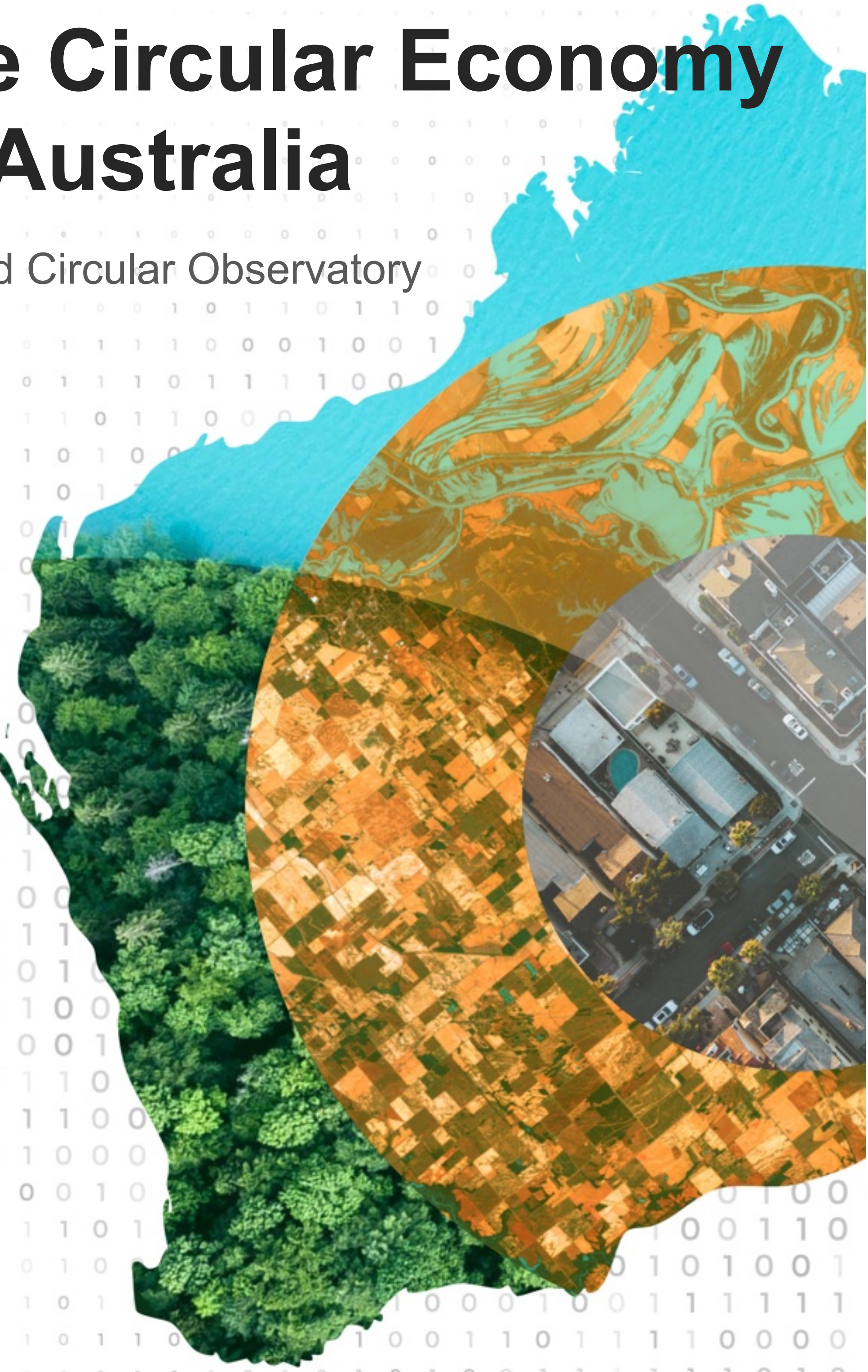
Mapping the Circular Economy of Western Australia

Towards a Science-based Circular Observatory



Stage 1

Mapping the Circular Economy of Western Australia:
Towards a Science-based Circular Observatory–Stage 1

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About PATREC

The Planning and Transport Research Centre (PATREC) is a collaboration between the Government of Western Australia and local universities, constituted to conduct collaborative, applied research and teaching in support of policy in the connected spaces of transport and land use planning. The collaborating parties are The University of Western Australia, Curtin University, Edith Cowan University, the Department of Transport, Main Roads Western Australia, the Western Australian Planning Commission and the Western Australian Local Government Association.

