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A Value-centric Approach for Circular Businesses to Reduce Virgin Material in the Construction Sector

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Lead organisation: Innovation Value Institute



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5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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What did the research aim to address?

Ireland faces increasing demand for construction materials due to population growth, housing delivery objectives and major infrastructure plans, strengthening the need to retain the value of construction and demolition materials and reduce extraction of primary aggregates.

The Value-centric Approach for Circular Businesses to Reduce Virgin Material in the Construction Sector (VISION) project identified practical, value-centric pathways to reduce Ireland's reliance on virgin construction materials by increasing value-preserving reuse and high-quality recycling in the construction sector.

The project combined international best-practice analysis, capability maturity assessment, stakeholder engagement and system dynamics modelling. This integrated approach examined material flows and barriers across policy, market, data, infrastructure and technical dimensions, and assessed the potential effects of selected interventions on virgin material demand and emissions.

What did the research find?

The study identified major gaps in reuse markets, recycling infrastructure, data systems and policy implementation. Stakeholder engagement through interviews confirmed inconsistent guidance, limited enforcement and weak market signals as key barriers.

The project developed two major outputs: (1) a set of best-practice guidelines tailored to Ireland and (2) a system dynamics simulation model demonstrating how interventions such as higher recycled concrete aggregate limits and increased soil reuse can significantly reduce virgin material demand and associated emissions.

The findings advance current evidence by providing an integrated, value-centric approach that links policy, market and technical levers. Limitations include data gaps on high-value recycling and assumptions within the modelling scenarios, which may evolve as new national datasets become available.

How can the research findings be used?

The findings provide an evidence base for coordinated action by policymakers, local authorities and industry. The best-practice guidelines can inform circular construction policy and implementation, while the system dynamics model can support testing of policy options and assessment of their potential effects on material demand and emissions. Priority actions include strengthening reuse and recycling markets and infrastructure, improving data collection, consistent policy implementation, and reviewing technical and regulatory conditions that affect the use of secondary materials, including recycled concrete aggregate.

The research can directly influence environmental outcomes by enabling higher-value recovery of construction and demolition materials, reducing demand for virgin aggregates, lowering waste generation and supporting national climate targets. Current opportunities include aligning public procurement with circular requirements, scaling up pilot deconstruction and reuse projects, and embedding material passports in forthcoming digital construction initiatives.

Further work is needed to improve national data on high-value recycling, assess economic incentives for reuse markets and refine regulatory pathways for secondary materials. Continued stakeholder collaboration will be essential to ensure consistent implementation and long-term sectoral transformation.

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Prepared by

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This report is based on research carried out/data from March 2023 to February 2026. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The VISION project supports Ireland's transition to a more circular and resource-efficient construction sector by reducing reliance on virgin materials through improved recovery and reuse of construction and demolition (C&D) materials, supported by enabling policies, infrastructure and business models. Despite growing national and European Union (EU) ambitions, Ireland remains heavily dependent on primary aggregates, with most recovered materials used in low-value applications. The project reviewed international best practices, analysed circularity indicators, engaged industry stakeholders and developed a system dynamics model to identify policy and market interventions that could promote higher-value circularity.

Context and Rationale

Growing demand for housing and infrastructure is increasing Ireland's need for construction materials, while EU regulations are driving greater material reuse and waste reduction. While Ireland's recovery rates for C&D waste have improved, the majority of materials re-entering the construction value chain are of lower value. International examples from countries including the Netherlands, Finland and Belgium demonstrate that circular construction practices, such as digital material passports, reuse marketplaces, selective deconstruction and high-value recycling, can significantly reduce environmental impacts while generating economic and societal benefits. The VISION project examined how these value-centric approaches could be adapted and implemented in Ireland.

Key Findings

Ireland remains highly dependent on virgin materials. Analysis of circularity indicators shows that although Ireland recovers large volumes of C&D waste, very little is reused or recycled into high-quality construction products. Compared with high-performing EU countries such as the Netherlands and Finland, Ireland does not have established reuse markets, pre-demolition auditing practices or specialised recycling infrastructure.

Measurement of circularity is fragmented. Existing metrics such as the Circular Material Use Rate offer only a partial view of circularity and do not distinguish between high- and low-value recovery. Ireland lacks a coherent national measurement framework to track material life cycles, value retention and product-level performance.

Policies supporting circularity are ambitious but are inconsistently implemented. Although Ireland has introduced strong policy signals through the Waste Action Plan for a Circular Economy (2020–2025), the Whole of Government Circular Economy Strategy 2022–2023 and EU-aligned targets, stakeholders still report uncertainty due to inconsistent guidance, limited enforcement and unclear approval pathways for reused materials. Consequently, investment in circular practices remains limited. Since this research was completed, the Whole of Government Circular Economy Strategy 2026–2028 has introduced targeted actions for the construction sector.

Circular business models are underdeveloped. The construction sector continues to operate largely on linear economic principles. Procurement tends to prioritise upfront cost rather than long-term value, and few pilots have tested circular models such as leasing, remanufacturing, component-as-a-service or modular construction. Successful international models rely on regulations, digital traceability and functioning secondary markets, which Ireland has not yet fully established. The Whole of Government Circular Economy Strategy 2026–2028 includes targeted actions to advance circular construction practices.

High potential exists for value-preserving recovery. Ireland has significant untapped potential for the reuse of materials such as structural steel, timber, facade elements and interior components. The increasing adoption of building information modelling, digital inventories and material passports offers the traceability needed to enable certified reuse. Industry recognises this potential, but infrastructure and standards are lacking.

System dynamics modelling highlights the impact of targeted interventions. The VISION simulation model shows that:

- current practices offer limited circularity benefits and negligible emissions reductions;
- increasing limits on recycled concrete aggregate use can significantly reduce demand for virgin sand and gravel;
- soil reuse has substantial potential to reduce landfill dependency;
- cement manufacturing remains the dominant source of emissions, indicating that circularity must be paired with decarbonisation measures.

Key Recommendations

Strengthen policy tools and incentives. To stimulate a functioning circular market, Ireland should introduce:

- mandatory pre-demolition audits;
- certification pathways and quality standards for reused materials;
- incentives for design-for-disassembly and modular construction;
- preferential public procurement for circular construction;
- tax or levy adjustments to favour reuse over disposal.

Develop national and regional infrastructure for reuse. Specialised hubs are needed to support high-value recovery. These could provide:

- sorting, storage and testing facilities;
- quality certification and compliance checks;
- digital marketplaces and logistics services;
- support for selective deconstruction practices.

Support circular business model innovation. Shifting from linear to circular practices requires:

- pilot projects and demonstration sites;
- innovation funding and risk-sharing mechanisms;
- collaborative trials across industry, local authorities and designers;
- development of services such as component leasing, remanufacturing and take-back schemes.

Invest in skills, capacity and collaborative platforms. Capacity building is essential to scale up circularity. Priority areas include:

- training in selective deconstruction and material recovery;
- design-for-disassembly and life-cycle assessment;
- digital competencies for building information modelling, traceability and data governance;
- networks linking industry, academia and government.

Pair circularity with decarbonisation efforts. Because cement production remains the primary emissions source, Ireland must combine circular practices with:

- low-carbon cement alternatives;
- carbon capture and storage;
- low-emission procurement requirements.

Support the development of a national roadmap to reduce virgin material use. A key recommendation is to support and build upon the Circularity Roadmap for the Construction Sector currently being developed by the Department of Climate, Energy and the Environment under the Whole of Government Circular Economy Strategy 2026–2028. The roadmap should provide a coordinated framework for reducing virgin material use, increasing the reuse and recovery of construction materials, and accelerating the adoption of circular construction practices across Ireland.

The roadmap should set targets for reducing virgin aggregate use, expand opportunities for reuse and recycling, guide investment in circular infrastructure and skills, and establish a framework for monitoring progress. By providing clear direction and long-term certainty, it would encourage investment in circular solutions and support Ireland's alignment with EU circular economy and climate goals.

Conclusion

Ireland has clear potential to transition towards a value-centric construction sector. However, this requires coordinated action across policy, markets, technology, skills and data systems. The VISION project provides evidence-based insights, a maturity framework and a system dynamics model that together offer a roadmap for reducing virgin material use, strengthening reuse markets and enabling high-value circularity. With the right enabling conditions, Ireland can deliver a more resource-efficient, low-carbon and resilient construction sector, while advancing national climate goals and supporting economic and social well-being.

