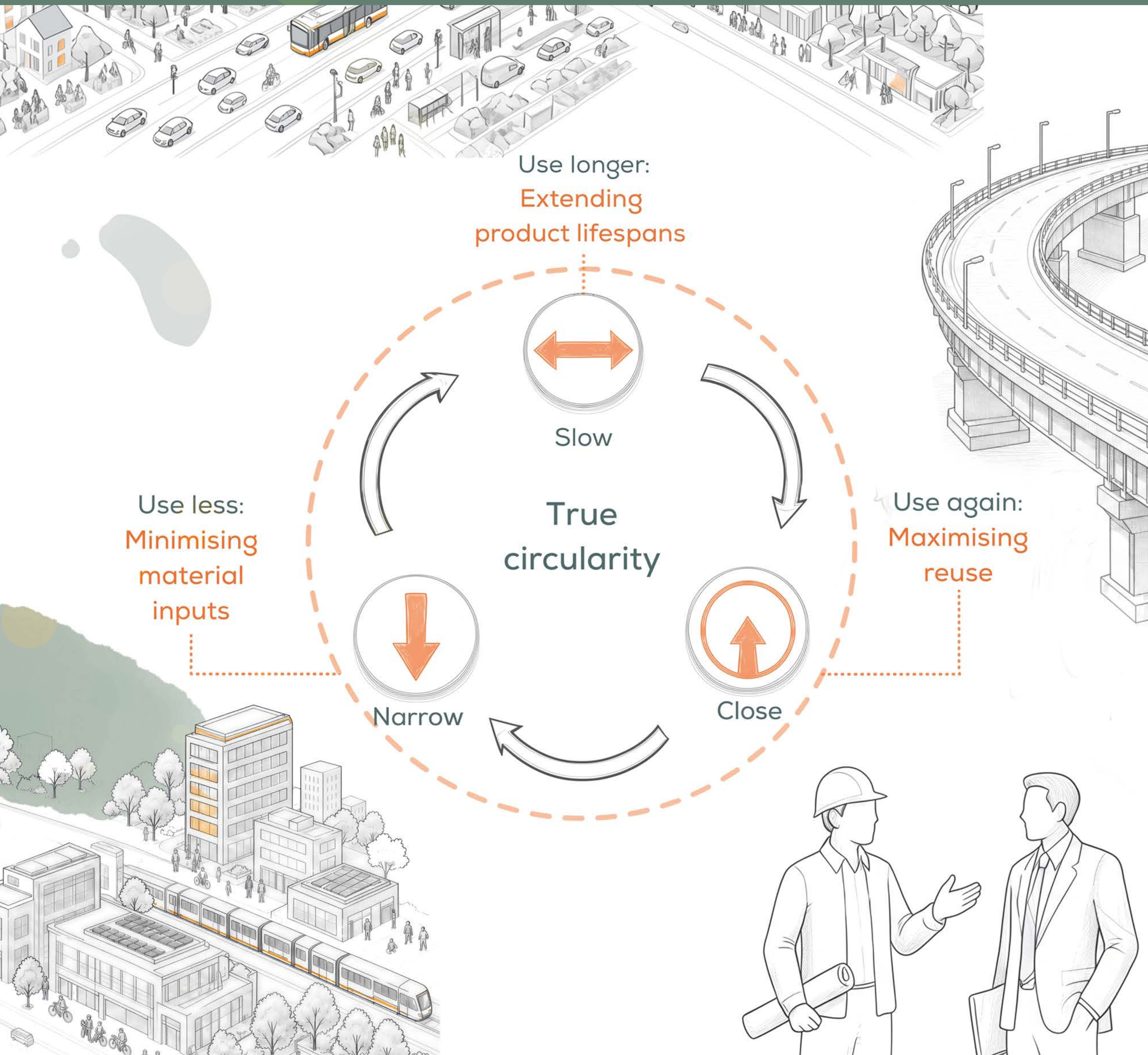
Policy Brief

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.**

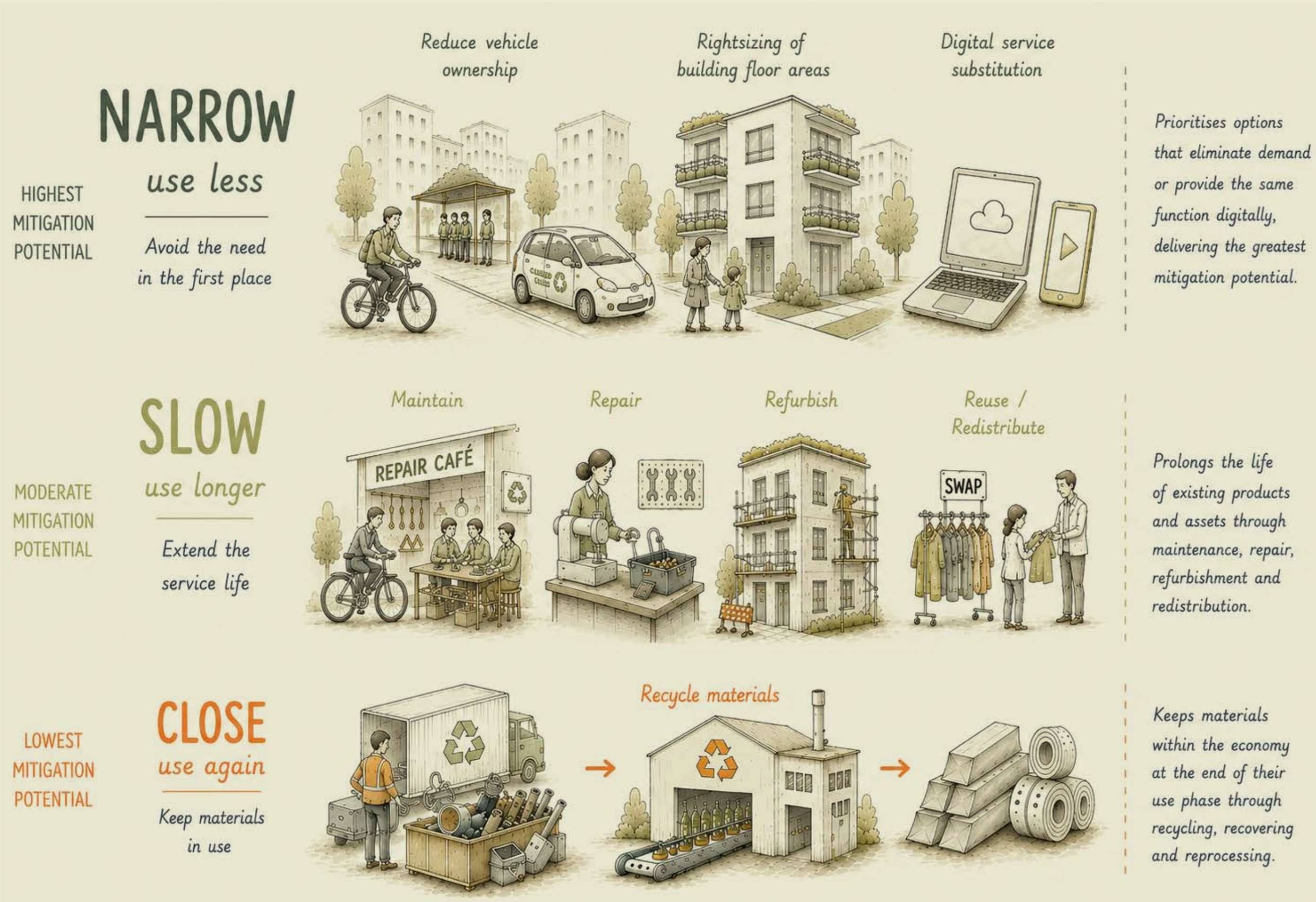


Figure 1. Narrow, Slow, Close: how circular economy strategies contribute to climate mitigation (developed with support of AI)

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.**

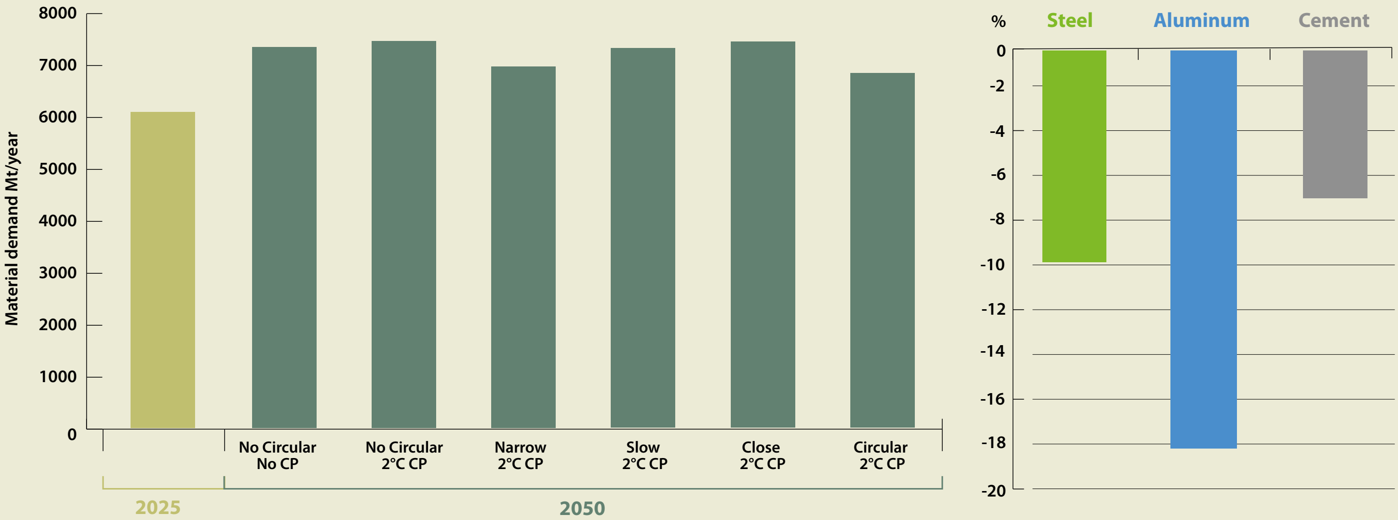


Figure 2. Total material demand in 2025 and across circular economy and climate policy pathways in 2050 (left), and percentage reductions in steel, aluminium and cement demand under the combined circular economy pathway compared with climate policy alone in 2050 (right)

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

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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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/**

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