



## **DELIVERABLE 1.3**

# **CircEular policy recommendations to smooth circular economy for climate change mitigation**

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# CircEULAR

## Developing circular pathways for an EU low-carbon transition

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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| <b>Deliverable description:</b>   | D1.3 presents the five policy briefs developed by the CircEULAR project and the process through which they were defined and produced. It provides an overview of their content and evidence base, synthesises the cross-cutting key messages and policy recommendations emerging across the series. It also outlines the policy brief drafting process and how their development was embedded within CircEULAR's policy dialogue process and the wider stakeholder engagement. |
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| Version | Date       | Issued by   | Description  | Summary of changes                        |
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| 1       | 2.08.2026  | Sara Giorgi | First draft  | n/a                                       |
| 2       | 28.08.2026 | Sara Giorgi | Second draft | Revised based on internal review comments |
| 3       | 15.09.2026 | Sara Giorgi | Third draft  | Included all five finalised policy briefs |



## Executive Summary

Deliverable 1.3 presents the five policy briefs developed by CircEULAR and synthesises the main policy messages and recommendations emerging across them. The briefs translate evidence generated through the project's modelling, pathway development, empirical and social research, and stakeholder engagement into concise policy-oriented outputs addressing different dimensions of the transition towards a circular, low-carbon economy.

The five briefs address complementary and deliberately cross-cutting policy questions:

- *Circular economy modelling for EU decision-making* examines how circular strategies can be better represented in models informing EU policy;
- *Pathways to climate neutrality* assesses which circular strategies can make the greatest contribution to greenhouse gas mitigation;
- *Circular consumption* identifies the conditions enabling or constraining demand-side circular practices across housing, mobility and digitalisation;
- *Circular without rebounds* examines how to mitigate rebound effects in corporate circular practices looking both at behavioural and market responses; and
- *Urban planning and data-driven approaches enable low-carbon cities* analyses how urban form and spatial planning influence emissions and resource demand.

Together, they span policy action from the EU to national, regional and local levels and draw on complementary evidence including integrated and sectoral modelling, surveys and interviews, economic analysis, evidence synthesis and spatial modelling.

Circular economy policy needs to move beyond recycling towards reducing material demand, extending product lifetimes, reuse and repair, which can strengthen climate mitigation and reduce transition costs. Circular alternatives alone, however, do not guarantee lower resource use: uptake depends on wider economic, social and infrastructural conditions, while rebound effects can offset gains. Digitalisation can both enable and undermine circularity.

The briefs contain specific policy recommendations, presented in full and with their supporting evidence. Collectively, they point to five overarching directions: **prioritise material and resource demand reduction; make circular choices practical and attractive; integrate circularity across policy areas and governance levels; anticipate rebound effects; and strengthen data, modelling and monitoring**. These are particularly relevant to the forthcoming Circular Economy Act and to strengthening circularity across existing EU policy frameworks.

The briefs were developed collaboratively within the CircEULAR consortium, coordinated by T6. Consortium-wide brainstorming expanded the originally envisaged three briefs into five cross-cutting topics, supported by a co-designed template, policy mapping, bilateral support and iterative editorial and graphical development. Their development was embedded within CircEULAR's wider stakeholder engagement and policy dialogue. Emerging findings and recommendations were discussed with policy actors throughout the project and at the final Brussels policy event in May 2026. These exchanges informed the final refinement of the briefs and helped connect CircEULAR's evidence with policy priorities and implementation realities.

## Keywords

Policy dialogue, policy recommendations, stakeholder engagement, policy mapping



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## Abbreviations

|             |                                                                                                           |
|-------------|-----------------------------------------------------------------------------------------------------------|
| CircEULAR   | Developing circular pathways for an EU low-carbon transition                                              |
| Climate-KIC | Climate Knowledge and Innovation Community                                                                |
| CMCC        | Euro-Mediterranean Center on Climate Change                                                               |
| DG          | Directorate-General                                                                                       |
| DG-AGRI     | Directorate-General Agriculture and Rural Development                                                     |
| DG-CLIMA    | Directorate-General Climate Action                                                                        |
| DG-EMPL     | Directorate-General for Employment, Social Affairs and Inclusion                                          |
| DG-ENV      | Directorate-General Environment                                                                           |
| EEA         | European Environment Agency                                                                               |
| EMPA        | Swiss Federal Laboratories for Materials Science and Technology                                           |
| EU          | European Union                                                                                            |
| EUBUCCO     | European Building Stock Characteristics in a Common and Open Database                                     |
| IAM(s)      | Integrated Assessment Model(s)                                                                            |
| ICLEI       | Local Governments for Sustainability (formerly International Council for Local Environmental Initiatives) |
| IIASA       | International Institute for Applied Systems Analysis                                                      |
| INEGI       | National Institute of Statistic and Geography                                                             |
| ITF         | International Transport Forum                                                                             |
| ITU         | International Telecommunication Union                                                                     |
| JRC         | Joint Research Council                                                                                    |
| LMU         | Ludwig-Maximilians-Universität München                                                                    |
| NGOs        | Non-governmental organisations                                                                            |
| OECD        | Organisation for Economic Co-operation and Development                                                    |
| PIK         | The Potsdam Institute for Climate Impact Research                                                         |
| RUG         | University of Groningen                                                                                   |
| SAS         | Story and Simulation                                                                                      |
| T6          | T6 Ecosystems                                                                                             |
| UN          | United Nations                                                                                            |
| UNFCCC      | United Nations Framework Convention on Climate Change                                                     |
| WP          | Work Package                                                                                              |
| WRAP        | The Waste & Resources Action Programme                                                                    |



# CircEULAR policy recommendations to smooth circular economy for climate change mitigation

## 1. Introduction

This deliverable presents the outcomes of Task 1.4 Policy recommendations and outreach, focusing on the translation of CircEULAR's research and stakeholder engagement into policy-relevant findings and recommendations. This introduction outlines the purpose of the deliverable and its structure.

### 1.1 Deliverable purpose

Task 1.4 aimed to derive recommendations for policymakers working on circular economy strategies across CircEULAR's focus areas. The implementation of the task evolved alongside the project's wider stakeholder engagement approach. As documented in Deliverable 1.2<sup>1</sup>, stakeholder engagement was integrated into the CircEULAR research process and contributed at different stages to pathway development, research validation and policy reflection. Stakeholders helped to challenge and refine assumptions, contextualise emerging findings, identify implementation considerations for circular strategies and strengthen their relevance to policy and practice. Policy dialogue took place throughout the project through workshops, bilateral exchanges, online sessions, partnerships and dedicated policy events rather than as a discrete activity undertaken once the research had been completed.

Against this background, D1.3 focuses specifically on the translation of this wider body of evidence into five CircEULAR policy briefs. The briefs address distinct but complementary areas of the project's research and bring together findings from modelling, empirical (including survey and interviews), evidence reviews with insights generated through stakeholder engagement and policy dialogue. Rather than reporting the underlying stakeholder research and engagement activities in detail, which are documented elsewhere in CircEULAR deliverables (D1.1<sup>2</sup> and D1.2), D1.3 describes the process through which the policy briefs were developed and provides an overview of their key messages and recommendations.

### 1.2 Deliverable structure

The deliverable is structured into four further sections:

- **Section 2: Developing policy recommendations through policy dialogue** builds on the policy dialogue process documented in Deliverable 1.2 and focuses on the role of the policy briefs within this process. It describes how emerging findings, key messages and preliminary recommendations were presented and discussed with policymakers and other stakeholders, and how these exchanges informed the further development and refinement of the five briefs.
- **Section 3 – Producing the policy briefs: the process** describes the collaborative process undertaken within the CircEULAR consortium to conceptualise, design, develop and finalise the five policy briefs. It outlines how priority topics and content were collectively identified, how research partners worked together to draft and refine the briefs, and how a

<sup>1</sup> Giorgi, S., Passani, A., Krey, V., and Jovanovic, M. (2026). Final Report on Community Building and Events (CircEULAR Deliverable 1.2).

<sup>2</sup> Thuermer, G., & Passani, A., (2023). CircEULAR stakeholder dialogue protocols and methods (CircEULAR Deliverable 1.1).



coordinated process of policy, editorial and design support was used to develop the briefs from initial concepts into the final outputs.

- **Section 4 – Developing the policy briefs: the content** provides an overview of the focus and evidence underpinning each of the five briefs and synthesises the main findings and policy recommendations emerging across them.
- **Section 5 – CircEULAR policy briefs** includes the five final policy briefs.

## 2. Developing policy recommendations through policy dialogue

As documented in Deliverable 1.2, the development of CircEular's policy recommendations formed part of a broader, nested stakeholder engagement process. Stakeholder engagement provided the overarching approach, integrating external knowledge, expertise and perspectives throughout the research process, while policy dialogue formed a cross-cutting strand within this approach, ensuring that policy considerations were addressed alongside the development of CircEular's research. The policy briefs and recommendations developed were, in turn, a central component of this policy dialogue, providing a mechanism for translating research findings and stakeholder insights into policy-relevant outputs.

Policy dialogue was embedded throughout the project via workshops, online sessions, bilateral exchanges, strategic partnerships and dedicated policy events. As shown in Figure 1, the policy dialogue process had three interconnected components: **ongoing policy exchanges with stakeholders; dedicated policy-focused events; and the development of policy briefs and recommendations**. The ongoing policy exchanges consisted primarily of targeted bilateral and small-group interactions with actors working on policy across different stakeholder groups throughout the project. These exchanges had specific objectives linked to different stages of the research, such as testing and validating pathway development, sense-checking modelling assumptions and discussing applicability of emerging findings. The final policy event, by contrast, was targeted particularly at EU institutional policymakers and provided an opportunity to present and discuss emerging policy insights and recommendations, gathering feedback to inform their final refinement. These elements supported a continuous dialogue with actors involved in policy development, implementation, evidence generation and evaluation, while enabling emerging findings and their policy implications to be considered throughout the research.

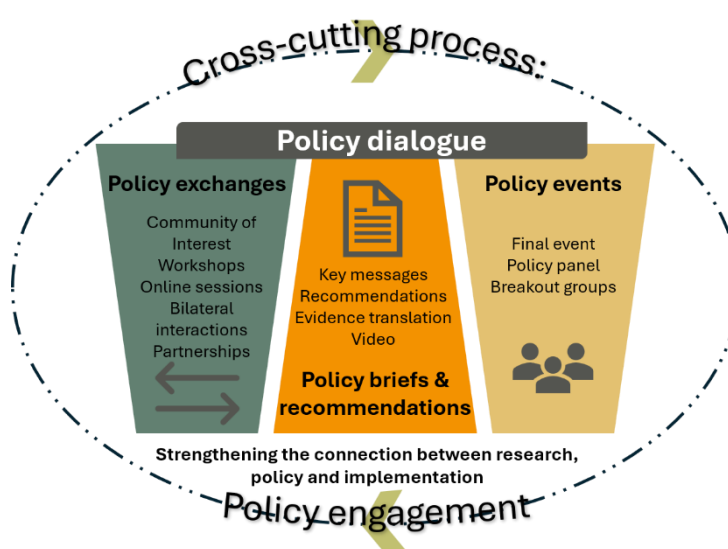


Figure 1 - CircEular's policy dialogue process

As the project progressed, this dialogue increasingly focused on **sense-checking, improving and validating emerging research findings throughout the research process especially the pathway development**, rather than consulting policy stakeholders only once results had been finalised. Policy actors participated at key stages, including the first stakeholder meeting in March 2024, the joint EEA and CIRCOMOD event in September 2024, the online pathway workshops in Spring 2025, and stakeholder events as part of the consortium meetings in Groningen (September 2024) and Berlin (September 2025). Across these activities, CircEular engaged with organisations including **Climate-KIC, EEA, DG ENV, DG CLIMA, DG AGRI, DG EMPL, JRC, ITF, ICLEI, ITU and WRAP**. National and local policy engagement also included representatives of ministries, environmental agencies and municipal departments working on housing, waste and urban and spatial planning especially at the events in Groningen and Berlin. This provided an established



policy community with which emerging findings and their implications could be discussed as the research developed.

The five policy briefs were conceived as part of this ongoing dialogue rather than solely as final dissemination outputs. Emerging key messages and recommendations were presented at the final policy event, *Modelling to Policy: Circular Economy Pathways Towards Net-Zero*, organised jointly by CircEular, [CIRCOMOD](#) and [CO2NSTRUCT](#) in Brussels on 28 May 2026. The event brought together more than 160 participants (90 online, 72 in-person) from policy, research, industry and civil society and included a high-level policy panel with **DG ENV, DG CLIMA, DG EMPL, and the OECD**. It provided an opportunity to discuss emerging evidence and recommendations with actors involved in policy development, implementation and evaluation. Rather than presenting final conclusions, the discussions enabled participants to explore underlying assumptions, implementation conditions, trade-offs and uncertainties and to consider how the findings related to current policy priorities. Three breakout discussions focusing on **construction and material value chains; mobility and housing services; and system-wide enablers** provided more targeted opportunities to examine the emerging findings. Discussions highlighted, among other issues, the need to broaden circular economy interventions beyond waste management and recycling; better account for implementation conditions and geographical differences; consider digitalisation, behaviour and rebound effects as cross-cutting factors; and strengthen the connection between modelling evidence and policy implementation. Participants also emphasised the importance of data availability, policy sequencing, governance arrangements, skills and clearer communication of modelling assumptions and uncertainties.

The feedback and perspectives generated through these exchanges were subsequently considered in the further refinement of the policy briefs. In this way, the five briefs continued the approach established through CircEular's wider stakeholder engagement activities, providing a mechanism for considering research evidence alongside policy priorities and implementation realities.