1 Introduction

For decades, global industries have predominantly operated under a linear economic model defined by a take–make–dispose approach (Oluleye *et al*., 2022). Growing concerns about resource scarcity, environmental degradation and long-term sustainability have prompted a global shift towards the circular economy (CE), an economic model centred on resource efficiency, waste minimisation and the regeneration of materials and products (Tokazhanov *et al*., 2022).

Within a CE framework, traditional end-of-life concepts are replaced by strategies such as reducing, reusing, recycling and recovering materials across all stages of production, distribution and consumption. These strategies aim to maintain materials in circulation for as long as possible while reducing waste generation and environmental pressures (Garcia-Saravia Ortiz-de-Montellano and van der Meer, 2022; Kazmi and Chakraborty, 2023).

Rapid population growth, urbanisation and the continued uptake of linear economic practices have accelerated the depletion and inefficient use of natural resources (Shooshtarian *et al*., 2020). As a result, the construction sector faces increasing pressure to adopt more sustainable and circular practices. Globally, the sector accounts for approximately 50% of raw material consumption, 40% of energy use, 35% of greenhouse gas emissions and 35% of total waste generation (Kazmi and Chakraborty, 2023), positioning it as a critical target for climate and resource-efficiency interventions.

Under the European Union (EU) Waste Framework Directive (2006), construction and demolition (C&D) waste includes all materials generated during construction, renovation and demolition works, including unused or surplus materials. According to Rondinel-Oviedo (2023), the stages generating the highest levels of waste include demolition (35%), coarse plastering (25.3%), earthworks (21.9%), foundation/structure work (11.3%) and thin plastering (5.7%).

Ireland's construction sector has expanded significantly in recent years, supported by increased investment across residential, commercial and civil engineering projects (Dermody, 2023). The sector employs approximately 170,000 people, with growth forecast to continue as national housing, infrastructure and regional development objectives advance (Construction Industry Federation, 2024). The National Planning Framework reinforces this trajectory, guiding population growth, housing delivery and regional development while integrating sustainability targets (Department of Housing, Planning and Local Government, 2018).

As activity increases, so too does waste generation. The most recent figures show a 10% increase in C&D waste in Ireland (EPA, 2023). Ireland's obligation to meet national and EU sustainability commitments such as those set out in the European Green Deal places additional pressure on the sector to adopt circular practices (DECC, 2021). Although the CE offers a compelling pathway for reducing waste, conserving resources and mitigating climate impacts, significant barriers continue to constrain the uptake of CE practices within the construction sector (Oluleye *et al*., 2022; Papamichael *et al*., 2023).

This study investigates these barriers by examining international experiences with CE adoption and identifying the specific challenges facing Ireland. The overarching goal of this report is to address a critical knowledge gap by identifying opportunities to reduce Ireland's reliance on virgin materials within an expanding construction sector. To achieve this, the research involved:

- identifying best practices implemented in high-performing EU countries;
- assessing opportunities for applying these practices in Ireland;
- conducting a feasibility study;
- developing a simulation tool to model alternative construction material scenarios.

The feasibility study examined the practical viability of best-practice options to reduce reliance on virgin materials in construction, informed by analytical modelling, stakeholder input and policy alignment. Building on this analysis, the policy brief translated key findings into concise, actionable guidance for policymakers and stakeholders. Together, these outputs connect the project's technical and comparative research to implementation-focused steps supporting policy development and delivery.

The research produced two primary outputs, discussed in detail in Chapter 4:

1. a simulation model for scenario planning and decision support;
2. a set of best-practice guidelines for circular construction to reduce the use of virgin materials in Ireland.

2 Circular Economy Adoption in Ireland

The EU's European Green Deal (2019) represents a comprehensive response to climate change and environmental degradation, with two central long-term goals:

1. achieving climate neutrality by 2050;
2. reducing net greenhouse gas emissions by at least 55% by 2030.

To align with these ambitions, Ireland has introduced several national strategies and policies that support the transition towards circularity.

The Waste Action Plan for a Circular Economy (2020–2025) set out measures to conserve resources, reduce waste and accelerate Ireland's shift away from linear consumption models (DECC, 2020). The plan emphasised improved C&D waste management, waste prevention, reuse and higher-value resource recovery – critical considerations given Ireland's projected growth in construction under the National Development Plan.

The Whole of Government Circular Economy Strategy 2022–2023 was Ireland's first national framework dedicated to advancing CE practices across all sectors. The strategy emphasised treating C&D waste as a valuable secondary resource, reducing dependence on virgin aggregates and promoting greater reuse and recycling (DECC, 2021). This was succeeded by the Whole of Government Circular Economy Strategy 2026–2028: Accelerating Action, published on 26 February 2026 (DCEE, 2026), which includes specific actions for the construction sector.

Ireland's national housing plan, Housing for All, published in 2021, also incorporated CE principles by prioritising waste reduction, reuse of materials, cost-effective waste management and reduced reliance on virgin materials throughout construction (Department of Housing, Local Government and Heritage, 2021).

The Circular Economy Programme 2021–2027, led by the Environmental Protection Agency (EPA), identifies construction as a priority sector (EPA, 2021a).

Central to the programme is the waste hierarchy, which prioritises:

- prevention and reuse;
- preparing for reuse (including repair);
- recycling;
- recovery (e.g. energy recovery, backfilling);
- disposal.

The Circular Economy and Miscellaneous Provisions Act 2022 provides the legislative foundation for CE implementation, focusing on promoting the use of recycled materials and streamlining end-of-waste and by-product approval pathways (Government of Ireland, 2022).

The National Waste Management Plan for a Circular Economy 2024–2030 further operationalises CE policy by setting quantitative targets. For C&D waste, the plan establishes a 12% reduction target by 2030, to be achieved through an annual 2% reduction (Local Government Ireland, 2023).

Circular Economy (Waste Recovery Levy) Regulations 2023, introduced as part of the Waste Action Plan for a Circular Economy, aim to reduce the amount of waste sent to landfills and promote responsible waste management practices. The levy is charged at €10 per tonne and applies to C&D waste (S.I. No. 441/2024 – Circular Economy (Waste Recovery Levy) Regulations 2024). The €10 per tonne levy is being introduced on a phased basis under S.I. No. 441/2024: it applied to municipal landfills from 1 January 2025, was extended to other large EPA-licensed recovery sites from 1 September 2025, and was further extended to smaller local authority permitted and certified sites from 1 March 2026.

Ireland's Climate Action Plan (2024) reinforced these ambitions by targeting:

- optimised raw material use;
- sustainable construction practices;
- increased public-sector leadership in CE adoption (DECC, 2024).

EPA data shows that most final treatment of C&D waste in 2023 took place in Ireland (95%), with only 5% exported abroad for final treatment, predominantly metal waste sent for recycling. There are also significant tonnages of exported waste used for recycled aggregates. Backfilling is the most significant treatment operation overall, reflecting the high tonnages of soil and stones in the C&D waste stream. Nearly 100% of metal C&D waste is recycled, and segregated wood, paper, glass and plastic achieve a recycling rate of 57%. There is still significant room for improvement, especially if Ireland is to meet its CE goals.

3 Methodology

To identify best practices that could be adopted in Ireland, this study followed a structured, multi-stage process. The first stage involved selecting two key circularity indicators to assess EU countries' progress towards a CE: the Circular Material Use Rate (CMUR) and the C&D mineral waste recovery rate. These metrics were chosen because they capture both economy-wide material circularity and sector-specific performance within the construction sector. Based on their performance using these indicators, countries were shortlisted to identify those demonstrating significant progress, providing a basis for exploring the policies and measures supporting their transition.

The second stage focused on identifying best practices implemented by the selected countries. This involved reviewing official government websites, national CE portals and public policy repositories containing strategies, action plans and legislative frameworks related to circularity. From these sources, relevant national plans, official documents and policy instruments were collected. The subsequent subsections describe each step of this process in more detail.

The overarching goal of the analysis was to evaluate and rank the circularity performance of EU countries in the construction sector across two points in time. This comparative assessment enables an understanding of how countries have progressed in material circularity and directly addresses the research question: Which EU countries exhibit the strongest and weakest circularity performance in the construction sector at each time horizon? To ensure consistency and comparability, the analysis draws exclusively on data obtained from Eurostat, which offers harmonised and reliable metrics across EU countries. It should be noted, however, that calculation methodologies for waste statistics are not consistent across EU countries. For example, Ireland uses waste generation figures while most other EU countries use different methods, which may affect the comparability of cross-country rankings and should be acknowledged as a methodological limitation.

