTask Name	Waste Group	Step (Optional)	Description SubTask/Step	Partners										Start	End				
							WEEE Forum	UNI PAR	BRGM	Chalmers	GTK	IMU	RECHARGE	SGU	TU B	Leiden Uni	ViTO	EmPa	UCL			
2	2.1	2.1.1	Scenario mapping	ALL		Map various studies from the academic, policy, and gray literature for future scenarios and assess the applicability within FutuRaM	X	X	X	X	X	X	X	X	X	X	X	M01	M05			
2	2.1	2.1.2	Scenario methods	ALL		Compile various methodologies for scenario development and assess their applicability for developing scenarios on material recovery and circular economy for Europe	X	X	X	X	X	X	X	X	X	X	X	M02	M05			
2	2.1	2.1.3	Scenario storylines	ALL		Flesh out the storylines of the 3 main scenarios	X		X					X	X				M05	M08		
2	2.1	2.1.4	Qualitative scenario development	ALL		Use the chosen methods and qualitative methods to develop the three main scenarios to be used in FutuRaM (e.g. BAU, increased material recovery, and full circular economy)		X		X			X		X	X		X	M07	M11		
2	2.2	2.2.1	Emerging technology assessment for future material use	ALL		Compile information on emerging technologies for sectors associated with waste streams, including changing material use	X	X	X	X	X	X	X	X	X	X	X		M03	M10		
2	2.2	2.2.2	Emerging technology assessment for recovery	ALL		Compile information on emerging technologies for sectors associated with waste streams, including changing material use	X	X	X	X	X	X	X	X	X	X	X		M07	M11		
2	2.2	2.2.3	Technology quantification	ALL		Develop methods for a quantified assessment of technology implementation (e.g. market share)		X		X										M11	M16	
2	2.2	2.2.4	Technology intergration	ALL		Quantitatively integrate future technologies into the scenarios		X		X										M16	M20	
2	2.2	2.2.5	Technology integration	ALL		Quantitatively integrate future technologies into the scenarios with Tasks 4.1 and 4.2 Compile (and possibly harmonize) present and future material use based on emerging technology assessment (Subtask 2.2.1)													M14	M20		
2	2.3	2.3.1	Future product/resource material composition	ALL		Identify methods for imputing missing composition data	X	X	X					X	X	X	X	X		M06	M18	
2	2.3	2.3.2	Methods for data gaps in future compositions	ALL		Create database of material compositions for future products/waste streams for each scenario in combination with WP3	X							X	X					M14	M20	
2	2.3	2.3.3	Create database of future waste stream compositions	ALL		Compile preliminary results from Tasks 4.1 and 4.2 and WP3, and harmonize initial waste stream results, feeding back to these tasks		X	X	X				X	X	X	X	X		M18	M20	
2	2.4	2.4.1	Harmonization of future material waste stream material recovery	ALL		Evaluate the use of S-LCA, tecnoeconomic assessments, cost-benefit analysis, multi-criteria analysis using information from both the waste stream models and the UNFC case studies								X	X				M18	M21		
2	2.4	2.4.2	Develop methods for environmental and social and economic assessments	ALL		Implement methods chosen from subtask 2.4.2 to assess the social, economic, and environmental impacts for each scenario (thus quantify environmental and socioeconomic impacts of SRM recovery under each scenario)			X	X		X								M18	M30	
2	2.4	2.4.3	Perform social, economic and environmental assessments	ALL		Adapt/modify/streamline the methodology for application within the context of the UNFC				X		X	X			X	X				M30	M36
2	2.4	2.4.4	Feedback with UNFC methodology	ALL		Compile all the modelling and case study information thus far and prepare for report writing				X		X	X		X	X	X	X			M24	M36
2	2.5	2.5.1	Compile information for the report	ALL		Write the report on the bottlenecks, environmental, and socioeconomic impacts of secondary material recovery	X	X	X	X	X	X	X	X	X	X	X			M37	M43	
2	2.5	2.5.2	Report writing	ALL		Report review by stakeholders and partners	X	X	X	X		X	X	X	X	X	X				M44	M45
2	2.5	2.5.3	Report reviewing	ALL		Revise report based on recommendations	X	X													M46	M46
2	2.5	2.5.4	Report revising	ALL		Deliver final report															M47	M47
2	2.5	2.5.5	Report delivery	ALL																	M48	M48

Table 13.9: Work breakdown structure for work package two

Title	Leader/M		Year 1				Associate	Year 2 with document				Year 3				Year 4				TBD		20/05/2024						
			1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47		
1 Conceptual and Methodological Development	Empa											M6														D1.1		
1.1 Develop, harmonize and integrate framework, concepts, methods and tools	Empa																										D1.2	
1.2 Proposal on SRMs statistics to the EC	Empa																										D1.3	
1.3 Draft reporting standard in line with the UNFC	UNITAR																											
2 Foresight for Future Secondary Raw Materials	ULEI																											
2.1 Develop scenario storyline	ULEI																											
2.2 Integrate future technologies into the scenarios	Chalm																											
2.3 Forecast material composition and products for each scenario	TUB																											
2.4 Quantify environmental and socioeconomic impacts of the scenarios	ULEI																											
2.5 Env. and socio-econ. impacts and bottlenecks of future scenarios	ULEI																											D2.1
3 Secondary Raw Material Composition	TUB																											
3.1 Agree composition data templates for SRM potential	TUB																											
3.2 Collect, update, and consolidate composition data for SRMs	TUB																											
3.3 Extend waste stream composition assessment to SRMs	TUB																											D3.1
4 Stock and Waste Flow Characterization	UNITAR																											
4.1 Quantify stocks and flows of ProSUM streams	UNITAR																											
4.2 Quantify stocks and flows of CDW, MinW, SLASH	ULEI																											
4.3 Quantify SRM stocks and flows	UNITAR																											D4.1
5 SRM availability assessment in line with the UNFC ...	LMU																											
5.1 Map current practice, gaps and future needs for SRMs	LMU																											
5.2 Use case studies to test (...) in line with the UNFC	LMU																											D5.1
6 Development of data information system for EU	BRGM																											
6.1 Data model, registries and harvesting for SRM-KB	BRGM																											
6.2 API : Injection web services and diffusion web services	BRGM																											M21
6.3 Web site: developing the SRM-KB in EU	BRGM																											D6.1
7 Exploitation, Communication & Dissemination	SPI																											
7.1 Communication, dissemination and exploitation plan	SPI																											M15
7.2 Stakeholder mapping, consultation and engagement	WF																											D7.4
7.3 Developing a business plan for the KERs	SPI																											D7.3
7.4 Communication & dissemination tools and activities	WF																											M22
7.5 Dissemination	SPI																											M10,D7.5
7.6 Clustering activities	WF																											M9
8 Project Management	WF																											M14
8.1 Consortium & Admin Management	WF																											M1
8.2 Scientific Management	UNITAR																											M5
8.3 Reporting and Legal & Financial Management	WF																											M5
8.4 Risk Management	WF																											D8.1
8.5 Data Management Plan	Empa																											D8.2
8.6 Creation and management of the Advisory Board	WF																											M2
8.7 Ethics requirements	WF																											D8.3

Table 13.10: Gantt chart for the entire FutuRaM project

5077
5078
5079

5080

END OF REPORT

5081
5082

FutuRaM

Future availability
of secondary
raw materials