### 3. Producing the policy briefs: the process

The five policy briefs were developed through a collaborative process within the CircEULAR consortium, coordinated by T6. The process aimed to identify areas where CircEULAR's research could make a clear contribution to ongoing policy discussions and translate this evidence into a coherent set of policy-oriented outputs.

The foundations for this process were established through an internal policy group set up in September 2024, initially involving **RUG, CMCC, IIASA, LMU, PIK, UOXF, INEGI and T6**, and subsequently opened more broadly to interested consortium partners. As CircEULAR's research matured, the group provided a space to consider emerging policy implications and possible topics for policy briefs. A dedicated brainstorming exercise during the consortium meeting in September 2025 marked an important step, with partners collectively identifying themes and considering where sufficiently mature evidence existed to support substantive policy messages and recommendations. While the originally three policy briefs were envisaged, broadly aligned with CircEULAR's three focus areas (buildings and household services, mobility and digitalisation), the consortium agreed to develop five briefs organised around cross-cutting policy topics that better reflected the breadth and interconnections of the project's emerging findings. The consortium also agreed that the preparation and finalisation of the briefs should be a collective effort and foresee the collaboration amongst multiple partners.

These discussions resulted in five complementary policy brief topics covering:

- **circular economy modelling for EU decision-making;**
- **pathways to climate neutrality;**
- **enablers and barriers to demand-side circularity;**
- **rebound effects associated with corporate circular practices; and**
- **urban planning and data-driven approaches for low-carbon cities.**

For each topic, a core group of interested research partners was formed, with lead authors taking primary responsibility for developing the content and other partners contributing relevant evidence, expertise and review.

A common policy brief template was developed through a collaborative co-design process within the consortium, discussed through the internal policy group in a meeting open to all interested partners. The resulting template provided a common framework for the five teams, with guidance on content and length while retaining flexibility to accommodate different research topics and types of evidence. The agreed structure comprised:

- Title and subtitle
- Key messages
- Policy recommendations
- Policy context
- Why this matters
- What the evidence shows
- Research Methodology
- CircEULAR project summary
- References
- Further information and authors



T6 provided ongoing support throughout both on the structure, drafting and review. Bilateral meetings were held with policy brief leads to agree the focus and structure of individual briefs, clarify the principal messages and recommendations and support their positioning within relevant policy debates. T6 also developed a shared Miro Board which mapped the relevant EU policies and initiatives to the five brief topics and highlighting areas of overlap (see partial screenshot of Miro Board in Figure 2).

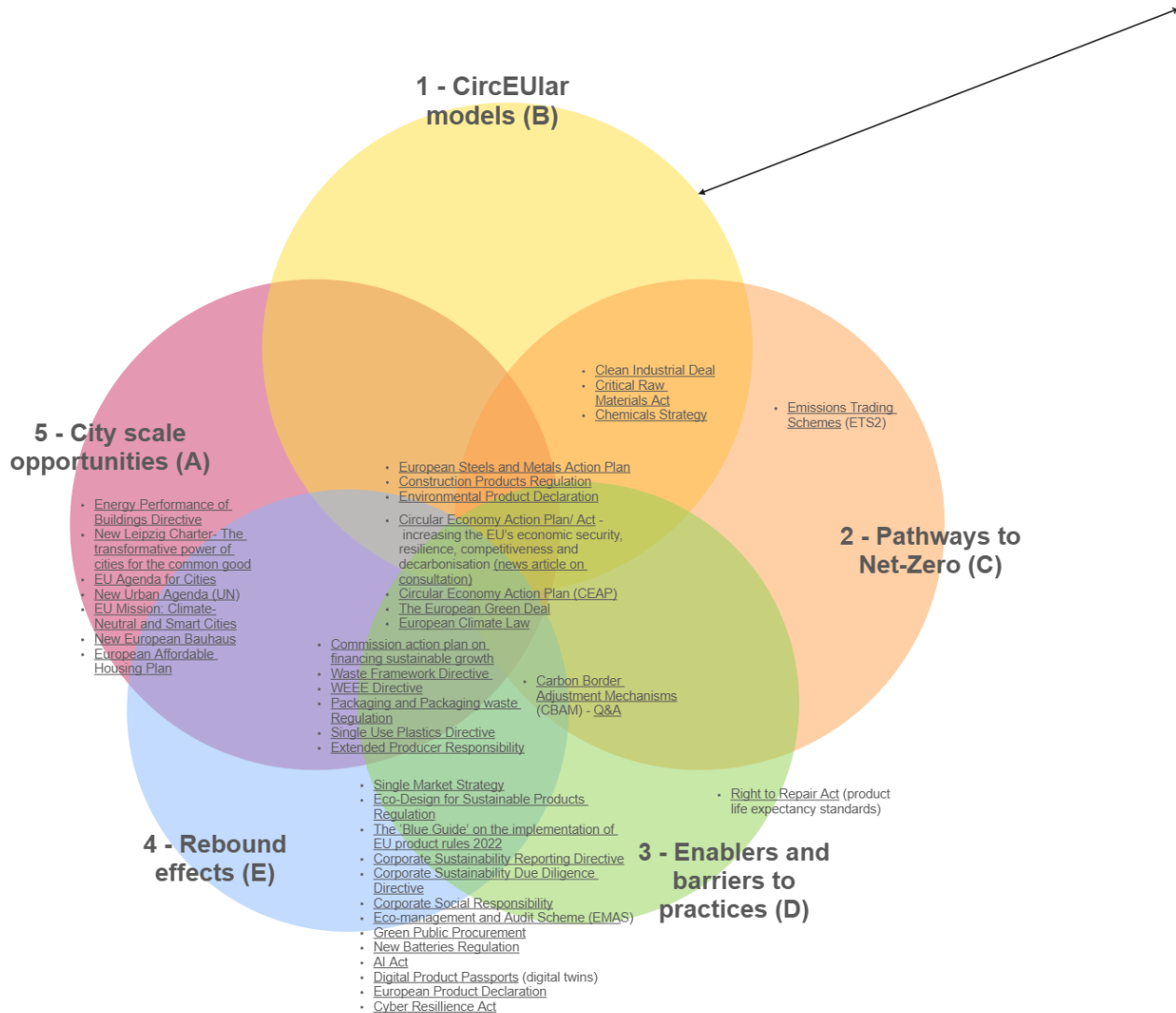


Figure 2 - Miro board extract: Mapping relevant EU policies on to CircEULAR policy briefs

The resource provided direct links to relevant policies, reports, initiatives and partnerships, bringing key contextual material together in one shared space. Policy brief leads used this resource to develop the “Policy context” sections, situate findings within the existing and emerging policy landscape and frame recommendations in relation to relevant policy instruments and developments.

Drafting proceeded iteratively within each policy brief group, with lead authors and contributors developing and reviewing the content and text. T6 provided policy anchoring, editorial review and coordination across the series, focusing on the clarity and accessibility of findings, the relationship between the evidence and recommendations, and consistency across the five briefs. Feedback



generated through the policy dialogue described in Section 2 was also considered during refinement.

Once the substantive content had been agreed, T6 undertook the final editorial of the text which was then validated by the policy brief authors. T6 then developed the graphical production of the five briefs in terms of layout, style and images, a consistent format and visual identity was applied across the series, this phase was also done in a collaborative and iterative fashion.



## 4. Developing the policy briefs: the content

This section provides an overview of the content and evidence underpinning the five CircEULAR policy briefs and the different policy questions they address. It then considers the briefs collectively to identify the cross-cutting key messages and policy recommendations emerging across the series.

### 4.1 Purpose and scope of the policy brief series

Building on CircEULAR's modelling, empirical and social research, pathway development and stakeholder engagement, the five policy briefs translate the project's findings into concise and accessible messages for policymakers. Their purpose is to distil key evidence, identify its implications for policy and formulate actionable recommendations relevant to decision-making at European, national, regional and local levels.

Policy briefs play a particularly important role in bridging the gap between evidence generation and policy action. By synthesising complex modelling results and pathway analysis into policy-relevant messages, they help decision-makers understand the synergies, trade-offs and implementation implications associated with different circular economy interventions. They also provide a mechanism for highlighting uncertainties, data limitations and rebound effects, thereby supporting more informed and transparent policymaking.

Rather than being organised around CircEULAR's three focus areas individually, the briefs address cross-cutting policy questions reflecting the interconnections within the project's research. Collectively, they consider how circularity can be better represented in models used for decision-making; which circular strategies make the greatest contribution to climate mitigation; the conditions enabling or constraining circular consumption; how rebound effects may reduce anticipated environmental gains and ways to mitigate them; and how urban form and spatial planning influence emissions and resource demand.

### 4.2 Overview of the five policy briefs

The briefs draw on complementary forms of evidence, ranging from integrated and sectoral modelling and pathway analysis to surveys, qualitative interviews, evidence synthesis and spatial analysis. Table 1 summarises their respective focus and principal evidence base and indicates the main governance levels at which their recommendations are most directly relevant, based on the policy actors, instruments and areas of intervention addressed in each brief. These levels are indicative rather than exclusive, as several recommendations have relevance across multiple levels of governance.

The portfolio of briefs, therefore, examines circular economy transitions at different scales and from different analytical perspectives: from the models and evidence informing EU policy, through system-wide transition pathways and behavioural and market responses, to the spatial conditions affecting implementation in cities



Table 1 - CircEULAR policy briefs at a glance

| Policy brief (PB)                                                        | Focus                                                                                                                         | Main CircEULAR evidence                                                                                                                                 | Main policy level(s) |
|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| PB1 - Circular economy modelling for EU decision-making                  | Improving how circular strategies are represented in models informing EU policy                                               | Integrated modelling across CircEULAR's focus areas; scenario narratives; empirical analysis and stakeholder engagement                                 | EU                   |
| PB2 - Pathways to climate neutrality                                     | Assessing and prioritising circular strategies according to their contribution to climate mitigation                          | Stakeholder co-developed pathways; integrated assessment and sectoral modelling; empirical research, interviews and evidence synthesis                  | EU                   |
| PB3 – Circular consumption                                               | Understanding what enables or constrains uptake of circular consumption practices across housing, mobility and digitalisation | 80 qualitative interviews; Circular Consumption Survey of 5,651 respondents across five European countries                                              | EU/ national         |
| PB4 – Circular without rebounds                                          | Understanding and mitigating rebound effects associated with corporate circular practices                                     | Rebound framework and economic analysis; employee survey (n=3,391); consumer survey (n=5,651); quantitative analysis of digitalisation and resource use | EU/ national         |
| PB5 – Urban planning and data-driven approaches enable low-carbon cities | Understanding how urban form and spatial planning influence emissions and resource demand                                     | Berlin travel analysis using double machine learning; Porto block-level analysis using artificial neural networks                                       | Local/ regional/ EU  |

### 4.3 Cross-cutting key messages

Although each brief addresses a distinct research question, several findings recur across the series.

**Circular economy policy needs to move beyond recycling.** CircEULAR's evidence consistently highlights the importance of higher-value circular strategies. The modelling work shows that current policy and modelling strategies underrepresent measures that reduce material demand, extend product lifetimes, promote reuse and support repair. The pathway analysis identifies a consistent GHG mitigation: **Narrow** strategies that avoid material and energy demand provide the greatest climate mitigation potential, followed by **Slow** strategies extending product lifetimes, while **Close** strategies centred on recycling and material recovery provide comparatively smaller gains.

**Circular economy strategies can strengthen climate mitigation, particularly when interventions work together.** Full implementation of circular strategies under a 2°C-compatible pathway reduces both the carbon price required to achieve climate targets and overall macroeconomic mitigation costs by around one fifth by 2050. The evidence also shows that buildings, mobility, urban form and digitalisation interact, meaning that coordinated interventions can deliver greater benefits than measures implemented in isolation.

**Providing circular alternatives does not necessarily result in lower consumption or resource use.** The consumption evidence demonstrates that availability alone is insufficient to change practices, with barriers to both shared mobility and housing rightsizing showing that access, affordability, convenience and social factors all influence uptake. The rebound analysis similarly shows that circular goods and services may complement rather than substitute resource-intensive consumption, while savings in costs or resources can generate additional demand elsewhere.

**Digitalisation can both enable and undermine circularity.** Digital technologies can facilitate sharing, second-hand markets, predictive maintenance, product information and more efficient



resource use. At the same time, easier consumption and expanding digital infrastructure can increase energy and material demand, as illustrated by the growing resource requirements of data centres. Across the briefs, it is shown that the environmental contribution of digitalisation, therefore, depends on how technologies and digital services are designed and governed.

#### **Urban form and spatial planning are key levers for circular and low-carbon cities.**

Infrastructure, economic conditions, behaviour and urban spatial structure influence whether circular strategies achieve their intended results. The Berlin and Porto analyses demonstrate this particularly clearly: accessibility, density and location are major determinants of mobility emissions and resource demand.

Taken together, the briefs show that realising the potential of circularity requires attention not only to individual technologies or practices, but also to the **systems and enabling conditions that determine how they are implemented, adopted and ultimately affect resource use and emissions.**

### **4.4 Cross-cutting policy recommendations**

Each of the five policy briefs develops a set of recommendations responding to its specific research findings and policy context. These **20 recommendations across the five briefs (four for each one) are presented in full in the individual briefs in Section 5 and should be read alongside the evidence and analysis on which they are based.** Rather than reproducing them here, this section provides an analytical read-across of the recommendations, highlighting five overarching directions for policy action that emerge across the series. Together, they are particularly relevant to the development of the forthcoming **Circular Economy Act (CEA)** and to strengthening the integration of circularity across existing EU policy frameworks.