Circularity criteria were selected to reflect both construction-specific performance measures and broader material circularity considerations, with CMUR serving as a central indicator. The following sections outline the methodology in detail.

3.1 Identification of Circular Economy Indicators

Since the launch of the European Green Deal in December 2019, EU countries have increasingly adopted CE policies and developed indicators to evaluate their performance. From these, two circularity indicators were selected for this study due to their direct relevance to material circularity and construction sector performance:

1. CMUR;
2. C&D mineral waste recovery rate.

These indicators were chosen because they capture both general material circularity (CMUR) and sector-specific construction performance (C&D mineral waste recovery rate), thereby enabling a balanced and comprehensive assessment.

3.1.1 Circular Material Use Rate

CMUR measures the proportion of recycled materials re-entering the economy, indicating the extent to which secondary materials substitute for virgin resources (Moraga *et al*., 2019). As an economy-wide indicator, CMUR captures the total volume of recycled materials circulating back into use, regardless of the sector in which they originated. It is therefore used to assess a country's overall progress towards a circular transition.

CMUR is calculated using two components: total recycled materials and the total domestic material input, which comprises virgin, imported and secondary materials (Moraga *et al*., 2019). This enables the metric to estimate the share of recycled materials within a country's overall material consumption.

Despite its usefulness, CMUR has limitations. It is not sector specific, meaning that it provides only a general overview of material circularity and does not directly reflect circularity within individual sectors such as construction. In addition, the metric primarily focuses

on recycling, without capturing higher-value circular strategies such as reuse, repair or reduction. As a result, while CMUR offers valuable contextual insight into national circularity performance, it cannot serve as the sole indicator for ranking countries in this study.

3.1.2 Construction and demolition mineral waste recovery rate

CMUR provides a broad, economy-wide perspective on material circularity, offering insight into the overall recycling performance of EU countries. However, to assess circularity specifically within the construction sector, a more targeted indicator is required. For this reason, we incorporate the mineral waste from the Eurostat C&D dataset, which captures waste streams such as concrete, bricks, tiles and ceramics generated through C&D activities (Eurostat, n.d.).

This indicator was selected because it most directly reflects the end-of-life material flows within the construction sector. Although other Eurostat indicators such as the trade of recyclable raw materials (imports and exports) could be included in the analysis, these would shift the focus away from construction-specific performance towards a more general assessment of material circularity. To maintain analytical clarity and sectoral relevance, the study therefore anchors its assessment on C&D mineral waste recovery.

Within this dataset, these two indicators – CMUR and C&D mineral waste recovery – are of particular importance, with each capturing distinct recovery pathways for C&D mineral waste. These indicators form the basis for evaluating how effectively EU countries are managing construction-related materials and reintegrating them into the CE.

4 Findings

To evaluate Ireland's position in the European circular construction landscape and to identify potential improvement pathways, the study analysed EU-wide data from Eurostat using the two selected circularity indicators (CMUR and C&D mineral waste recovery rate). This comparative assessment highlighted significant variation across Member States.

By comparing EU countries across these two metrics, it was possible to identify both the leading and lagging performers in construction circularity.

High-performing countries such as Finland, the Netherlands and Italy demonstrate strong recycling systems and advanced recovery practices. Finland, for example, makes extensive use of energy recovery, while the Netherlands places significant emphasis on high-value recycling and materials reuse. In contrast, countries including Romania, Portugal and Bulgaria continue to rely heavily on disposal and demonstrate less-developed circularity systems.

Ireland's performance sits mid range. Although Ireland has made progress in managing and treating construction waste, a substantial proportion is still directed towards backfilling, a lower-value recovery option within the waste hierarchy. In comparison, leaders such as the Netherlands show significantly higher levels of reuse and high-value recycling, keeping materials in productive circulation for longer.

Overall, the comparison reveals a clear opportunity for Ireland: by adopting policies and practices used by the top-performing countries, particularly those that prioritise reuse and high-value recycling, Ireland can enhance its construction circularity performance and reduce its reliance on lower-value treatment options.

4.1 Recommended Best Practices for Ireland

To identify practices that could strengthen Ireland's transition towards circular construction, this study examined the approaches adopted in countries that demonstrate strong performance in circularity. Rather than directly transferring these practices, the recommendations are adapted to Ireland's specific policy, market and infrastructure context. To support this process, the Innovation Value Institute's IT Capability Maturity Framework was used as a guiding structure. This framework provides a systematic way to assess Ireland's current position, identify capability gaps and outline progressive steps towards higher levels of circularity maturity.

The recommended practices are organised into five macro-themes, derived from the key barriers and enabling factors identified by Munaro and Tavares (2023). Each theme represents a foundational capability area required for advancing circular construction in Ireland.

4.1.1 Economic capabilities

A major barrier to advancing circularity in the construction sector is the current economic landscape. In many cases, recycling and reuse remain more costly than disposal, making landfilling or low-value recovery the cheaper option. Although over 90% of Ireland's C&D waste is officially classified as "recovered", the vast majority is used for low-value purposes such as backfilling rather than being recycled into higher-value construction products. This represents a significant loss of economic value, even where recovery technically occurs.

To reverse this trend, high-value recycling must become more cost-competitive. This could be supported through targeted financial mechanisms, including tax incentives, grants or differential levies that reward reuse and discourage disposal. In parallel, companies can leverage financial instruments such as green bonds or specialised investment funds to support the development of advanced recycling technologies and facilities.

Building these economic capabilities is essential. Ensuring that the circular option becomes the financially advantageous option will be critical to accelerating Ireland's transition towards a high-value, resource-efficient construction sector.

4.1.2 Institutional capabilities

Circular construction cannot be achieved by any single government agency or industry actor in isolation. It requires coordinated collaboration across the entire ecosystem, including builders, designers, local authorities, financial institutions and academic partners. Countries that are further advanced in circular construction typically maintain permanent multi-stakeholder platforms that bring these groups together to share knowledge, align objectives and drive collective action.

In Ireland, progress has often been fragmented, with individual organisations running separate pilots or isolated projects. Strengthening institutional capacity will require the creation of national training centres, where skills, standards and best practices can be systematically developed and disseminated.

Targeted capacity building can have a transformative impact. For example, training demolition teams in selective deconstruction, the careful dismantling of buildings to preserve components for reuse, significantly increases the recovery of high-value materials compared with conventional demolition. Similarly, enabling architects and engineers to design for disassembly ensures that future buildings can be more easily deconstructed and their components reused, supporting long-term circularity. Such training can build on the EPA's Best Practice Guidelines for the Preparation of Resource & Waste Management Plans for Construction & Demolition Projects (EPA, 2021b), which provides a national reference point for embedding selective deconstruction and material recovery into project planning.

4.1.3 Informational capabilities

Effective circular construction depends on the availability of accurate, granular data. At present, Ireland collects statistics on overall C&D waste recovery; however, it does not distinguish between high-value recycling (materials re-entering construction as new products) and low-value applications such as backfilling. Without this level of detail, it is difficult to assess genuine progress or design targeted policy interventions.

Strengthening informational capabilities is therefore essential for generating transparency across the value chain. Tools such as material passports, which document the materials and components within a building, support future reuse during renovation or demolition. Similarly, national material databases can track flows across the life cycle, recording what is reused, recycled at high value or lost through disposal. Some of this data is already available: the EPA's By-Product Register and End-of-Waste Register allow datasets to be exported as searchable spreadsheets and show the volumes of material notified for different uses, including soil and stone, aggregates and asphalt road plannings. These registers offer a practical starting point for distinguishing high-value recovery from low-value applications such as backfilling and could be built upon for a more comprehensive national tracking system.

Beyond data systems, informational capabilities also involve knowledge dissemination. Public guidance, open-access case studies, professional training materials and awareness campaigns play a critical role in helping practitioners and the wider public understand the benefits of circular construction and how to implement it in practice.

Robust informational infrastructures ensure that Ireland can measure what matters, monitor progress and develop evidence-based policies that support a truly circular built environment.

4.1.4 Political capabilities

Government leadership is a decisive driver of circularity in the construction sector. Clear, consistent regulation and long-term strategic vision provide direction for the entire industry. Internationally, countries that have mandated circular practices in public building projects have helped establish strong markets for recycled materials and have accelerated adoption across the private sector.

Ireland has made progress through the publication of its latest CE strategy (DCEE, 2026) and the introduction of mandatory Green Public Procurement requirements. However, implementation challenges remain. Enforcement is limited, and building regulations have not yet incorporated the widespread use of recycled or reused construction materials.

Strengthening Ireland's political capabilities requires the country to go further by taking the following measures:

- Establishing explicit end-of-waste standards so that high-quality recycled materials can compete directly with virgin materials. The EU Joint Research Centre is currently developing end-of-waste criteria for C&D waste at the EU level, which Ireland should monitor and align with as these criteria are established. At the national level, the EPA published national end-of-waste criteria for recycled aggregate in 2023, with accompanying explanatory guidance, and there are also a number of single-case end-of-waste criteria in place for materials such as timber and wood. Equally important is the by-product route under Article 27 of the Waste Management Act, which is a significant part of the CE but is often overlooked: Ireland already has two national by-product criteria covering greenfield soil and stone and site-won asphalt. Both the end-of-waste and by-product mechanisms should be recognised as complementary pathways for diverting C&D materials from the waste stream.
- Enhancing compliance and enforcement mechanisms to ensure that policies are applied consistently across projects and regions. This should account for the updated end-of-waste regulations published in 2024 (EPA, 2024) and the revised by-product procedures, which are now overseen by the EPA, which together provide the regulatory basis against which compliance and enforcement should be assessed.
- Setting ambitious but achievable national targets, such as significantly reducing the use of raw construction materials by 2030.

These measures would provide the long-term policy certainty needed for industry to invest confidently in new technologies, processes and business models, ultimately supporting a more circular and resource-efficient construction sector.

4.1.5 Technological capabilities

The transition to a value-centric construction sector ultimately depends on the availability of appropriate technologies, infrastructure and tools. While Ireland diverts a significant share of C&D waste from landfill, much of this material is not returned to high-value applications. This is largely due to the limited number of advanced recycling facilities, deconstruction hubs and dedicated reuse centres, resulting in valuable materials being downcycled rather than preserved.

Building technological capability requires investment across several areas. These include specialised facilities capable of recycling concrete, timber, plasterboard and other materials into high-quality construction products; digital design tools such as building information modelling (BIM) linked to material passports that document the components within each building; and research and innovation focused on developing low-carbon and circular materials.

These technologies offer benefits far beyond waste reduction. They underpin the growth of new industries, create skilled jobs and strengthen Ireland's capacity to compete in a low-carbon global construction market. Developing robust technological capabilities is therefore not only an environmental imperative but also a strategic economic opportunity for Ireland.

4.2 Maturity Assessment Framework

Within each of the macro-themes, a set of capability blocks identifies the specific areas that require development in order to strengthen national capabilities. Each block addresses a critical component of the broader theme and is accompanied by recommended best practices. Central to this framework is the concept of maturity levels, which reflect the stage of development of each capability block (Figure 4.1). This study adopts a five-level maturity model to capture the range of possible capability stages at the national level. In Appendix 1, a detailed capability maturity assessment is provided to support the evaluation of a country's readiness and capacity to advance circular construction practices. This framework outlines progressively higher levels of capability, enabling policymakers and stakeholders to identify current strengths, gaps and priority areas for development.

The maturity levels are initial, emergent, foundational, advancing and optimising (see Figure 4.1).

Each maturity level in the framework represents a distinct stage along the capability development pathway for circular construction. At the foundational level, there is the minimum set of capabilities required

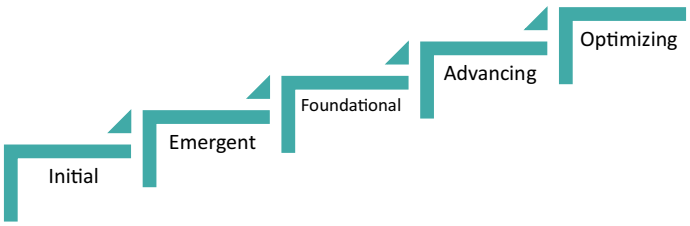

Figure 4.1. Maturity levels.

to ensure basic functionality across policy, data, skills and market structures. At the levels below this, there are substantial gaps where priority actions are needed to strengthen governance, build capacity and establish essential systems that enable progress to higher stages of maturity.

The ultimate objective is to advance towards the optimising level, where CE capabilities are fully embedded, continuously improved and supported by strong governance, routine monitoring, digital infrastructure and innovation ecosystems. At this stage, circular practices operate as standard industry norms rather than as isolated initiatives. Bringing these concepts together, Table 4.1 represents the proposed best-practice guide for Ireland.

4.3 Development of a Simulation Model

This section outlines the development of a system dynamics (SD) model designed to assess policy measures that support Ireland's transition towards a value-centric construction sector. SD offers a structured and rigorous approach for analysing complex systems characterised by feedback loops, non-linear interactions and time delays. The modelling approach integrates two complementary components:

1. causal loop diagrams, which map qualitative relationships and feedback mechanisms between system variables;
2. simulation modelling, which quantifies these relationships over time and tests the impact of alternative policy pathways.

Causal loop diagrams allow stakeholders to visualise how reinforcing or balancing feedback loops shapes long-term system behaviour. For example, an increase in housing construction raises demand for natural resources, resulting in more C&D waste and heightened environmental pressures. This represents a reinforcing loop, wherein initial changes intensify subsequent impacts. Simulation modelling builds on this qualitative insight by projecting how such dynamics evolve across multi-year time horizons.

The adoption of an SD approach was motivated by the need for a data-driven, integrated assessment tool capable of capturing Ireland's complex construction ecosystem. Traditional static assessments (e.g. single life-cycle analyses) cannot account for the dynamic interactions between material flows, recycling systems and emissions. The SD model, developed using the Vensim simulation software, overcomes this limitation by incorporating:

- stocks – materials in use, recycled materials, soil available for reuse;
- flows – construction demand, recycling and reuse rates, landfilling;
- emissions – from cement production, aggregate extraction, transport, waste processing and soil disposal.

This modelling approach enables the comparison of business-as-usual practices with more ambitious circular strategies and provides quantitative evidence on resource-efficiency gains and emissions reductions achievable through policy intervention.

SD is particularly valuable for policy analysis because it:

- facilitates understanding of complex material and emissions interactions within the construction supply chain;
- supports exploration of long-term and unintended consequences of policy options;
- allows systematic comparison of multiple scenarios;
- helps identify efficient and effective policy pathways for circular construction.

Table 4.1. List of capabilities

Macro-theme	Capability block	Maturity level				
		Initial	Emerging	Foundational	Advancing	Optimising
Economic capabilities	Incentives and circular finance	Seed grants for pilots Basic landfill levy	Targeted grants for deconstruction and sorting Risk-sharing facilities for SMEs	Tax allowances for CE investments Green bonds/finance lines	Outcome-based incentives linked to life-cycle assessment savings	Mainstream private finance products for reuse/recycling Shift fiscal burden from labour to materials
	Markets for secondary materials	Basic salvage and resale Pilot digital listings for reclaimed items	Regional reuse hubs Social enterprise deconstruction models	End-of-waste criteria for materials Quality standards and warranties	Nationwide digital marketplace with certification Public procurement anchors demand	Price benchmarks and long-term contracts Cross-border interoperability of standards
Institutional capabilities	Multi-stakeholder governance	Ad hoc working groups Actor mapping and initial MoUs	Formal multi-party platforms Regional public–private partnership clusters	National compacts with commitments Dedicated CE hubs/ secretariats	Annual reviews with scorecards Co-funded living labs in public projects	Legally anchored cooperation International cooperation via hubs
	Knowledge and skills platforms	Short CE courses and guidance Introductory webinars for SMEs	CPD on design for disassembly Vocational deconstruction training	CE in curricula and apprenticeships Standard training for procurement officers	Accredited CE professional pathways Communities of practice with toolkits	Mandatory CE competencies in licensing International exchange programmes
Informational capabilities	Data and measurement systems	Basic waste reporting Manual demolition inventories	National CE indicators with reports Pilot LCA in tenders	National LCA database Material passports linked to BIM	Tender scoring using CE calculators Dashboards for reuse and procurement outcomes	Interoperable data standards Third-party verification systems
	Awareness and knowledge sharing	Public CE guidance Showcase pilot site visits	Citizen/industry CE campaigns Open case-study libraries	National communications plan Annual CE showcases with awards	Media partnerships and curriculum tie-ins Buyer guides and standard clauses	Feedback loops from dashboards Export promotion of CE champions
Political capabilities	Green Public Procurement leadership	Voluntary CE tender clauses Basic buyer training	Mandatory CE criteria in selected tenders Pilots using LCA scoring	Standard procurement toolkit Post-grant CE reporting	Minimum recycled/reused thresholds Performance-based CE contracts	Government-wide CE procurement mandate Cross-border joint procurement
	Regulatory framework and enforcement	Basic C&D waste plans Sporadic audits	Draft end-of-waste criteria Guidance for reuse approvals	Codified end-of-waste criteria Building regulations updated for reuse	Deconstruction plan requirements Public compliance dashboards	Harmonised CE standards across regions Regulatory sandboxes for innovation
	Strategic policy and targets	High-level CE strategy statements No sector targets	Sector roadmaps with measures Consultations to set targets	Legally endorsed targets KPIs with annual reviews	Integrated fiscal, procurement and standards mix City region compact growth aligned to targets	2050 CE pathway with reviews Contribution to EU-wide targets