#### **Put material and resource demand reduction at the centre of circular economy policy.**

Move beyond a predominantly recycling and end-of-life focus by prioritising demand reduction, longer product lifetimes, reuse and repair. The forthcoming **CEA** provides an important opportunity to strengthen this upstream approach, while CircEULAR's modelling indicates that these strategies should also be better represented in the evidence informing EU climate policy, including the EU 2040 climate targets.

#### **Create the conditions that make circular choices practical and attractive.**

Circular outcomes cannot depend primarily on individual willingness or voluntary business action. Product regulation, economic incentives, infrastructure and service provision need to make lower-resource choices easier and more viable. The briefs identify opportunities through instruments including the Ecodesign for Sustainable Products Regulation (ESPR), Digital Product Passports (DPPs), Extended Producer Responsibility (EPR) and the Right to Repair Directive, alongside investment in public and shared mobility, housing options and compact urban development.

#### **Integrate circularity across policy areas and governance levels.**

Circularity should be addressed across climate, industrial, product, mobility, housing, digital and spatial policy rather than treated as a discrete policy domain. This requires greater coordination between interventions and governance levels and a stronger systems perspective in both policymaking and modelling, recognising interactions between material use, buildings, mobility, urban form and digitalisation.

#### **Anticipate and mitigate rebound effects.**

Circular interventions should be assessed not only for their direct benefits but also for behavioural



and market responses that may offset them. This means considering how cost savings, additional income, efficiency gains and new services affect overall consumption and using complementary measures to safeguard absolute resource reductions. Relevant entry points identified in the briefs include the **Corporate Sustainability Reporting Directive (CSRD)**, EPR schemes, ESPR durability requirements and standardised **Life Cycle Assessment (LCA)** approaches.

**Strengthen the evidence, data and monitoring needed for circular economy policy.**

Better modelling, harmonised data and systematic monitoring are needed to understand whether circular strategies deliver their intended resource and climate outcomes. Recommendations include strengthening the representation of circularity in EU policy models, developing more consistent information on material stocks and flows, and improving interoperable data at urban level. PB1 specifically proposes an EU material stocks and flows observatory building on data and expertise from Eurostat, the European Commission's JRC and EUBUCCO.

Taken together, the recommendations point towards a **more upstream, systemic and evidence-led approach to circular economy policy**: one that reduces resource demand, creates the conditions for circular practices to become viable at scale, anticipates unintended consequences and connects circularity more effectively across policy domains and governance levels.

The five policy briefs in Section 5 provide the detailed recommendations, supporting evidence and specific policy entry points underpinning these overarching directions.



## 5. CircEULAR policy briefs

This section includes the five final CircEULAR policy briefs developed under Task 1.4. The briefs are reproduced in full below, in the following order.:

1. ***Circular economy modelling for EU decision-making***  
*Linking models and data to support evidence-based circular economy and climate policy*
2. ***Pathways to climate neutrality***  
*Prioritising circular economy strategies for net-zero greenhouse gas emissions*
3. ***Circular consumption***  
*Enablers and barriers to demand-side circularity*
4. ***Circular without rebounds***  
*Mitigating rebound effects in corporate circular practices through EU policy*
5. ***Urban planning and data-driven approaches enable low-carbon cities***  
*Evidence from Berlin and Porto integrated spatial studies*

# Circular economy modelling for EU decision-making

Linking models and data to support evidence-based  
circular economy and climate policy



## Key messages

### Beyond recycling

Current EU models underestimate the potential of higher-value circular strategies. The CircEULAR toolbox extends modelling to assess material demand reduction, product lifetime extension, reuse and repair.

### Circular economy is missing from climate modelling

Climate models omit measures such as housing and appliance sharing, reduced car ownership and rebound effects, underestimating circularity's mitigation potential. Including these measures shows circular strategies can halve material demand and transform the embodied emissions of key sectors.

### Circularity must be assessed as a system

Linking sectoral, economic and environmental models enables system-wide assessment of circular strategies across buildings, mobility and digitalisation.

### Open and better data strengthens policy

Open data and transparent models improve representation of material stocks, consumer behaviour, stakeholder input and regional differences, strengthening the reliability and policy relevance of circular economy assessments.

## Policy recommendations

### Extend circularity beyond waste policy and modelling

- **Integrate higher-value circular strategies into transport, buildings and digital policy**, shifting the focus from recycling towards material demand reduction, lifetime extension, reuse, repair and asset utilisation. Require impact assessments to account for material flows, embodied emissions and infrastructure material demand. This will ensure their full climate and resource impacts are captured.

### Adopt a systems approach to circular economy modelling

- **Apply the systems-based modelling approach already used for EU climate and energy policy to circular economy modelling**. Strengthen links between sectoral, economic and environmental models to enable system-wide assessment of circular strategies across buildings, mobility and digitalisation. This will improve the impact assessment of material demand, greenhouse gas emissions and cross-sector interactions, providing a stronger evidence base for policymaking.

### Incorporate circular economy strategies into EU climate and energy modelling

- **Systematically incorporate demand-side and lifetime-extension strategies into the Commission's suite of linked models underpinning EU climate and energy policy**, including those supporting the 2040 climate target. Represent currently overlooked measures, such as building reuse, sharing and reduced car ownership. This will improve scenario analysis and estimates of material demand and greenhouse gas emissions.

### Support open and harmonised data for circular economy

- Actors like Eurostat, the European Commission's Joint Research Centre and relevant research partners could build on EUBUCCO and other open datasets from CircEULAR to **establish a harmonised EU material stocks and flows observatory**. The observatory would track buildings, infrastructure and products; supporting reuse (e.g. vacant buildings) and reducing unnecessary new construction.





## Policy context

The European Union (EU) positions the circular economy as a core pillar of its sustainability, resilience and competitiveness agenda. The Circular Economy Action Plan seeks to shift the EU from a linear “take–make–dispose” system towards a more circular and resource-efficient economy and is a key element of the European Green Deal. The Action Plan is complemented by several initiatives, including the Ecodesign for Sustainable Products Regulation, the European Steel and Metals Action Plan, and the Clean Industrial Deal.

The EU recognises the circular economy as central to reducing greenhouse gas (GHG) emissions and achieving climate neutrality by 2050. However, much of the policy landscape remains focused on waste and recycling rather than whole-system circularity [7]. This highlights **the need for robust quantitative evidence to support regulatory approaches**, including the forthcoming Circular Economy Act.

## Why this matters

Despite recent progress, current EU-level modelling only partially represents circular economy strategies, limiting the evidence available to support policymaking. **Existing modelling** frameworks, therefore, **need to represent a broader range of circular strategies** while accounting for their technical and socio-economic feasibility. In contrast to energy modelling, **significant data gaps persist for material stocks and flows, limiting the accuracy and comprehensiveness of analyses** [1]. Addressing these gaps requires open access to data, starting with publicly funded datasets including those generated through EU-funded projects, alongside transparent models to improve reproducibility, verification, cross-country comparison and policy learning.

## What the evidence shows

### Beyond recycling: accounting for the full potential of circular economy strategies

Existing EU legislation remains primarily focused on recycling targets and end-of-life waste management. CircEular broadens the evidence base by assessing higher-value circular strategies that reduce material demand and extend product lifetimes.

CircEular extends circular economy modelling beyond recycling by applying the **Narrow-Slow-Close** framework [10]. This enables the assessment of strategies that reduce material demand through improved product design, material efficiency and lower activity levels (narrow), extend product lifetimes through repair, reuse, refurbishment and repurposing (slow), and recover materials through reuse and recycling (close). >>

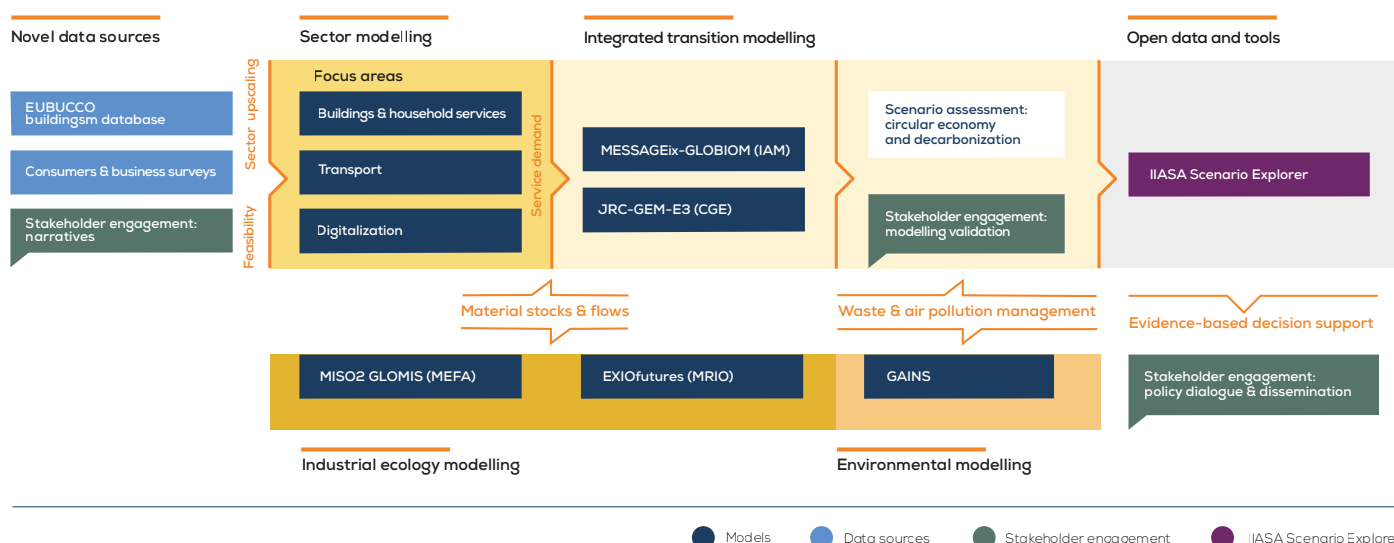


The results reveal a clear hierarchy in mitigation potential. **Narrow strategies deliver the greatest climate benefits, followed by slow strategies, while close strategies – including recycling – provide comparatively smaller gains.** Fully realising the potential of the circular economy requires modelling frameworks and policies that prioritise higher-value circular strategies across transport, buildings, household appliances and digital technologies, complementing existing climate and waste policies.

Circular economy strategies interact across sectors, value chains and environmental systems. Assessing their impacts therefore requires an integrated modelling approach that captures material demand, economic activity, environmental impacts and climate outcomes within a single analytical framework.

**CircEular provides a comprehensive ecosystem of interlinked models spanning buildings and household services, transport, digitalisation and material systems (Figure 1).** The framework combines integrated assessment modelling (MESSAGEix-GLOBIOM [2]); detailed sectoral models for buildings, transport, materials and household appliances; industrial ecology models of material stocks and flows (MISO2, GLOMIS and EXIOfutures); environmental modelling (GAINS); and computable general equilibrium modelling (JRC-GEM-E3) – **all in dark blue**. Novel data sources, including EUBUCCO, consumer [12] and business [13] surveys, (**in light blue**) and stakeholder engagement input at key points [11] (**in green**), further strengthened the evidence base and supported scenario development and validation.

By linking these complementary models, CircEular quantifies how circular economy strategies influence material demand, product stocks and flows, greenhouse gas emissions, air pollution and wider economic outcomes under different transition pathways. This approach provides a more systemic quantitative assessment of circular economy strategies and their potential towards climate targets at the EU and global level.



**Figure 1.** Overview of the CircEular modelling ecosystem – Systematic modelling approach to circular economy



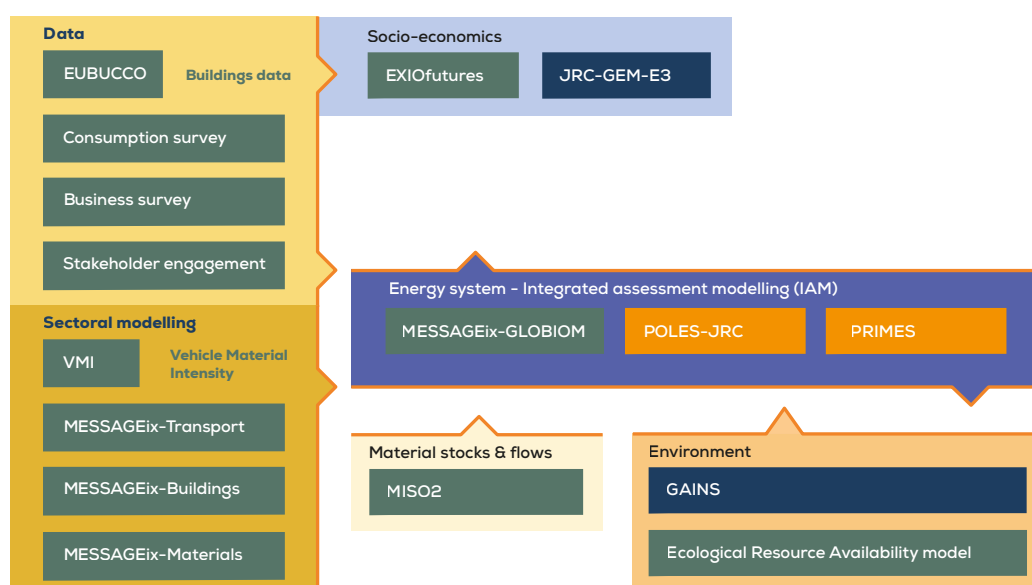
## Strengthening the EU toolbox with enhanced modelling capabilities

The European Commission uses a suite of linked models to support impact assessments for climate and energy policies, including the EU's 2030 and 2040 climate targets [8,9]. Integrating CircEular's modelling capabilities would strengthen its ability to assess circular economy strategies and their contribution to climate and energy objectives.