Table 4.1. Continued

Macro-theme	Capability block	Maturity level				
		Initial	Emerging	Foundational	Advancing	Optimising
Technological capabilities	Recycling and reuse infrastructure	Improved site segregation Small-scale salvage operations	Deconstruction crews and hubs Regional reuse depots	Advanced recycling facilities Network of deconstruction and remanufacture sites	Industrial-scale closed-loop recycling Routine use of certified secondary aggregates	National network of reuse and recycling parks Cross-region capacity balancing
	Circular design and digital tools	Guidance on adaptability and disassembly Basic BIM with limited data	Standards for modules and reversible design Pilot material passports with BIM	Core CE design measurement methods Mandatory material passports	Automated passports from BIM	Reversible building systems mainstreamed
	Innovation and certification	Innovation vouchers for pilots	Pre-standardisation test projects	National quality assurance certification for secondary materials	Third-party warranties for reused components	Mutual recognition of certificates internationally

CPD, continuing professional development; KPI, key performance indicator; LCA, life-cycle assessment; MoU, memorandum of understanding; SMEs, small and medium-sized enterprises.

4.3.1 The model

The model quantifies potential reductions in virgin aggregate consumption through increased recycling of demolished concrete. Concrete production requires fine aggregates (sand) and coarse aggregates (gravel/stone). Crushed concrete from demolition can substitute for a proportion of these materials as recycled concrete aggregate (RCA). The model simulates annual demolition outputs, housing completions and policy-imposed limits on the level of RCA substitution.

The simulation tracks how the volume of demolished buildings influences the availability of recyclable concrete. It also estimates the aggregate demand arising from new housing construction. Policy parameters, such as the maximum allowable RCA content, determine how much recycled material can realistically replace virgin aggregates. The model ultimately calculates the annual savings of sand and gravel under different scenarios. The model's user interface is shown in Figure 4.2. The VISION tool can be found at https://apps.ivi.ie/vision-project/.

The model simulates:

- annual volumes of demolished buildings and associated recyclable concrete;
- annual numbers of newly constructed housing units and related concrete demand;
- policy-driven limits on maximum RCA content in new concrete;
- resulting reductions in virgin sand and gravel demand under different policy scenarios.

4.3.2 Model objectives

The primary objective of the model is to construct a comprehensive representation of circular construction material flows in Ireland. Specifically, the model seeks to:

- develop a stock-and-flow model capturing the life cycle of concrete and soil within the construction sector;
- integrate major variables informed by Irish datasets, standards and technical guidance;
- design a suite of scenarios to test alternative circular policy measures and operational strategies;
- estimate carbon dioxide (CO_2) emissions associated with cement production, aggregate extraction, material transport, waste processing and soil disposal;
- provide an interface created using Streamlit, enabling policymakers, engineers and stakeholders to interact with the model and visualise outcomes.

4.3.3 System dynamics modelling

This study employed an SD approach using the Vensim modelling platform to represent the complex interrelationships between housing demand,



Figure 4.2. VISION tool user interface. Reproduced with permission from the Innovation Value Institute, Maynooth University.

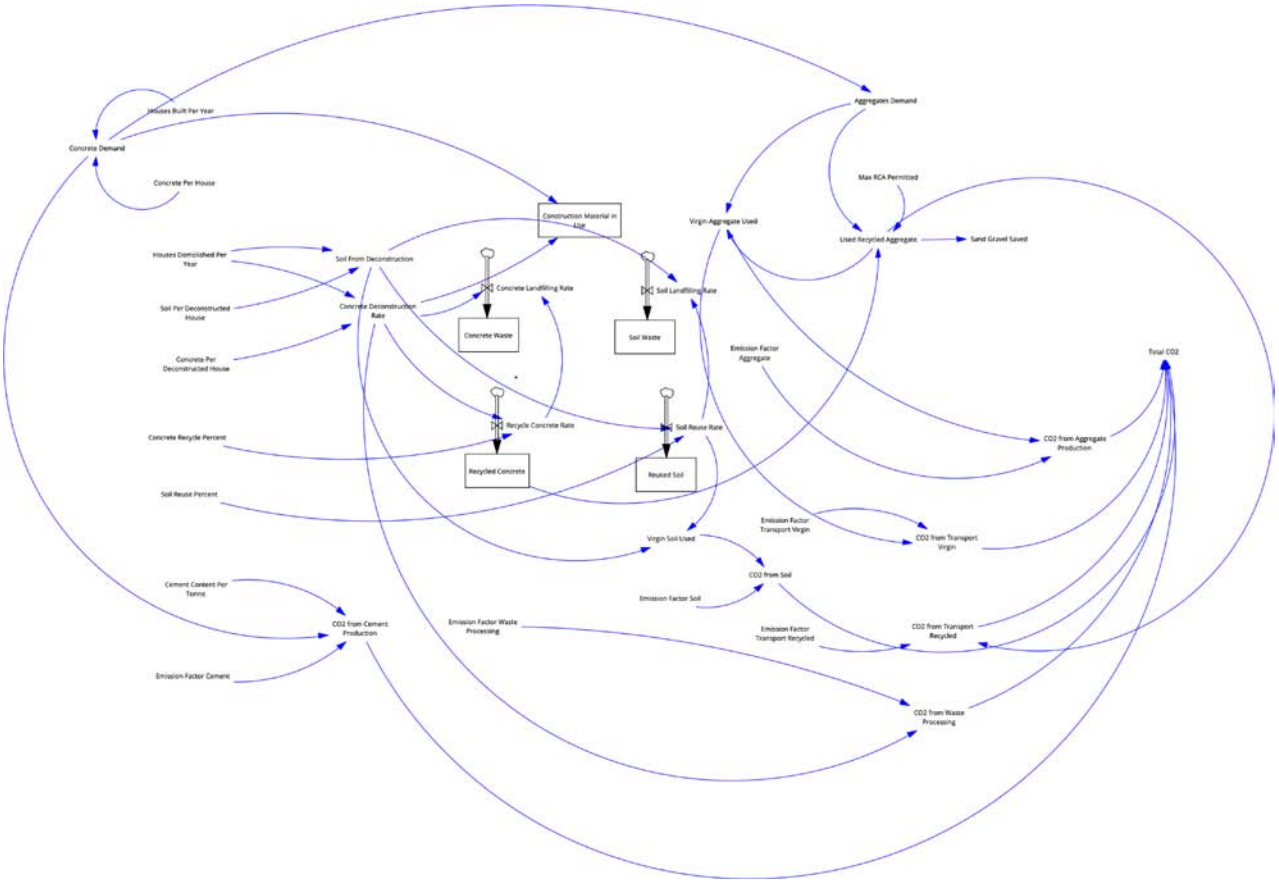

Figure 4.3. Simulation model in Vensim.

material flows, recycling rates and associated environmental impacts. SD is particularly suitable for analysing systems characterised by feedback loops, accumulations and time delays, all of which are central features of C&D waste management. Unlike static assessment tools (e.g. one-off life-cycle assessments), SD enables the modelling of evolving system behaviours over time and is therefore well suited for exploring long-term CE strategies in Ireland (Woodward and Duffy, 2011; OECD, 2022). The simulation model in Vensim is presented in Figure 4.3.

4.3.4 Stocks, flows and feedback loops

The Vensim model is structured around key stock variables, which represent accumulations of materials within the system, and flows, which capture the movements of materials between stages of the construction life cycle. The principal stock variables include:

- concrete demand – modelled as a function of annual housing completions, based on Central Statistics Office housing output data (CSO, 2023);
- concrete waste – generated during demolition and deconstruction activities, representing a potential source of RCA;
- soil waste – produced through excavation and demolition, with subsequent flows determined by reuse potential or landfill disposal; Article 27 (by-product) and Article 28 (end-of-waste) declarations to the EPA would enhance the dataset underpinning these flows and should be considered for future model iterations.

Flows were defined to represent the pathways of material movement, including recycling flows, soil reuse flows and extraction of virgin aggregates. Feedback loops were incorporated to demonstrate how increased rates of recycling and reuse reduce the demand for virgin aggregates and diminish reliance on landfilling.

4.3.5 Emissions representation

The model also includes a detailed representation of CO_2 emissions associated with both production and

logistical processes. Emission sources incorporated into the model include:

- cement manufacturing;
- quarrying of virgin aggregates;
- preparation of recycled aggregates;
- soil landfilling;
- transport emissions (Meddah, 2017; EPA, 2023).

By disaggregating emissions into these categories, the model enables precise estimation of the contribution of each component to the total carbon footprint and allows the evaluation of intervention impacts on individual emission sources.

4.3.6 Model boundary and purpose

The model was developed to assess how changes in recycling rates, soil reuse practices and RCA policies influence material flows and environmental outcomes within Ireland's construction sector. Specifically, it evaluates impacts on:

- demand for virgin aggregates and soil;
- total waste generation;
- CO_2 emissions;
- volumes of recycled and reused materials.

To capture these dynamics, the model simulates three interconnected subsystems:

1. a construction subsystem – representing material inputs and demand for aggregates and soil;
2. a demolition and deconstruction subsystem – capturing the generation of C&D waste;
3. a circular recovery and CO_2 emissions subsystem – modelling recycling processes, soil recovery, RCA utilisation and associated emissions.

These subsystems were selected based on observed C&D waste trends in Ireland and the country's evolving policy ambitions for circularity and emissions reduction (EPA, 2023; DETE, 2024).

4.3.7 Variable sourcing and formula justification

To ensure transparency, reproducibility and scientific rigour, all model variables were sourced exclusively from peer-reviewed literature, national and international governmental reports or recognised environmental databases. This approach supports the credibility of the modelling framework and aligns with best practices in CE and environmental-systems research.

Detailed definitions of all the variables are provided in Appendix 2.

4.3.8 Scenarios and simulation

The simulation period extended from 2025 to 2055, aligning with EU targets on waste recovery and long-term climate objectives (European Commission, 2020; DETE, 2024). Three scenarios were developed:

1. a base case – reflecting the continuation of current practices (low recycling rates, low soil reuse rate, restrictive RCA substitution limits);
2. a moderate policy scenario – incorporating incremental improvements consistent with emerging policy directions (moderate increases in recycling and reuse);
3. an advanced circular strategy – representing the ambitious uptake of circular practices, including higher recycling rates, increased soil reuse and broader utilisation of RCA.

Each scenario adjusted key parameters such as recycling rates, reuse percentages and limits on RCA substitution in order to assess potential environmental outcomes.

4.3.9 Value of the system dynamics approach

The SD methodology provided the following important benefits:

- **Dynamic representation.** It captured evolving relationships between material demand, waste generation and emissions – relationships that static models cannot adequately reflect.
- **Long-term forecasting.** It enabled forward-looking projections essential for strategic policy development and infrastructure planning.
- **Enhanced communication.** Vensim's graphical and visual outputs enabled clearer communication of system behaviour, supporting stakeholder understanding of how circular construction dynamics evolve over time (Fahy *et al*., 2025).

Overall, SD modelling in Vensim proved to be a robust tool for analysing Ireland's construction material flows and evaluating the potential of circular strategies to reduce emissions and conserve resources.

4.3.10 Model linkages

The model's causal relationships reflect the following real-world interactions:

- higher construction activity increases concrete demand and associated emissions;
- demolition events generate waste materials, increasing future recycling opportunities;
- expanded recycling and reuse reduce dependence on virgin aggregates and soil;
- RCA policy limits constrain substitution opportunities even when recycled materials are available;
- all processes, from material production to waste treatment, contribute to CO_2 emissions.

These linkages enable a holistic evaluation of CE policies and their environmental implications.

5 Implications for Policy and Practice

The use of SD modelling in Vensim, supported by Streamlit-based scenario visualisation, provides powerful insights into the policy and industry interventions required to accelerate Ireland's transition to a value-centric construction sector. The results show that although individual gains from specific interventions may appear modest, cumulatively they can deliver substantial improvements in resource efficiency and emissions reduction over time.

5.1 Policy Implications

The modelling outcomes highlight several critical areas where policy action is needed.

5.1.1 Current recovery practices are insufficient

The base case (scenario 1) demonstrates that Ireland's existing recovery framework delivers limited circularity benefits. Under current conditions, fewer than 20,250 tonnes of concrete are recycled over the 30-year horizon, and only 4500 tonnes of soil are reused. This has virtually no impact on emissions, which remain at approximately 3.99 billion kilograms of CO_2, underscoring that current practices slow deterioration but fall well short of the ambitions set out in the EU Waste Framework Directive (EPA, 2023). Strengthening both regulation and incentives is therefore essential. In addition, where end-of-waste status has been granted for any C&D material, that material is classified as a product rather than as waste and would not appear in waste statistics, meaning that actual circularity performance may be somewhat underrepresented in the model baseline.

5.1.2 Increasing recycled concrete aggregate substitution delivers significant material savings

Simulation results indicate that raising the cap on RCA use can dramatically enhance material recovery. Under scenario 3, increasing the RCA limit by 30 percentage points (to 70%) more than doubles the volume of recycled concrete (to 47,250 tonnes) and increases sand and gravel savings by approximately 40%. These results align closely with Vensim's feedback loops, which show exponential increases in recycling once restrictive caps are lifted.

To enable this, policymakers should revise technical standards supported by certification frameworks such as those proposed by the Irish Concrete Federation in 2020 to ensure safety and quality while expanding opportunities for RCA utilisation.

5.1.3 Cement manufacturing remains the dominant emissions source

Across all scenarios, cement production consistently accounts for the largest share of CO_2 emissions. Even under the most ambitious interventions, annual emissions plateau between 700,000 kg and 750,000 kg, demonstrating that recycling alone cannot deliver deep decarbonisation. Reducing cement-related emissions will require parallel measures, including:

- adoption of low-carbon cement binders;
- deployment of carbon capture, utilisation and storage technologies;
- strengthening of green public procurement requirements (DETE, 2024).

These measures must accompany circularity policies to achieve meaningful emissions reduction across the sector.

5.2 Implications for Industry Practice

The modelling also highlights several strategic implications for the construction industry.

5.2.1 Investment in recycling infrastructure is essential

The Vensim results show that increases in recycling rates trigger exponential growth in recovered materials. However, such outcomes cannot be realised without adequate infrastructure for crushing, sorting and transporting recycled materials. Scenario 3's

projected recovery volumes would be impossible to achieve with the current capacity of Ireland's infrastructure. Significant investment in recycling facilities, logistics networks and deconstruction equipment is therefore necessary.

5.2.2 Soil reuse can greatly reduce landfill dependency

The scenarios illustrate the potential of soil recovery to reduce landfill use. Under scenario 3, soil reuse reaches 13,500 tonnes, nearly double the amount in scenario 1. This demonstrates the importance of integrating soil reuse considerations into project planning, including site design, excavation management and developer waste management plans. Embedding these practices early can reduce disposal costs and enhance compliance with CE principles.

5.3 Strategic Implications

Overall, the findings indicate that Ireland's construction sector requires a dual-track policy approach. There is a need to:

- accelerate recycling and reuse through supportive policy, infrastructure investment and updated technical standards;
- address cement emissions directly through technological innovation, regulatory reform and procurement standards that prioritise low-carbon materials.