**Figure 2** illustrates the potential linkages between the CircEular modelling ecosystem (in green; see **Figure 1** for more details) and the European Commission's climate and energy modelling toolbox (in orange), highlighting shared models (in blue).

Together, these linkages broaden the representation of these circular economy strategies and practices across the following areas:

- **Buildings** – Shared living space, reduced household appliance ownership and reuse of vacant buildings, supported by detailed building-and city-level modelling;
- **Transport** – Reduced car ownership, trade-offs between vehicle lifetime extension and electrification, transport infrastructure, and changes in vehicle material intensity;
- **Digitalisation** – Energy and material demand associated with data centres;
- **Material stocks and flows** – Improved assessment of material stocks and flows for electric vehicles, household appliances and data centres, supporting implementation of the Critical Raw Materials Act and the RESourceEU Action Plan;
- **Waste management** – New linkages between sectoral and waste management models improve assessment of how product design and use patterns shape end-of-life treatment and secondary material availability;
- **Industry** – Integration of bottom-up sectoral models with macroeconomic analysis to assess how circular strategies reduce demand for energy-intensive materials and products; and
- **Rebound effects** – Explicit assessment of rebound effects when evaluating the climate mitigation potential of circular economy strategies.



**Figure 2.** Linking CircEular modelling to EU modelling toolbox



CircEular modelling toolbox



EU modelling toolbox



Part of both modelling toolboxes



## Towards improved representation of circular economy strategies in EU models

Current large-scale models represent only a limited set of circular economy strategies, focusing primarily on recycling and reuse. They also rely on simplifying assumptions that can overlook mass balances, thermodynamic constraints and interactions across sectors [4, 5, 6]. CircEULAR addresses these limitations by introducing **detailed modelling of material stocks and flows and extending model capabilities to represent strategies that narrow, slow and close material cycles**.

The EU's experience using models to inform climate and energy policy provides a strong foundation for circular economy modelling. As with climate modelling, these models are designed to explore the implications of different policy choices rather than predict precise outcomes. **Their results should therefore be interpreted alongside expert judgement and stakeholder evidence.**

The examples below illustrate how the CircEULAR enhanced modelling capabilities could strengthen the EU's modelling toolbox for circular economy policymaking, as shown in **Figure 2**.

### Buildings

Current EU models have limited capacity to assess the reuse of vacant buildings and building lifetime extension (slow strategies) because they lack detailed information on building stocks and vacancy. Reusing existing buildings, however, could substantially reduce demand for new construction, along with the associated material use and greenhouse gas emissions.

CircEULAR addresses this gap by combining the [EUBUCCO](#) building database with [MESSAGEix-Buildings](#) to assess the reuse of vacant buildings and lifetime extension across Europe through stock-turnover modelling. The results show these circular strategies can reduce material-related embodied emissions in new constructions by 22% by 2050 compared with a reference scenario [14]. These findings provide a stronger evidence base for policies that promote building reuse and reduce unnecessary new construction [3].

### Mobility

High-resolution modelling of transport infrastructure with GLOMIS enables assessment of the material stocks, flows and emissions associated with infrastructure expansion, maintenance and renewal. Linking this model with **MESSAGEix-GLOBIOM** [2] enables evaluation of the combined effects of demand and supply-side circular economy strategies. Without circularity measures, material stocks in EU mobility infrastructure could increase by almost 60% between 2024 and 2060. Meeting this demand would require around 1.8 Gt of annual material >>



inflows and generate 1.3 GtCO<sub>2</sub> of cumulative emissions. Integrating circularity measures reduces cumulative emissions by 40–45%, demonstrating that omitting circular economy strategies from current modelling underestimates their contribution to EU climate targets [15].

### Improved open data and models

Gaps in data on material stocks and flows, together with limited information on behavioural and contextual factors, constrain the assessment of circular economy strategies. CircEULAR addresses these gaps by integrating existing and novel open datasets and models, improving transparency, reproducibility and robustness of circular economy assessments.

The open-source [EUBUCCO](#) database provides information on more than 320 million buildings across Europe, including building footprints, height, number of floors and use type. It is complemented by new datasets on consumer behaviours and preferences related to sharing, second-hand markets, modal shift and downsizing, enabling more realistic assessment of circular economy strategies by accounting for behavioural feasibility alongside technical potential [12, 13]. Key datasets and scenario results are also made openly available through [IIASA's Scenario Explorer](#), enabling policymakers, researchers and other users to visualise, compare and explore scenarios through an intuitive web interface.

Circular economy modelling can be integrated incrementally into the EU's existing suite of linked climate and energy models, building on established modelling capabilities. This would strengthen evidence-based policymaking by providing a more comprehensive assessment of greenhouse gas emissions, material demand and circular economy strategies across sectors.

## Research Methodology

CircEULAR models circular economy strategies through a structured three-stage process that integrates models, tools and data, supported by empirical analysis and stakeholder engagement, as depicted in Figure 1. The process begins with the establishment of a common modelling protocol and the development of scenario narratives to ensure alignment across the modelling ecosystem.

During the **Explore** stage, the models were improved to enable enhanced representation of a broader set of circular economy strategies across sectors and were individually parameterised, translating qualitative scenario narratives into quantitative model parameters. During the **Expand** stage, complementary models were progressively coupled within each focus area, integrating new datasets and evidence from empirical analysis, interviews and stakeholder dialogues to refine model parameters, assumptions and feasibility.



Finally, during the **Consolidate** stage, the linked models were integrated across focus areas and joint scenarios were developed, providing results on the potential and feasibility of circular economy strategies at the European level. This process was applied across the project's focus areas (buildings and household services, mobility, and digitalisation) and key sub-topics, including household appliances and waste.

Figure 1 provides an overview of the modelling ecosystem, while the references listed below provide further details on the individual models and datasets.

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## Models and tools

### Sector modelling

- MESSAGEix-Buildings building sector model: <https://doi.org/10.1007/s10584-021-03229-3>
- MESSAGEix-Transport transport sector model: <https://docs.messageix.org/projects/models/en/stable/transport/index.html>
- MESSAGEix-Materials industry sector model: <https://docs.messageix.org/projects/models/en/latest/material/index.html>
- GLANCE household appliances model: <https://doi.org/10.5281/zenodo.21542463>

### Integrated transition modelling

- MESSAGEix-GLOBIOM integrated assessment modelling (IAM) framework:
  - <https://iiasa.ac.at/models-tools-data/messageix>
  - [docs.messageix.org/projects/models/en/stable/global/index.html](https://docs.messageix.org/projects/models/en/stable/global/index.html)
- JRC-GEM-E3 computable general equilibrium (CGE) model: [https://joint-research-centre.ec.europa.eu/what-we-do/scientific-tools-and-databases/general-equilibrium-model-economy-energy-environment/overview-jrc-gem-e3-model\\_en](https://joint-research-centre.ec.europa.eu/what-we-do/scientific-tools-and-databases/general-equilibrium-model-economy-energy-environment/overview-jrc-gem-e3-model_en)

### Industrial ecology modelling

- MISO2 material stocks and flows model: <https://boku.ac.at/miso>
- GLOMIS: <https://link.springer.com/article/10.1007/s44498-026-00132-x>
- EXIOFutures: <https://zenodo.org/records/22707658>

### Environmental modelling

- GAINS emission and pollution model: <https://iiasa.ac.at/models-tools-data/gains>

### Open data sources and tools

- EUBUCCO buildings database: <https://eubucco.com>
- IIASA Scenario Explorer: <https://circeular.apps.ece.iiasa.ac.at>



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## CircEular project

CircEular is a Horizon Europe project (2022–2026) led by the International Institute for Applied Systems Analysis (IIASA) and involving 11 European partners. It develops integrated modelling frameworks and circular pathways for a net-zero economy, with detailed analysis of mobility and buildings as material-intensive demand sectors, and digitalisation as a potential enabler of circularity. Combining quantitative modelling, qualitative research, and stakeholder engagement, the project generates evidence to support Europe's climate and circular economy objectives. **Visit our website:** <https://circeular.org/>

CircEular has been funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

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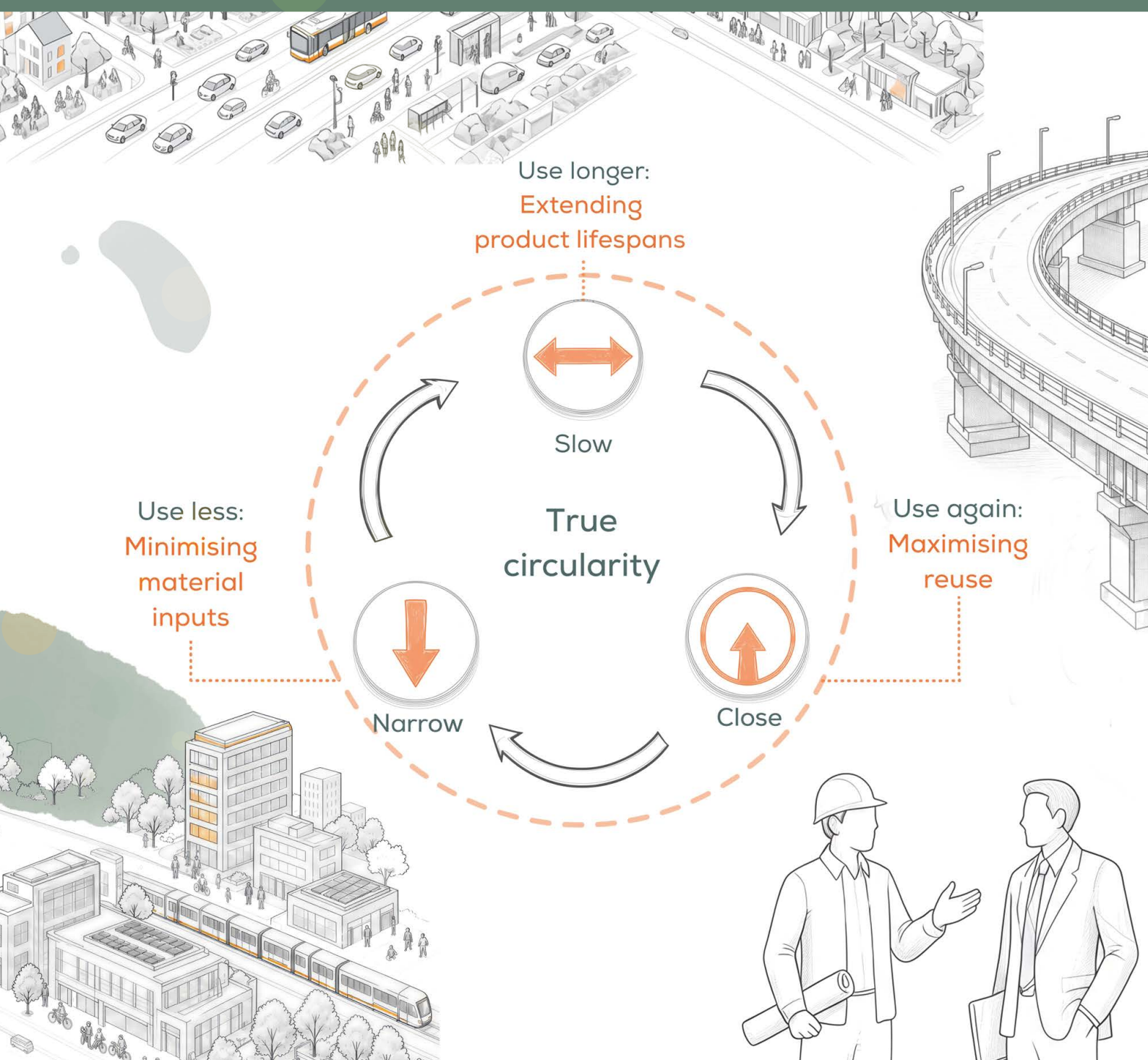
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# Pathways to climate neutrality

Prioritising circular economy strategies for net-zero greenhouse gas emissions





## Key messages

### Circular economy complements climate mitigation

Circular economy strategies enhance conventional mitigation. Their contribution, however, is not uniform: **strategies that reduce material demand (Narrow) deliver the greatest climate benefits, followed by those that extend product lifetime (Slow), while recycling and material recovery (Close) make a smaller contribution.**

### Circular economy lowers mitigation costs

Circular economy strategies make **achieving the Paris Agreement more cost-effective**. Under a 2°C-compatible pathway, full implementation of circular economy strategies reduces both the carbon price needed to achieve climate targets and overall macroeconomic mitigation costs by around one fifth by 2050.

### Climate benefits depend on integrating buildings, mobility and urban form

Rightsizing buildings, shifting from private vehicles to shared and public transport, and promoting compact, mixed-use cities reduce demand for space, travel and infrastructure. Together, these strategies reinforce one another, **increasing the effectiveness of circular economy measures in delivering emission reductions.**

### Circular economy reduces material and mitigation pressures

Circular economy strategies reduce reliance on land-based carbon mitigation and ease emissions reductions where technological options are limited. Circular economy strategies **reduce demand for bulk materials by around 10% for steel, 7% for cement and 18% for aluminium by 2050** and the environmental pressures associated with mining and primary material production.

### Digitalisation's climate mitigation potential requires policy alignment

Digitalisation can strengthen both circular economy and conventional mitigation by enabling shared mobility, predictive maintenance, product passports and second-hand markets. Without deliberate policy alignment, however, digitalisation may lead to **an increase in low-occupancy vehicle travel, an expansion in the energy and material footprint of digital infrastructure, and an acceleration in material-intensive consumption.**

## Policy recommendations

### Prioritise high-impact circular strategies

- Broaden and coordinate circular economy policy beyond existing frameworks by strengthening supply chain governance, extending producer responsibility, supporting circular business models and improving product information. Prioritise policies that reduce material demand and extend product lifetimes, as these strategies deliver the greatest climate mitigation potential.