While circularity measures can significantly reduce virgin material use and dependence on landfilling, they must be complemented by targeted decarbonisation efforts in cement production. Without addressing both tracks simultaneously, national emissions will not reflect the full benefits of improved material circularity.

6 Recommendations

Ireland's transition towards a value-centric construction sector requires a coordinated, whole-system approach supported by strong governance, robust data, targeted investment and cross-sector engagement. Based on the findings of this study, the following recommendations outline the structural, policy and operational actions needed to significantly reduce the use of virgin materials and accelerate high-value circularity.

6.1 Develop a National Roadmap to Reduce Virgin Material Use

A central recommendation of this research is the development of a national roadmap for circular construction materials, led by government and co-designed with industry, local authorities and academic partners. This roadmap should support the Whole of Government Circular Economy Strategy 2026–2028, which commits the Department of Climate, Energy and the Environment to publishing a Circularity Roadmap for the Construction Sector. This recommendation should be updated to support and build upon the roadmap already under development and reframed accordingly. The roadmap should:

- set clear national targets for reducing virgin aggregate consumption by 2030 and 2050;
- establish phased timelines for increasing RCA limits, expanding reuse of soil and construction components, and integrating circular design principles;
- define priority actions for scaling up reuse, selective demolition and advanced recycling;
- provide a coordinated investment plan for regional recycling infrastructure, deconstruction hubs, digital traceability systems and skills development;
- include a national monitoring and reporting framework, ensuring annual progress tracking and evidence-based policy adjustments.

A national roadmap would offer the long-term certainty that industry needs to invest in circular solutions and would align Ireland's material use goals with the EU's CE and climate targets.

6.2 Strengthen Multi-stakeholder Collaboration and Governance

Effective circularity requires cooperation across all actors in the construction ecosystem. Ireland should establish a permanent national circular construction forum, composed of policymakers, industry leaders, waste operators, local authorities, academia, financial bodies and standard-setting organisations.

This forum should:

- coordinate the implementation of the national roadmap;
- oversee the development of quality standards, certification pathways and end-of-waste criteria;
- facilitate shared learning through working groups on reuse, recycling, digital tools and procurement;
- serve as a platform for regional collaboration, enabling hubs to align practices, share capacity and scale up innovations;
- promote active engagement with EU and international networks.

The EPA should be explicitly included in this forum, given its regulatory role in determining end-of-waste and by-product status, so that the body responsible for these decisions is directly represented alongside the other actors. Embedding structured collaboration ensures continuity, reduces fragmentation and accelerates the mainstreaming of circular practices across the sector.

6.3 Enhance Policy, Standards and Regulatory Certainty

Ireland should strengthen and modernise its policy and regulatory landscape through the following measures:

- Introducing mandatory pre-demolition audits for all significant projects. Oversight responsibility for mandatory pre-demolition audits should be assigned to a designated body – for example, local authorities, in line with planning consent conditions, or the EPA as part of waste licensing requirements – to ensure enforcement and consistency across jurisdictions.

- Expanding end-of-waste criteria for recycled aggregates, timber, plasterboard and other priority materials. Note that the EU Joint Research Centre is currently developing end-of-waste criteria for C&D waste at the EU level. Ireland should actively monitor and engage with this work, and align national criteria development accordingly, rather than acting in isolation. It should be noted that national criteria are already in place for recycled aggregates, where the EPA has led with the 2023 national end-of-waste criteria, and that a number of single-case decisions also exist for timber and wood. Although the foundational criteria for aggregates were established by the EPA, the development of criteria for any further material streams should be industry led, with the EPA providing oversight rather than driving each new standard.
- Updating building regulations and technical guidance to enable certified reuse and higher RCA substitution.
- Mandating circularity criteria in public procurement, including recycled content thresholds and life-cycle-based scoring.
- Improving enforcement of existing waste management plans to ensure compliance and quality assurance.

Clear, consistent regulation is critical for stimulating investment and ensuring safe, high-quality circular practices.

6.4 Invest in Recycling, Reuse and Digital Infrastructure

To unlock high-value material recovery, Ireland must invest in:

- advanced recycling facilities capable of producing certified secondary aggregates and other recovered materials at scale;
- regional reuse hubs that provide sorting, testing, storage and marketplace functions;
- deconstruction facilities and equipment, supporting selective dismantling and high-value salvage;
- integration of BIM, digital material passports and national databases to track material flows and enable traceability;
- ongoing research and development in the areas of low-carbon materials, reversible building systems and circular construction technologies.

Strategic infrastructure investment is essential to overcome current capacity limitations and deliver a consistent supply of high-quality secondary materials. Potential funding streams could include Exchequer capital, EU structural and cohesion funds (e.g. the European Regional Development Fund), the EPA Research Programme, Enterprise Ireland innovation funding and private sector co-investment through public–private partnerships.

6.5 Support Circular Business Models and Innovation

Ireland should stimulate market creation and innovation through:

- pilot and demonstration projects showcasing reuse, component leasing, modular construction and remanufacturing;
- innovation grants, tax incentives and risk-sharing mechanisms for small and medium-sized enterprises adopting circular practices;
- certification, warranty and insurance frameworks that reduce perceived risk for investors and builders;
- development of new service-based models, such as take-back schemes and materials-as-a-service.

Sustained innovation will drive competitiveness and accelerate the commercial viability of circular solutions.

6.6 Build Skills, Competencies and Public Awareness

To ensure long-term transformation, Ireland should:

- integrate circular principles into architectural, engineering and construction curricula;
- develop specialised training for selective deconstruction, life-cycle assessment and digital tools;
- provide targeted capacity building for local authorities and procurement officers;
- run national awareness campaigns highlighting the value, safety and economic benefits of secondary material use.

A skilled workforce and informed public are crucial to embedding circularity as standard practice.

7 Conclusion

The VISION project demonstrates that Ireland has significant potential to transition towards a value-centric construction sector, in which use of virgin materials is dramatically reduced, high-value recovery is increased and national climate and resource-efficiency goals are supported. Current practices, while achieving high overall recovery rates, do not retain material value, with most C&D waste diverted to low-value backfilling. International best practices, coupled with the SD modelling developed in this study, clearly show that targeted policy intervention, expanded reuse infrastructure and higher RCA substitution limits can deliver meaningful reductions in resource extraction and emissions.

Realising this potential requires coordinated, multi-stakeholder action and long-term strategic planning. A national roadmap for circular construction materials, supported by strong governance, robust standards, digital traceability systems and well-designed fiscal incentives, can provide the clarity and direction needed to guide the sector through this transition. At the same time, investments in infrastructure, skills and innovation will enable Ireland to build mature markets for secondary materials and ensure long-term competitiveness.

With the right enabling conditions, Ireland can move from incremental improvement to systemic transformation, creating a resilient, low-carbon and resource-efficient construction sector that is aligned with EU circularity targets. The VISION project provides both the evidence base and the practical tools to support this change, laying the foundation for a more sustainable built environment for decades to come.

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Appendix 1 Capability Assessment