### Integrate circularity into urban planning

- Strengthen integrated urban planning by combining transit-oriented development, mixed land use, urban densification and demand-side transport policies. By reshaping the spatial structures that determine material and energy demand across buildings and mobility, these measures amplify the impact of individual circular economy strategies while reducing the overall cost of achieving climate targets.

### Align digitalisation with climate goals

- Promote digital applications with proven climate benefits; strengthen and extend regulatory requirements to minimise the environmental footprint of digital infrastructure; and manage the indirect environmental impacts of digital applications in energy and material-intensive sectors. Together, these measures will help ensure digital technologies accelerate rather than undermine progress on climate mitigation and circular economy goals.

### Monitor the effectiveness of circular economy strategies

- Support continued monitoring of the effectiveness of circular economy strategies while expanding the empirical evidence base on circular practices and their scalability across different institutional and socioeconomic contexts. Use this evidence to refine policy design, improve implementation and minimise the risk of policy failure.



## Policy context

The **EU Circular Economy Action Plan (CEAP)**, adopted in 2020 as a cornerstone of the European Green Deal, established a framework for sustainable product design, circular consumption and waste reduction. Its implementation has been reinforced through the **Ecodesign for Sustainable Products Regulation**, **Right to Repair Directive** and **Critical Raw Materials Act**, strengthening product sustainability, repairability and resource security.

While these policies have advanced the EU's circular transition, they primarily focus on product lifetime extension and recycling. The modelling presented in this policy brief shows that **strategies to reduce material demand offer the greatest climate mitigation potential but remain underrepresented in current policy**. The forthcoming **Circular Economy Act** provides an opportunity to better align circular economy policy with the EU's climate neutrality objectives.

## Why this matters

Most existing emissions pathways focus on supply-side technological solutions and include only a limited range of circular economy strategies [1,2]. As a result, they underestimate the system-wide climate mitigation potential of material efficiency and demand-side measures. Better integration of material systems and integrated assessment models is needed to capture the impacts of circular economy strategies across the economy [3,4].

**CircEular addresses this gap** by integrating a broader range of circular economy strategies into climate modelling across three high-impact areas: mobility, buildings and household services, and digitalisation. Co-designed with stakeholders, the project develops circular economy pathways and assesses their system-wide contribution to achieving net-zero greenhouse gas emissions in Europe and worldwide. **The findings provide new evidence to inform the design of the Circular Economy Act and strengthen the contribution of circular economy policy to the EU's climate neutrality objectives.**

## What the evidence shows

### The Narrow–Slow–Close hierarchy: not all circularity is equal [10]

**CircEular's analysis reveals** (as shown in Figure 1) a consistent GHG mitigation hierarchy across all sectors examined. **Narrow strategies, which avoid emissions-intensive material and energy use in the first place, show the largest climate mitigation potential.** Interventions such as reducing private vehicle ownership, rightsizing residential floor areas, and substituting physical goods with digital or shared services address the root causes of material demand rather than managing its consequences. **Slow strategies, including repair, refurbishment and lifetime extension, provide a secondary but consistent contribution by extending the service life of existing stocks and delaying new material demand. >>**

Close strategies, centred on recycling and material recovery, are among the most established circular economy measures but exhibit the lowest mitigation potential. Recycling rates for major bulk metals are already comparatively high, the long service lives of buildings and vehicles delay the return of materials to the secondary production cycle, and quality degradation limits the substitution of recycled for primary material in demanding applications. **This hierarchy is not yet reflected in current EU policy, which remains more strongly focused on product lifetime extension and recycling than on reducing material demand.**



**Figure 1.** Narrow, Slow, Close: how circular economy strategies contribute to climate mitigation (developed with support of AI)

Beyond reducing emissions under a 2°C-compatible pathway, **full implementation of circular economy strategies reduces both the required carbon price and macroeconomic mitigation costs by around one fifth by 2050**, demonstrating that ambitious circular economy action can make climate mitigation substantially more cost-effective.



### Buildings and household services: stocks, space, and appliances [11,12,13]

Europe's existing building stock is a major determinant of future energy and material demand. With more than 200 million buildings, their service life, renovation depth and future floor area will have a greater influence on long-term emissions than the technologies used in new construction. The modelling identifies **rightsizing, i.e. reducing average per-capita floor area through co-habitation and space sharing, as one of the highest-impact Narrow strategies**, as it reduces both operational energy use and the demand for construction materials. For household appliances, **lifetime extension of white goods such as washing machines reduces both embodied and operational GHG emissions**, with embodied emissions becoming increasingly important as energy supply decarbonises. Consumer survey evidence further shows that many European households are willing to adopt circular economy practices but continue to face structural, financial and informational barriers to doing so.

### Mobility: shared services, right-sizing, and infrastructure materials [14,15,16]

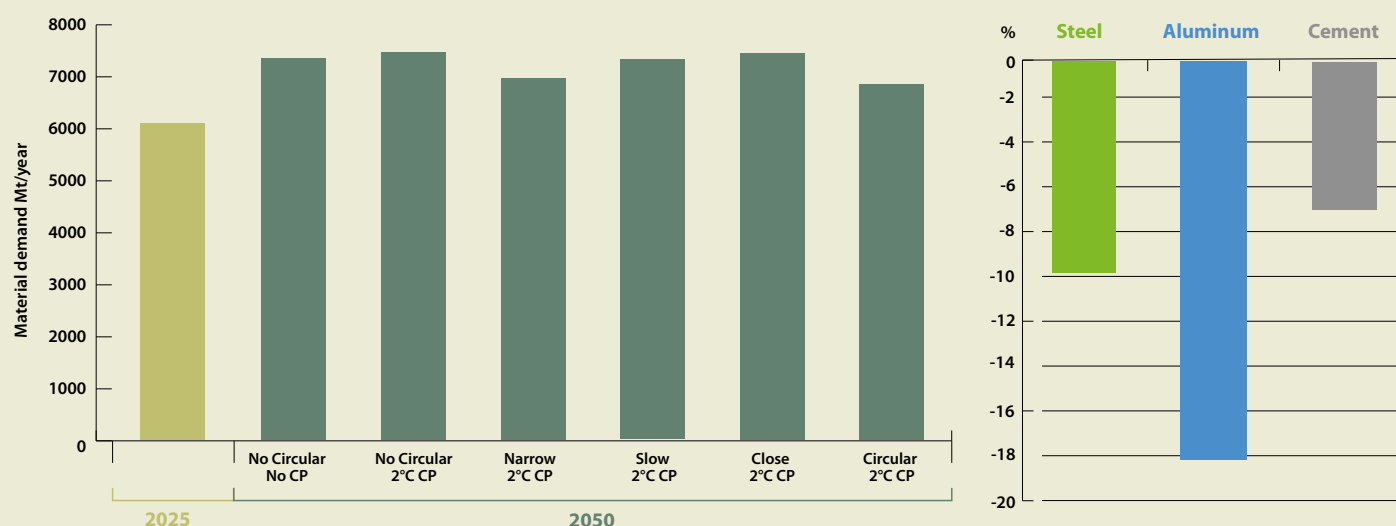
In the mobility sector, **the most effective circular economy interventions reduce private vehicle ownership and shift travel towards shared and public transport modes**. Mobility infrastructure – including roads, bridges, tunnels, railways, airports and fuelling stations – is a substantial and often-overlooked source of embodied material demand, particularly for cement and steel. Vehicle right-sizing and mode shifts simultaneously reduce fleet-level material stocks and infrastructure requirements, generating compound benefits across material supply chains. Shared electric vehicles, when genuinely operated at high occupancy, can deliver significant lifecycle GHG reductions relative to conventional private ownership. However, the material footprint of fleet electrification depends critically on whether total vehicle stocks grow or contract: a growing electric fleet may not reduce overall material demand relative to a stable conventional one.

### Urban form and system-wide material benefits [17,18]

Both the buildings and mobility findings point to a cross-cutting result: **the spatial structure of cities determines the effectiveness ceiling for individual circular economy measures**. Integrated urban planning, combining densification, transit-oriented development, mixed land use and demand-side transport policy, reshape the spatial conditions that drive material and energy demand across both sectors simultaneously. The analysis finds that coordinated urban planning can contribute approximately 14% of combined transport and building-sector GHG reductions by 2050, without requiring any new low-carbon technologies. **These system-wide benefits arise because compact, mixed-use urban form simultaneously reduces travel distances, lowers per-capita floor area demand, enables district-scale building renovation and makes shared mobility economically viable. >>**



Beyond these integrated climate benefits, circular economy strategies also substantially reduce material demand and resource extraction. By contrast, conventional mitigation measures tend to increase material demand as a result of deploying more material-intensive low-carbon technologies. As shown in Figure 2, under a 2°C-compatible (2°C) climate policy (CP) pathway, Narrow, Slow and Close strategies each **reduce total material demand, with the greatest reduction achieved when circular economy strategies are combined**. Full implementation can reduce bulk material demand by 2050 by 10% for steel (260 Mt), 7% for cement (320 Mt) and 18% for aluminium (40 Mt) compared with a 2°C-compatible climate policy pathway without circular economy strategies.



**Figure 2.** Total material demand in 2025 and across circular economy and climate policy pathways in 2050 (left), and percentage reductions in steel, aluminium and cement demand under the combined circular economy pathway compared with climate policy alone in 2050 (right)

## Digitalisation: enabling or undermining the transition? [19]

Digitalisation can either strengthen or undermine circular economy pathways, depending on how digital technologies are developed and governed. Digital technologies enable circularity through product passports, second-hand trading platforms, predictive maintenance and real-time mobility optimisation. However, the same digital infrastructure is also an increasing consumer of energy and materials, while digital platforms can amplify resource-intensive activity by lowering the cost of consumption. The analysis finds that the difference between an enabling and an undermining digitalisation trajectory is comparable in magnitude to the full uncertainty range across different socio-economic futures, placing digitalisation governance on a par with conventional climate policy in strategic importance. **The findings demonstrate that the climate benefits of digitalisation cannot be assumed and depend on explicit coordination between digital and climate governance.**



Taken together, these findings show that **the climate benefits of the circular economy depend not only on improving material efficiency, but on reducing material demand, optimising the use of existing assets, integrating land-use and mobility planning, and ensuring that digitalisation actively supports rather than undermines the transition.** They provide a stronger evidence base for embedding circular economy strategies within the EU's climate policy framework and maximising their contribution to climate neutrality.

## Research Methodology

Narratives and quantitative pathways were co-developed with stakeholders using the **Story and Simulation** approach [5]. Initial circular economy-driven emissions pathways were developed through iterative consortium workshops before being refined through stakeholder engagement [6,7]. The pathways also draw on empirical research into circular production and consumption, including case studies, interviews and surveys across Europe [8,9], complemented by evidence synthesis from the wider literature and upscaled for model-based analysis.

The **MESSAGEix-GLOBIOM-GAINS** integrated assessment modelling framework was extended to represent material stocks and flows through linked service demand modules for **buildings** [MESSAGEix-Buildings], **household appliances** [GLANCE] and **transport** [MESSAGEix-Transport]. These modules are integrated with **MESSAGEix-Materials**, which represents material supply industries and recycling pathways for steel, cement, aluminium and chemicals, enabling quantification of both the energy and material implications of circular economy strategies.

To capture transport-related material demand, **MESSAGEix-Transport** is linked to **GLOMIS**, which estimates mobility infrastructure requirements, and the **Vehicle Material Intensity** model, which represents vehicle material composition. Finally, the **GAINS** model quantifies interactions between greenhouse gas mitigation, air pollution control and waste management.



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## Models and tools

### Sector modelling

- MESSAGEix-Buildings building sector model: <https://doi.org/10.1007/s10584-021-03229-3>
- MESSAGEix-Transport transport sector model: <https://docs.messageix.org/projects/models/en/stable/transport/index.html>
- Vehicle Material Intensity Model: <https://zenodo.org/records/22710310>
- GLANCE household appliances model:  
<https://doi.org/10.5281/zenodo.21542463>  
<https://zenodo.org/records/22707658>
- MESSAGEix-Materials industry sector model: <https://doi.org/10.5194/gmd-17-8321-2024>

### Integrated transition modelling

- MESSAGEix-GLOBIOM integrated assessment modelling (IAM) framework:  
[docs.messageix.org/projects/models/en/stable/global/index.html](https://docs.messageix.org/projects/models/en/stable/global/index.html)

### Industrial ecology modelling

- MISO2 material stocks and flows model: <https://boku.ac.at/miso> <https://doi.org/10.5281/zenodo.12795905>
- GLOMIS: <https://doi.org/10.1007/s44498-026-00132-x>

### Environmental modelling

- GAINS emission and waste model: <https://iiasa.ac.at/models-tools-data/gains> <https://doi.org/10.1038/s41467-021-27624-7>

### Open data sources and tools

- EUBUCCO buildings database: <https://eubucco.com/>
- IIASA Scenario Explorer: <https://circeular.apps.ece.iiasa.ac.at/>



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State Secretariat for Education,  
Research and Innovation SERI



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# Circular consumption

Enablers and barriers to demand-side circularity





## Key messages

### Higher-impact practices drive circularity

Dematerialisation strategies – reducing car ownership and living space – offer the greatest circularity gains, yet practical, economic and social barriers persist.

### Car sharing remains a niche mobility option

Cars provide convenience, autonomy and status that alternatives struggle to match. 73% of respondents with access rarely or never use car sharing, limiting its potential to replace ownership.

### Rightsizing is an untapped opportunity

More than a quarter (28%) of respondents are willing to move to a smaller home if a suitable one is available, while 27% already share residential space, mainly entrances and hallways.

### Digitalisation can support circular consumption

Two-thirds (66%) of respondents say digital platforms improved access to local services. However, repair, borrowing and lending receive less digital support, and easier online purchasing may increase consumption.

## Policy recommendations

### Make circular choices the easiest choices

- **Shift responsibility for circularity upstream** by embedding it in product design and production, rather than relying on consumers to make costly circular choices. **Strengthen policy coherence and improve implementation** of the Ecodesign for Sustainable Products Regulation, Digital Product Passports and Extended Producer Responsibility across Member States; making durable, repairable and reusable products the default.

### Reduce dependence on private car ownership

- Invest in public transport, walking and cycling while embedding car sharing in multimodal mobility systems. Support **compact neighbourhoods, mixed-use buildings, 15-minute cities, and reform incentives that favour car ownership** (tax breaks, scrappage schemes and free or low-cost parking). Incentives, awareness campaigns and better integration with public transport, can increase car sharing and reduce reliance on private cars – complementing rather than replacing public transport and active mobility.

### Govern digitalisation for circular outcomes

- Make digital platforms active enablers of circular consumption, limiting ICT's environmental impacts and avoiding additional consumption. **Develop standards for simple, trustworthy and inclusive digital platforms** that prioritise repair, reuse, sharing and second-hand markets through information on repair, durability and provenance, search and recommendation systems, and targeted financial incentives. Further extend the principles of the Right to Repair framework to digital marketplaces and support social research to better understand how digitalisation can enable and maintain circular practices.

### Make rightsizing a realistic housing option

- Reduce financial barriers to rightsizing across life-stages through relocation grants, **rent-retention schemes, tax incentives and shared housing matching services**. Housing and renovation policies should support flexible, mixed-use homes and shared spaces that accommodate diverse household types, making appropriate floor space per person practical and attractive.





## Policy context

The European Green Deal and the proposed Circular Economy Act provide the overarching policy framework for reducing material use, improving resource efficiency and supporting circularity across the EU. Within this broader context, several policy initiatives address the enablers and barriers affecting demand-side circularity. The **Ecodesign for Sustainable Products Regulation** and the **Right to Repair Directive** seek to extend product lifetimes by improving product durability, reparability and consumer access to information. **Digital Product Passports** increase transparency around product provenance, lifespan and repair options. Similarly, the **Waste Framework Directive** promotes waste prevention, reuse and more circular resource management, while **Extended Producer Responsibility** schemes strengthen incentives for durable, repairable and recyclable product design. **Green Public Procurement** leverages public purchasing power to stimulate demand for durable, repairable and resource-efficient products and services, helping suppliers invest in and scale circular solutions.

## Why this matters

Many circular economy policies focus on product design, production and end-of-life management. **Greater attention is now needed on the demand side to create the conditions that enable more circular consumption.** Despite the circularity benefits of, for instance, reducing car ownership, EU motorisation rates rose from 518 passenger cars per 1,000 inhabitants in 2016 to 578 in 2024 [1]. Creating those conditions requires coordination beyond individual consumers. Effective policy must identify and address the barriers that limit circular practices across mobility, housing and digitalisation, while strengthening the enabling conditions that make them practical, affordable and attractive.

## What the evidence shows

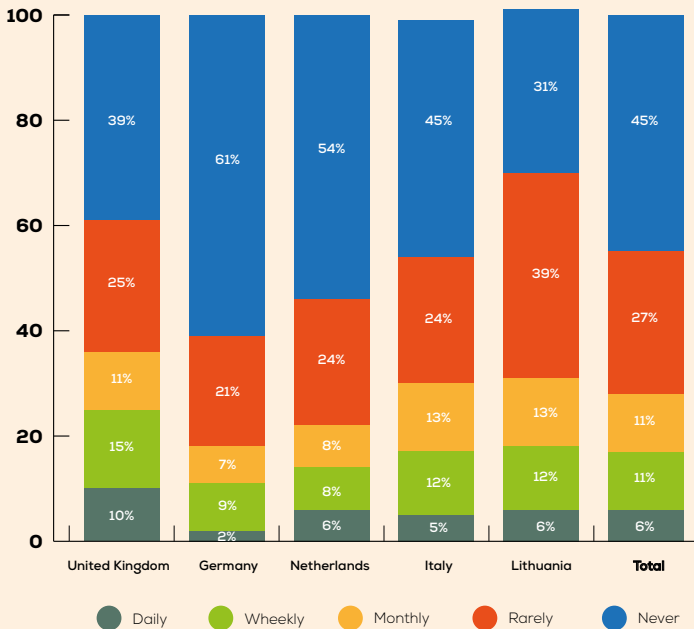
### Access to car sharing has limited impact on car ownership [3,4]

Greater access to car-sharing services has yet to translate into widespread use. Of the 2,558 respondents with access to car-sharing platforms, almost three-quarters (73%) use it rarely (27%) or never (45%). Regular users (17%) are typically male (57%), urban residents (73%) and have mid-to-high levels of education (79%). This indicates that uptake remains concentrated among specific groups. Similar use patterns occur among households with and without a car, showing that access alone is insufficient to shift mobility behaviour.

Country differences are modest. Germany reports the lowest uptake, with 82% rarely or never using available car-sharing services, while the UK has the highest regular use, at 24% daily or weekly. >>



## How often do you use car sharing?



Reducing private car ownership requires more than expanding access to car sharing. Interview insights suggest that car sharing works best as part of a wider multimodal mobility system. Interviewees without a car, particularly in dense urban areas, often view ownership as costly or unnecessary, favouring shared mobility and multimodal travel.

Car-sharing services facilitate occasional or leisure trips, highlighting their potential to reduce private car ownership. Expanding car sharing's contribution to circular mobility will depend on better mobility services, greater trust in sharing systems and broader shifts in social norms related to car private ownership. [2]

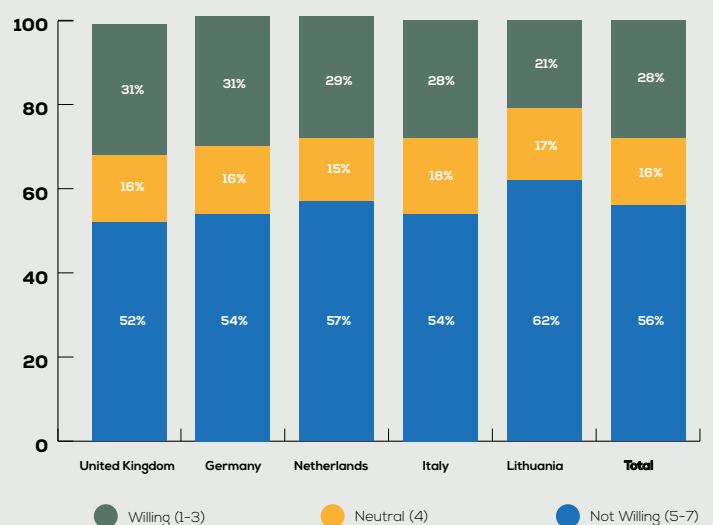
## Financial and practical barriers limit rightsizing [3,4]

Making better use of existing housing stock will require addressing the barriers to rightsizing. Over a quarter (28%) of respondents state they would consider moving to a smaller home if a suitable property were available, while 56% were unwilling to do so.

Relocation costs, the inconvenience of moving and reluctance to reduce living space were the main barriers. Willingness to downsize was broadly similar across countries. Lithuania reported the lowest willingness, likely reflecting that households already have the lowest living space per person.

Housing market conditions often prevent willingness from translating into action. In urban areas, many interviewees say downsizing would only be attractive if it offered a clear financial benefit, reflecting growing gaps between long-term rental agreements and current market rates. >>

### Willingness to live in a smaller home if readily available



The lack of suitable properties in highly pressurised housing markets also limits (local) relocation. Social norms, including expectations around shared spaces, also constrain more efficient use of housing. Past experience matters: 73% of respondents do not share any residential spaces, while those with prior experience of shared spaces are more willing to share in the future.

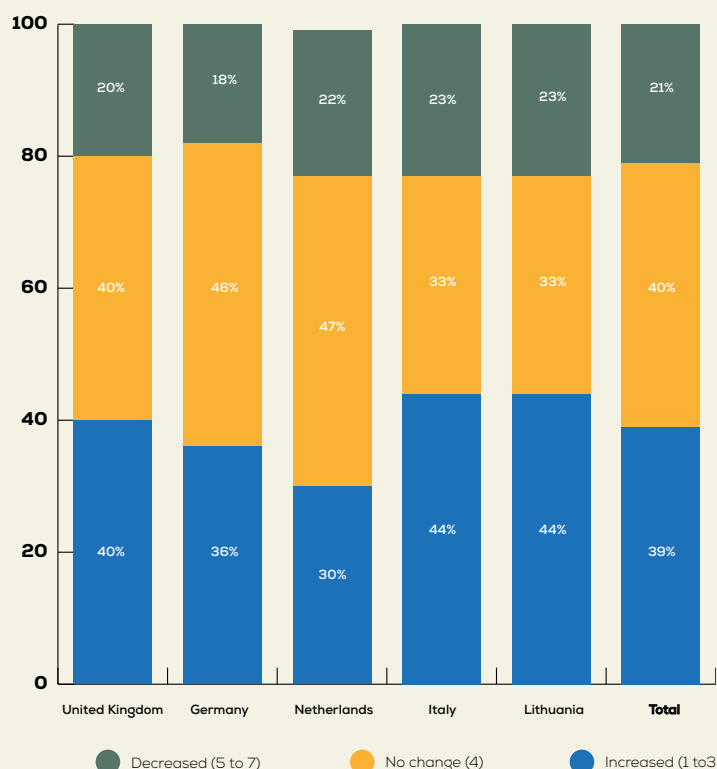
## Digitalisation is reshaping consumption [3,4]

Digitalisation can support circular consumption by improving access to services, information and second-hand markets. It can also increase efficiency and enable new business models that reduce the need for private ownership. Respondents report improved access to local services (65%), information (72%) and online banking and shopping (71%). Digital platforms also facilitate the recirculation of goods, with 74% of respondents engaged in second-hand trade reporting that offering goods online made recirculation easier.

The same digital technologies can also make purchasing goods and services faster, easier and cheaper, potentially increasing overall consumption while reducing the appeal of repair and other circular practices. Respondents were more likely to report increases than decreases in their consumption of media (50% vs. 18%) and household goods and services (35% vs. 21%). Many also associate digitalisation with higher energy use (39% reporting increased energy consumption compared with 21% reporting a decrease). Perceived increases were highest in Italy (44%) and Lithuania (44%), and lowest in the Netherlands (30%).

Without targeted measures, gains in access and efficiency may be offset by higher levels of consumption, limiting digitalisation's contribution to the circular economy and wider sustainability goals.

How do you feel digitalisation has affected the amount of energy you use at home?





## Research Methodology

The empirical evidence used in this study combines insights from 80 qualitative interviews and survey data on circular consumption practices. The Circular Consumption Interviews [4] were conducted between October 2023 and March 2024 using a mix of face-to-face and online interviewing techniques. Interviewees included both people who were already engaged in circular consumption practices as well as those who were not. Using a retrospective biographical approach, the interviews focused on past, current and future engagement in circular consumption practices, including life events and socio-economic factors that shaped their adoption. Interviews were conducted in the local language by CircEULAR research partners in the United Kingdom, Germany, the Netherlands and Italy.

The Circular Consumption Survey [3] was conducted online between October 2023 to March 2024, with 5,651 respondents across five countries. Nationally representative samples were selected based on age, sex, education level and region, with more than 1,000 respondents surveyed in each country. The survey examined engagement with circular consumption practices, including frequency of use and factors influencing (un)willingness to adopt these practices in the future. Results are based on descriptive and segmentation analyses of survey responses.