Macro-theme	Capability block	Maturity question	Maturity level				
			Initial	Emerging	Foundational	Advancing	Optimising
Economic capabilities	Incentives and circular finance	How well do financial incentives and funding mechanisms encourage CE practices in construction?	No financial incentives; circular practices are economically unattractive.	Limited or pilot incentives exist, but they are inconsistent and lack clear targeting.	Structured incentives are available (e.g. tax breaks, subsidies) for specific circular practices, with moderate uptake.	Broad financial mechanisms (loans, subsidies, green bonds) are integrated across the sector; adoption is widespread.	Comprehensive, stable and adaptable financial systems drive long-term investment in circular construction, ensuring international alignment.
	Markets for secondary materials	How established and effective are markets for secondary construction materials?	No established markets; secondary materials rarely used.	Small, fragmented initiatives exist; limited buyer–supplier connections.	Recognised markets exist with some trading platforms; moderate demand for secondary materials.	Well-functioning national markets supported by regulations and incentives; strong participation from industry.	Mature, transparent markets fully integrated into supply chains; active international trade of secondary materials.
Institutional capabilities	Multi-stakeholder governance	How coordinated are stakeholders in governing and advancing the adoption of CE practices in the construction sector?	No governance structures exist; decisions are fragmented.	Some stakeholder groups collaborate informally or on pilot projects.	Formal multi-stakeholder bodies exist, although participation is uneven.	Inclusive governance mechanisms exist with active engagement across industry, government and academia.	Robust governance with continuous coordination, accountability and cross-border collaboration.
	Data and measurement systems	What systems are in place to measure and monitor circularity in construction?	No data systems exist; circular practices are not measured.	Some data is collected on pilot projects, but it is not standardised.	Standardised data collection exists; indicators for circularity are available.	Comprehensive data platforms track performance across the sector; results inform decision-making.	Advanced, real-time, interoperable systems enable predictive insights and international benchmarking.
Informational capabilities	Knowledge and skills platforms	In what ways are knowledge and skills platforms supporting capacity building for circular construction?	No formal training or knowledge-sharing platforms exist.	Limited platforms or initiatives exist but have narrow reach.	Structured platforms exist, with moderate participation from professionals and students.	Widely accessible platforms, integrated with curricula and industry training, promote broad skills adoption.	Dynamic, globally connected platforms ensure continuous skills development and innovation leadership.
	Awareness and knowledge sharing	How widespread is awareness and understanding of circular construction practices across society?	Very low awareness; circularity is not a recognised concept.	Some awareness among niche groups; limited public campaigns.	Awareness programmes are structured and reach targeted audiences (professionals, students, decision-makers).	Broad awareness across the sector and society; best practices are widely shared.	High public understanding and demand for circular practices drive cultural and behavioural change.

Macro-theme	Capability block	Maturity question	Maturity level				
			Initial	Emerging	Foundational	Advancing	Optimising
Political capabilities	Regulatory framework and enforcement	How comprehensive and effective is the regulatory framework supporting circular construction, including enforcement?	No regulations exist; circular practices are voluntary.	Some fragmented or voluntary regulations exist; weak enforcement.	Regulatory frameworks exist, with moderate enforcement and compliance.	Strong, integrated regulations exist, with effective enforcement mechanisms.	Adaptive, internationally aligned regulations foster innovation and leadership in circularity.
	GPP leadership	To what degree does public procurement drive demand for circular construction practices?	No requirements for circularity in procurement.	Some pilot GPP projects include circular elements.	GPP policies with measurable criteria exist, applied in selected projects.	Circular GPP is mainstream in public construction projects; clear monitoring systems exist.	GPP is fully circular, driving innovation and setting international benchmarks.
Technological capabilities	Recycling and reuse infrastructure	How developed is the infrastructure for recycling and reusing construction materials?	No recycling/reuse infrastructure exists.	Some pilot facilities exist, serving limited areas.	Infrastructure exists in key regions; moderate material recovery.	Well-developed infrastructure supports large-scale recycling and reuse nationwide.	Highly efficient, technologically advanced systems with near-total material recovery and reuse.
	Circular design and digital tools	How widely are circular design principles and digital tools applied in construction projects?	No use of circular design or digital tools for circularity.	Pilot projects apply some circular design principles with basic digital tools.	Circular design is included in guidelines and increasingly adopted; BIM and similar tools support practices.	Circular design principles are standard practice; advanced digital tools enable optimisation.	Circular design and digital tools are fully embedded, with artificial intelligence and automation driving continuous innovation.
	Innovation and certification	How effectively do innovation systems and certification schemes promote circular construction practices?	No certification schemes or innovation initiatives exist for circularity.	Some fragmented certifications and innovation pilots are present.	Recognised certifications and structured innovation programmes exist, with moderate uptake.	Certifications are widely adopted; innovation is actively supported and integrated into practice.	Globally recognised certifications and continuous innovation ecosystems drive leadership in circular construction.

GPP, Green Public Procurement.

Appendix 2 Equations of the Simulation Model

This appendix outlines the rationale used to select each critical variable and describes the methodological reasoning behind the formulation of key equations. The explanations provide detail on how data sources informed parameter values, how assumptions were derived where data gaps existed, and how the mathematical structure of the model reflects real-world material flows and policy mechanisms.

A2.1 Stock and Flow Design

The model incorporates the following principal stock variables, each representing an accumulated material flow within the system:

- construction_material_in_use – accumulated concrete in buildings;
- recycled_concrete – total recovered RCA;
- reused_soil – cumulative reused soil;
- concrete_waste – landfilled concrete;
- soil_waste – landfilled soil.

These stocks are influenced by a series of flow variables, including:

- concrete_demand – based on houses built × concrete per house;
- concrete_deconstruction_rate – based on demolitions × concrete per house;
- recycle_concrete_rate – percentage of concrete recovered;
- soil_reuse_rate – percentage of soil reused;
- concrete_landfilling_rate and soil_landfilling_rate – residual waste flows.

Each flow variable was formulated using equations informed by empirical evidence from peer-reviewed literature and relevant policy documents.

See, for example, equation A2.1 (EPA, 2021b; Dacić *et al*., 2024):

$$\text{recycle_concrete_rate} = \text{concrete_deconstruction_rate} \times \text{concrete_recycle_percent} \quad \text{(A2.1)}$$

A2.2 Material Demand Logic

Concrete demand is modelled using the following relationship:

$$\text{houses_built_per_year} \times \text{concrete_per_house} = \text{concrete_demand} \quad \text{(A2.2)}$$

where houses_built_per_year = 25,000 (CSO, 2023) and concrete_per_house = 50 tonnes (IGBC, 2018).

The demolition rate is calculated using:

$$\text{houses_demolished_per_year} \times \text{concrete_per_deconstructed_house} = \text{concrete_deconstruction_rate} \quad \text{(A2.3)}$$

where the demolition rate was set at 1500 homes per year (EPA, 2021b).

A2.3 Circular Policies Integrated

Two key CE policy levers were incorporated into the model:

1. concrete_recycle_percent – the proportion of demolished concrete sent for recycling, which varies by scenario (30–60%);
2. max_RCA_permitted – a constraint that limits the share of RCA that can substitute for virgin aggregates in new construction.

These parameters align with EU recovery targets and public procurement ambitions aimed at increasing secondary material utilisation in the construction sector (WRAP, 2021; DETE, 2024).

The utilisation of recycled aggregate is modelled as:

$$\text{used_recycled_aggregate} = \text{MIN}(\text{recycled_concrete}, \text{concrete_demand} \times \text{max_RCA_permitted}) \quad \text{(A2.4)}$$

Virgin aggregate demand is then derived from the residual material requirement:

$$\text{virgin_aggregate_used} = \text{concrete_demand} - \text{used_recycled_aggregate} \quad \text{(A2.5)}$$

A2.4 Carbon Dioxide Emissions Logic

CO_2 emissions were estimated across five primary sources:

1. Cement production – based on:

   $$CO_2_from_cement_production = concrete_demand \times cement_content_per_tonne \times emission_factor_cement \quad (A2.6)$$

   where cement content = 0.3 and emission factor = 698 kg CO_2/tonne (DETE, 2024).

2. Virgin aggregate production – 9 kg CO_2/tonne (Inventory of Carbon and Energy Database v3.0).

3. Transport:

   (a) virgin transport: 100 kg CO_2/tonne;

   (b) recycled transport: 50 kg CO_2/tonne (WRAP, 2021).

4. Soil handling – 10 kg CO_2/tonne (ICLEI – Local Governments for Sustainability, 2023).

5. Waste processing – 30 kg CO_2/tonne of demolished concrete.

Total emissions are:

$$total_CO_2 = CO_2_from_cement_production + CO_2_from_aggregate_production + CO_2_from_transport_virgin + CO_2_from_transport_recycled + CO_2_from_soil + CO_2_from_waste_processing \quad (A2.7)$$

A2.5 Time Horizon and Output

- Time step: 1 year.
- Simulation period: 2025–2055.
- Outputs visualised:
  - total CO_2 emissions;
  - virgin aggregate used;
  - recycled concrete over time;
  - soil reuse trends.

The model outputs have been integrated into a Streamlit interface, enabling users to interactively explore and test alternative CE scenarios. This allows stakeholders to adjust key parameters, visualise outcomes in real time and assess the implications of different policies or material management strategies.

Abbreviations

BIM	Building information modelling
C&D	Construction and demolition
CE	Circular economy
CMUR	Circular Material Use Rate
CO_2	Carbon dioxide
EPA	Environmental Protection Agency
EU	European Union
RCA	Recycled concrete aggregate
SD	System dynamics

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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