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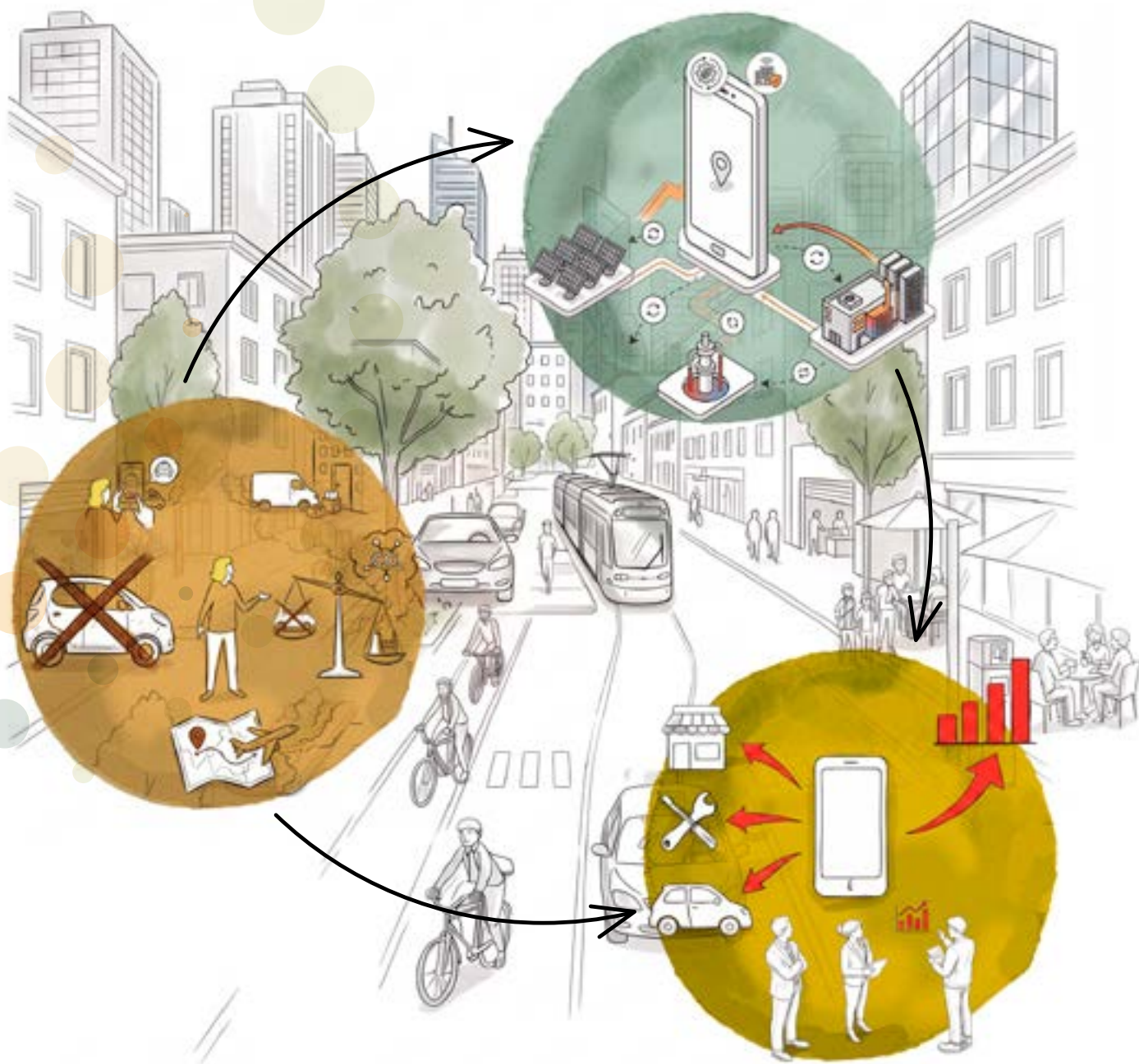
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# Circular without rebounds

Mitigating rebound effects in corporate circular practices through EU policy





## Key messages

### Rebound effects can offset circular economy gains

Circular practices do not automatically reduce resource use or strategic dependencies. Rebound effects – behavioural and market responses that offset environmental benefits – can arise when lower costs, higher profits or consumption shifts erode expected gains.

### Awareness of rebound effects is uneven

Nearly half (47%) of surveyed employees report moderate-to-high familiarity, but knowledge is concentrated among sustainability specialists.

### Circular services do not guarantee lower consumption

Shared mobility may complement rather than replace car ownership: 66% of surveyed consumers would retain a private car even if car-sharing were available.

### Digital applications can both enable and undermine circularity

Circular strategies could reduce projected fivefold growth in data-centre material demand by 20%. Digital applications in buildings can reduce waste and energy use, while mobility applications face greater rebound risks.

## Policy recommendations

### Embed rebound mitigation in corporate governance

- Strengthen the **Corporate Sustainability Reporting Directive** to integrate rebound risks into corporate governance and decision-making. Complementary support for employee training and recognition schemes can help companies identify and address rebound risks before they erode the expected environmental benefits of circular practices.

### Align economic incentives with circular outcomes

- Steer savings and profits generated through circular practices towards low-resource activities. Taxes on non-circular goods, subsidies for circular alternatives and substitution-oriented mechanisms in **Extended Producer Responsibility** schemes can strengthen the competitiveness of circular products and reduce rebound risks.

### Enable informed consumer and investor choices

- Improve access to reliable information on the resource intensity of products and services. >>

Product labelling, sustainability-oriented investment criteria, dedicated education programs and standardised methodologies such as **Life Cycle Assessment** can support more informed decision-making. Resource use and rebound-risk reporting under the **Corporate Sustainability Reporting Directive** can further support consumer and investor choices.

### Constrain virgin resource use and high-rebound activities

- Complement circular economy measures with policies that limit virgin resource extraction and resource-intensive consumption. Stronger environmental permitting, **Natura 2000** protections, sustainability criteria, extraction and import charges, durability requirements under the **Ecodesign for Sustainable Products Regulation** may reduce extraction of virgin resources. Where rebound risks remain high, quotas for high-impact activities might be needed. Together, these measures can help prevent rebound effects from offsetting environmental gains.





## Policy context

The **Circular Economy Act** strengthens raw material security by promoting circular material flows, resource efficiency and reduced material use, supporting the **European Green Deal** and **net-zero targets**. Ensuring that circular practices effectively reduce resource consumption and strategic dependencies remains a key challenge.

The **Corporate Sustainability Reporting Directive** requires large companies to disclose sustainability risks and opportunities related to social and environmental issues. The CSRD could be extended to capture rebound effects by requiring disclosure of related risks, such as whether circular products or investments replace options with lower overall environmental impacts.

Finally, the **Waste Framework Directive** implements the Extended Producer Responsibility scheme, which could further mitigate rebound risks through stricter reduction and substitution targets and differentiated fees favouring circular solutions.

## Why this matters

Rebound effects occur when behavioural or market responses reduce – or in some cases reverse (“backfire”) – the expected environmental benefits of circular practices. Drawing on evidence from the [CircEULAR project](#), this policy brief examines rebound effects arising from companies’ circular practices and their implications for EU resource use and strategic dependencies. It highlights how the EU can ensure that circular practices deliver their intended environmental and resource-saving benefits.

## What the evidence shows

**Circular practices do not automatically reduce resource use.** Rebound effects can arise through both cost and substitution dynamics. Practices that reduce production costs may increase resource use if lower prices stimulate additional demand or higher profits support resource-intensive activities. Circular products and services can reduce resource use when they replace more intensive forms of consumption, but may generate rebound effects when they complement existing consumption or displace more sustainable alternatives. Rebound risks are lower when demand for additional consumption is limited and consumers continue to favour low-resource alternatives over resource-intensive options [1].

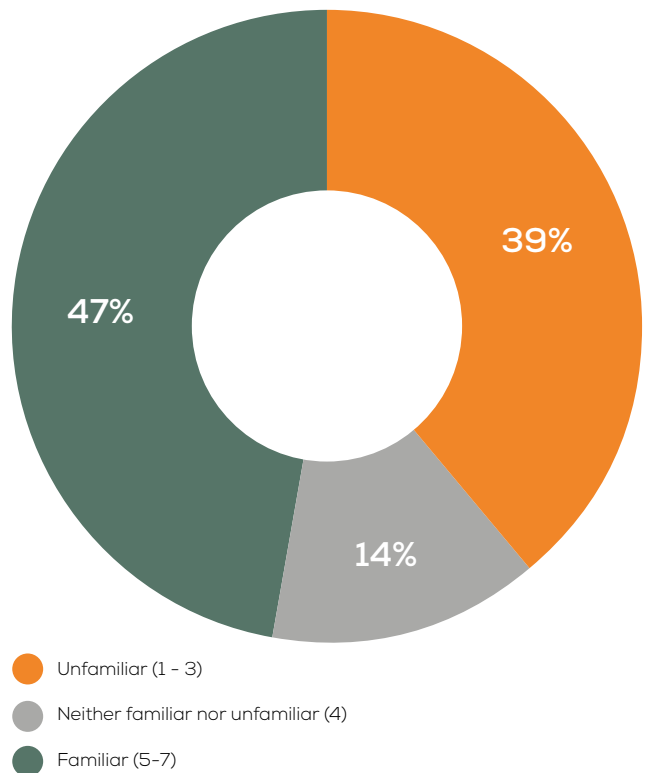


However, awareness of rebound effects remains concentrated among sustainability-oriented employees rather than embedded across organisations, potentially limiting companies' ability to identify and mitigate rebound effects.

Almost half (47%) of surveyed employees report moderate-to-high familiarity with rebound effects. Two-fifths (39%), however, indicate low or no familiarity, including 23% with no familiarity at all.

Awareness is highest among employees in sustainability-related roles, younger employees, and those with a strong sense of personal responsibility and environmental awareness. These findings are based on a non-statistically representative survey [2,3] of 3,391 employees across the mobility, building and manufacturing sectors.

**To what extent are you familiar with the concept of rebound effect?**



**Beyond individual companies, circular practices can reshape material flows, prices and consumption patterns.** By reducing material demand or increasing the supply of secondary materials, they can lower prices and influence resource use across the wider economy. Environmental gains therefore depend on high substitution rates, where circular goods and services replace rather than complement resource-intensive alternatives.





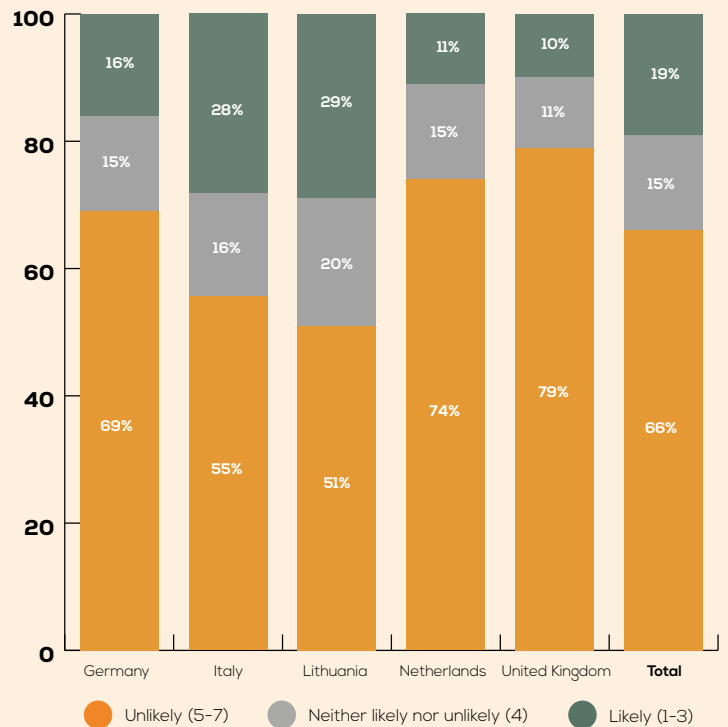
## Shared mobility may complement rather than replace private cars

Based on the consumer survey (n = 2,636), around two-thirds (66%) of respondents would be unlikely to give up their car if car-sharing services were available, while only 19% would be likely to do so [4].

Respondents in Italy and Lithuania appear slightly more willing to transition away from private car ownership than those in other surveyed countries, although reluctance remains high overall.

**Without substantial substitution away from private vehicles, shared mobility may complement rather than replace existing travel**, increasing overall mobility demand or displacing more sustainable modes such as walking and cycling.

### Would you get rid of your car if adequate car sharing was available?



**Achieving circularity also requires resources.** Recycling, transport, machinery and digital infrastructure can all increase demand for materials. Data-centre material demand is projected to increase fivefold by 2030, although circular strategies could reduce this growth by around 20% [5]. Expanding digital infrastructure may therefore increase demand for critical raw materials, particularly platinum group metals, where supply constraints are already acute.

## Digital applications can enable - and undermine - circularity

Circular practices enabled by digital applications can both reduce and increase resource use, depending on how they affect consumption patterns, substitution dynamics, and infrastructure demand. Resource savings can arise through substitution, higher utilisation of physical goods, and waste avoidance, for example through Building Information Modelling (BIM) and smart heating or cooling systems. In buildings, **digital applications have been associated with reductions in construction waste of up to 57%** (from BIM) and **reductions in energy use of up to 36%** (for smart building control technologies) [6]. >>



**Digital applications can also generate significant rebound effects through additional demand and substitution effects.** Shared mobility, for example, may substitute for cycling or public transport rather than private car ownership, while autonomous vehicles may create additional travel demand. Ride-hailing and autonomous vehicles have been associated with increases in energy use of up to 90% and 60%, respectively [6]. By contrast, rebound risks appear more limited in buildings, where there is less scope to increase additional heating or cooling in response to efficiency gains.

**Rebound risks differ across digital applications and sectors.** In mobility, digitalisation can stimulate additional activity and weaken substitution away from resource-intensive travel, while digitally enabled practices in buildings appear to deliver more stable efficiency gains and lower rebound risks.

**Circular practices are more likely to deliver lasting resource savings when wider market conditions reinforce them.** Redirecting cost savings towards low-resource activities, strengthening consumer and investor demand for circular alternatives, and constraining virgin resource extraction can all help reduce rebound effects [1].

**Efficiency improvements alone are insufficient indicators of environmental benefits, which depend on changes in consumption, infrastructure demand, and system-wide resource use.**

## Research Methodology

**Rebound framework:** The framework was developed through sequential economic reasoning and synthesises evidence from the rebound, circular economy and industrial ecology literatures to identify the conditions under which firm-level circular practices translate into economy-wide resource savings. It assumes that a significant share of profit-maximising firms adopts circular strategies, while some consumers are willing to pay more for circular goods. The analysis examines the short- to medium-term effects of a shift toward firm circular practices (excluding energy recovery) on macro-level resource use. Alternative scenarios are analysed based on how circular practices affect costs and resources, and whether market power is present in business-to-consumer sales. For each scenario, rebound mechanisms and the conditions under which rebound may be prevented or mitigated are identified based on economic reasoning and relevant literature. The analysis yields six conditions: (i) constrained virgin resource extraction; (ii) saturated consumer demand; (iii) redirection of cost savings and profits towards low-resource activities; (iv) high substitution rates of non-circular goods and services by circular alternatives; (v) consumer and investor preferences for low-resource activities; and (vi) access to reliable information and technologies supporting low-resource choices. The associated policy levers are derived from a literature review and should be understood as informed suggestions for materializing these theoretical conditions.



**Employee survey:** 3,391 surveyed employees through an online questionnaire across sectors: 19% of surveyed employees in mobility, 37% in buildings and 44% in manufacturing, and countries: 23% in the Netherlands, 23% in Germany, 26% in Italy, 8% in Lithuania, and 20% in the United Kingdom. This is not a statistically representative sample of the EU employee population (no representative quotas were used). Variables were identified as drivers only if they remained statistically significant after accounting for multiple other factors in a multivariable statistical analysis (pooled Ordinary Least Squares (OLS) estimation).

**Consumer survey:** A total of 5,651 observations were collected online using nationally representative quotas and weights assigned based on age, gender, education, and region. The countries covered were 19% of respondents in the Netherlands, 19% in Germany, 25% in Italy, 18% in Lithuania and 19% in the United Kingdom. Results are based on descriptive and segmentation analyses of survey responses. Results used here are based on a subsample of 2,636 consumers without access to car sharing.

**Digitalisation:** The digital applications with highest magnitude impact in each resource-using sector (mobility, buildings, industry) were identified. For each application, the recent literature was reviewed to provide quantitative estimates of indirect impacts on resource use (energy and materials), drawing on systematic reviews if available, and focusing where possible on empirical rather than prospective modelling studies.

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# Urban planning and data-driven approaches enable low-carbon cities

Evidence from Berlin and Porto integrated spatial studies



## Key messages

### Urban form is a powerful circular economy lever

Evidence from Berlin and Porto shows that **location, density, and accessibility to jobs, services, and public transport** are key drivers of low-carbon outcomes.

### Spatial planning drives system-wide impacts

Urban form is a major determinant of operational and embodied emissions, accounting for **up to 72% of transport emissions variation in Berlin and 65% of energy and material demand drivers in buildings and mobility in Porto**.

### Location is a primary climate lever

Site selection locks in emissions pathways for decades. In Berlin, current housing plans could generate **up to 62% higher mobility-related CO<sub>2</sub> emissions** than spatially optimised alternatives.

### Compact, mixed-use neighbourhoods deliver co-benefits

Evidence from Berlin and Porto shows that **compact, well-located, mixed-use development reduces transport emissions** while improving energy and material efficiency.

## Policy recommendations

### Make accessibility a core planning objective

- Embed accessibility to jobs, services, and public transport into spatial planning, housing, and mobility policies at national and local levels.
- **Set minimum accessibility standards and use accessibility and travel-related CO<sub>2</sub> indicators** to guide site selection and development decisions.
- Shift the focus from moving people faster to bringing destinations closer together.

### Focus on compact, transit-oriented development

- Direct new housing and redevelopment to **compact, walkable locations near public transport, jobs, and services**.
- Prioritise development around existing transit hubs and ensure measures are in place to manage land speculation, reducing car dependency and supporting accessible, low-carbon communities.

### Promote circular urban regeneration and compact development

- Prioritise **renovation, reuse, repurposing, and targeted densification** in well-connected urban areas before expanding into new sites.
- Align housing and retrofit programmes with compact city objectives to reduce energy, material use, and transport emissions, while supporting sustainable mobility.
- Monitor **rebound effects** to ensure efficiency gains deliver net environmental benefits.

### Strengthen data-driven urban planning

- National, regional, and city-level policymakers should develop **interoperable data platforms and open data systems** to support integrated planning across buildings, mobility, and resource use.
- Building permits, building certificates, and public transport operators' mobility data are key data sources for integrated urban planning. Embedding these data into city strategies helps align departments, identify synergies and trade-offs, monitor progress, and support **evidence-based decisions**.





## Policy context

Urban areas are central to delivering EU priorities under the European Green Deal, the EU Mission for Climate-Neutral and Smart Cities, and the Energy Performance of Buildings Directive, which promote climate neutral cities, zero-emission buildings, renovation, and local energy systems. The Circular Economy Action Plan also recognises the need to reduce resource use and emissions but gives limited attention to the role of cities and spatial planning. As the EU advances its Affordable Housing Plan, **housing delivery should support circularity objectives by prioritising refurbishment, reuse, and better use of existing floor space, while planning new housing in well-connected locations that reduce building footprints and enable low-emission mobility.**

## Why this matters

- **Buildings** account for **26% of global energy-related CO<sub>2</sub> emissions**, while **transport** accounts for **23%**, together making up roughly half of all energy-related CO<sub>2</sub> emissions worldwide [1].
- **Housing** and **food** account for over **70% of EU material demand**.
- **Urban sprawl** locks in car-dependent travel patterns for decades [8], making spatial structure a key climate policy lever [2].
- **Urban form** influences travel behaviour, energy use and material demand, with denser and more compact development requiring less energy and fewer materials.

Previous research showed links between urban form and travel behaviour, but it was difficult to separate built environment effects from individual travel preferences. Meanwhile, most urban decarbonisation strategies address transport, buildings, and resource use separately, overlooking opportunities to deliver savings considering the synergies across the three dimensions.

## What the evidence shows

CircEular studies in Berlin and Porto show that **urban planning can significantly cut emissions and resource use**. The Berlin study examined residents' travel patterns to show how the design of the city influences travel-related CO<sub>2</sub> emissions. The Porto study found that the way the city is physically shaped, namely, its layout and density, influences the city's energy and material demand.

**Together, these studies identify destination accessibility and population density as the most powerful levers for reducing emissions**





### Destination accessibility drives transport emissions – the case of Berlin [3,9]

Analysis of more than 32,000 Berlin residents shows that where people live has a major impact on travel-related CO<sub>2</sub> emissions, even after controlling for individual residential and travel preferences. Residents in central, mixed-use areas emit 26 percentage points (pp) less CO<sub>2</sub> than the city average, while those in exurban areas emit 35pp more – a gap of 61pp. Overall, **the built environment explains 72% of neighbourhood-level variation in travel-related CO<sub>2</sub> emissions**, even after accounting for residential self-selection (people choosing neighbourhoods that match their travel preferences). **Destination accessibility is the most important factor, accounting for 63% of the total built environment effect.** This is followed by population density (12%), transit accessibility (8%), street connectivity (5%), and land-use diversity (2%).

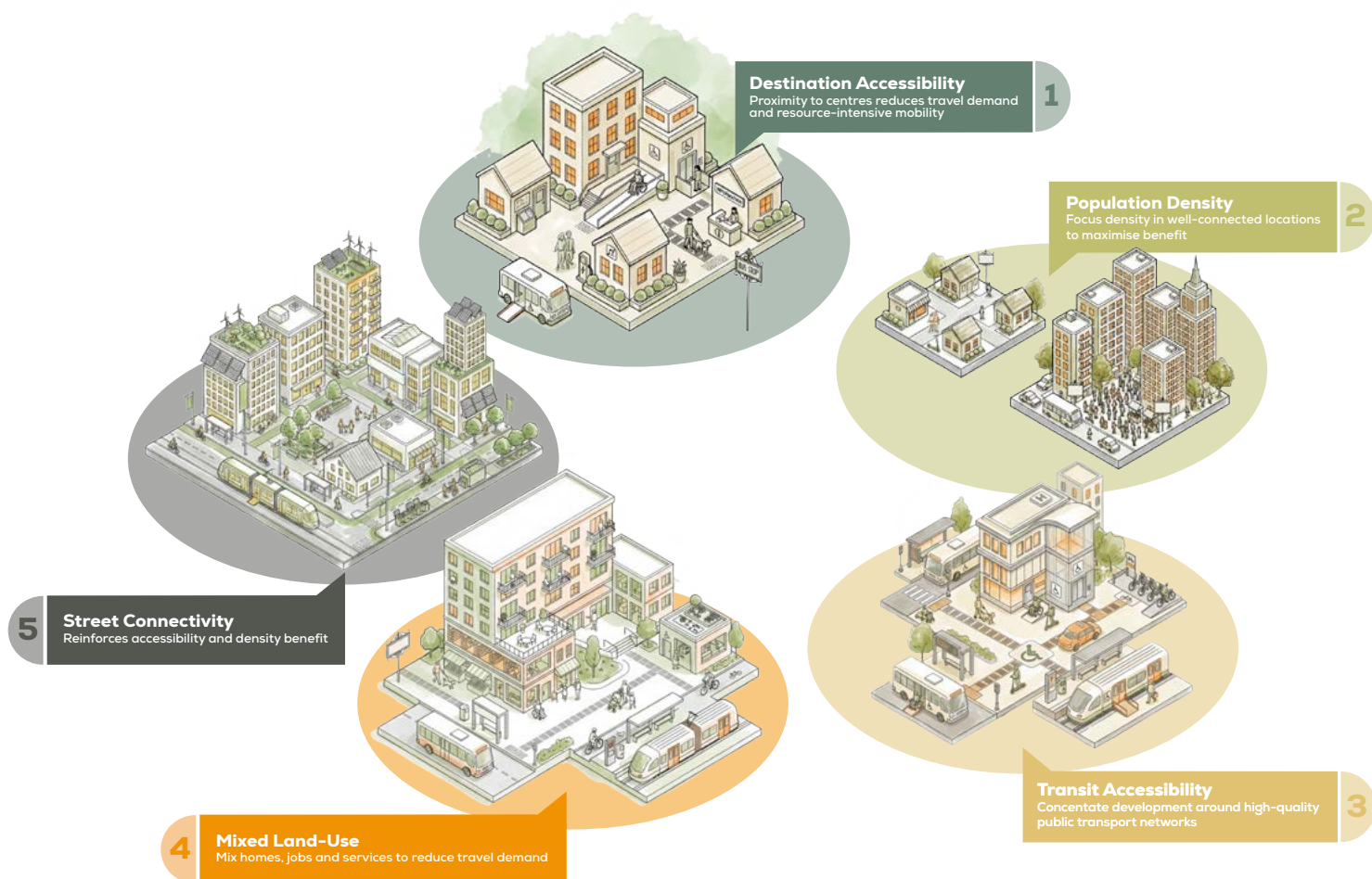
Failing to account for self-selection can overestimate these effects by 13–18%. Responses are strongest among middle-aged, high-income, car-owning households. Applied to Berlin's 64,000 planned new housing units, the analysis shows that 15 of 22 planned housing projects are likely to raise per-capita CO<sub>2</sub> emissions above the city average, mainly due to their distance from the city centre. A transit-oriented development scenario – focusing housing within a 7-minute walk of rail – would deliver 15pp below the city average and 27pp below planned settlements. A more ambitious compact development scenario, concentrating housing in the 20 lowest-emission neighbourhoods, could achieve a 43pp reduction compared to planned sites. Overall, **current housing plans are estimated to produce emissions 62% higher than this low-carbon optimum.**

### Density drives energy and material efficiency – the case of Porto [6,7]

In Porto, analysis of urban form, socio-economic, and behavioural factors shows that **urban form is among the strongest drivers of resource use, accounting for up to 65% of the variation across buildings and mobility.** Density is a key determinant of urban performance. Densification in central, well-connected areas reduces motorised travel demand, while increasing building heights can support sustainable mobility where land is scarce. A balanced mix of land uses can reduce mobility demand, lowering energy use and material consumption, as illustrated by the 15-minute city.

Urban form also affects building energy and material demand, alongside factors such as building age, type, and occupancy. Renovation can extend building lifespans and reduce resource demand. For example, using vacant floor areas in Porto would be sufficient to accommodate expected population growth until 2050. In cities where this potential is limited (e.g. Berlin, with scarcer vacant space), reconfiguration (e.g. rightsizing) and repurposing may offer viable alternatives, delivering important efficiency gains. Outcomes depend on where interventions occur, requiring spatially targeted planning. In most cases, **energy and material savings reinforce one another. When trade-offs do occur, such as increased cooling demand, they are typically smaller than the overall benefits.**

Drawing on evidence from Berlin and Porto, in the figure below, urban form levers are ranked by their impact on emissions and resource demand to support planning, zoning, and investment decisions.



**Urban form is a high-impact climate lever.** In Berlin, compact, transit-accessible development can cut emissions by up to 43pp compared with current plans [3,4]. In Porto, dense, well-located, mixed-use development reduces transport emissions while improving energy and material efficiency [5,6]. Together, the findings show that **spatial planning is essential for low-carbon, resource-efficient, circular cities**. Across both case studies, **the location of developments emerges as the primary emissions lever**. Berlin highlights destination accessibility, while Porto demonstrates the role of density and land-use mix in reducing energy and material demand.

**Densification must be location-sensitive:** density alone is not enough, as its climate benefits depend on where it occurs. Inner-city and transit-accessible areas deliver the greatest reductions, while poorly connected peripheral growth can increase emissions. Overall, **urban form shapes mobility, energy, and material demand simultaneously, meaning integrated spatial planning approaches deliver the greatest system-wide benefits**. This requires embedding spatially granular, data-driven analysis into planning decisions to guide site selection and appraisal.



## Research Methodology

The Berlin analysis uses travel diary data from around **118,000 trips made by 32,201 residents** across 190 neighbourhoods to examine how urban form, such as density, land-use mix, destination accessibility, and access to public transport, affects per-capita travel-related CO<sub>2</sub> emissions. Using double machine learning, the analysis isolates the impact of the built environment from socio-economic and behavioural factors and applies the model to **22 planned housing developments (~64,000 units)** and alternative compact and transit-oriented scenarios to estimate future emissions impacts.

For Porto, a machine-learning model based on artificial neural networks was used to analyse high-resolution urban data at block level, integrating urban form, socio-economic and behavioural drivers of both energy and material demand. Representative indicators were collected for **18 predictors** (urban form, socio-economic and behavioural) and **5 targets** (energy and material demand for buildings and mobility). The analysis considered **1,481 urban blocks**. The model identified cross-sectoral and spatial patterns, assessed the relative importance of different drivers, and explored alternative urban circularity pathways to 2050.

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