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Keywords

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Executive Summary

The circular economy is widely recognised as an effective model for mitigating waste production, preserving the functionality of resources and reducing dependencies on virgin materials. Transitioning Western Australia (WA) from a linear “take-make-waste” model to a circular economy is essential for achieving emission targets, reducing environmental impact, and generating economic value while maintaining people’s quality of life. While there is significant promise of resource efficiency gains, economic diversification, job growth and innovation, the implementation of a circular economy at multiple scales is inherently complex, highlighting the need for an evidence-based, system-wide approach that goes beyond current waste management strategies.

This report provides the first comprehensive assessment of the state of circularity in WA. We take a system-wide approach, focussing on several core aspects of a circular economy—resource inflows, built stocks and waste outflows—at the State, Greater Perth and municipal level. We evaluate WA’s capacity for circularity, the policy landscape, data and conceptual gaps and highlight key opportunities towards greater circularity and emission reduction across sectors and geographical scales. Finally, we outline a pathway towards a consistent, multi-scale indicator framework for building cross-sector capacity, and monitoring and driving circular outcomes.

Our findings reveal that while WA has one of the world’s most resource- and emission-intensive economies, the State is uniquely positioned to harness circular opportunities across its entire value chain, generating significant domestic, upstream and downstream benefits. However, this transition will require important shifts in policy, technology, and cross-sector collaboration.

Western Australia is characterised by significant material consumption and high levels of domestic extraction, underscoring both the challenges and opportunities for advancing a circular economy within the State. In 2021, total raw material consumption amounted to 114.1 Mt (42.9 t/capita), twice the OECD[1] average (21.6 t/capita) and more than three times the global average (12.7 t/capita). Of this, 80% (90.7 Mt) of demand occurred in Greater Perth, contributing to 79% (50 Mt) of WA’s greenhouse gas emission footprint[2]. This level of resource use highlights the material demands of WA’s economy and emphasises the need for more circular practices in industrial and end-use sectors.

Material productivity[3], which measures the efficiency of material consumption relative to the Gross State Product (GSP), stands at 3.2 billion AUD per Mt. Domestic extraction totalled 1,068 Mt in 2021, reflecting the State’s reliance on natural resource extraction to support its export-orientated economy. When factoring in raw material imports, this translates to a material intensity[4] of 3.1 Mt per billion AUD of GSP. This leading indicator demonstrates the State’s ability to generate economic value from material inputs but also points to areas where circularity improvements can help decouple economic growth from non-critical resource use. Municipal-level case studies (City of Canning and Bunbury) revealed a dependency on external supply, with only 4.7% (0.22 Mt) of the total raw material input originating from WA. This indicates that a significant portion of the cities’ environmental impact is embedded in upstream value chains, highlighting the importance of a lifecycle approach to enhancing circularity at the city and regional level.

To address these challenges, we propose WATCH (Western Australian Tool for Circular Horizons), a science-based digital circular observatory offering governments, industries and communities critical insights to support circular planning, monitor and report on enhanced material flows, and promote data-driven decision-making. By providing a comprehensive view of circularity at multiple scales, this digital public good aims to enhance cross-sector collaboration and strengthen WA’s capacity for transdisciplinary research and effective circular applications.

This report presents the first stage of WATCH development. Through local and State Government demonstrations, it provides a robust foundation for advancing circular economy practices and helps position WA as a leader in integrating circular economy and net zero approaches through a digital monitoring framework. As a basis for future research and development, it highlights the value of a systems approach to circularity, enabling policy alignment and effective implementation across actors, sectors and geographical scales, ultimately contributing to a more resilient and sustainable future for all Western Australians.

[1] Organisation for Economic Co-operation and Development.
[2] Lifecycle emissions include direct (scope 1), indirect (scope 2) and supply chain emissions (scope 3).
[3] Material productivity is presented on a raw material consumption basis. The efficiency of material consumption in the production of good destined for export is not included.
[4] Material intensity of raw material inputs is equal to RMI/GSP. Here, the area covered for material inputs completely overlaps with that in which added value is generated.

Key recommendations

From the research findings, we draw high-level recommendations on eight systemic themes to assist policy- and decision-makers in developing an environment conducive to circular actions:

- Developing a lifecycle-focused policy framework that considers environmental impacts, lifecycle costs, and trade-offs beyond localised end-of-life management, including the extraction of raw materials, sourcing, product manufacturing and usage (4.1)

- Evaluating economic instruments that make circular strategies more competitive, including taxation reforms, subsidies and resource allocation (4.2)

- Integrating circular economy strategies and approaches into WA's net zero policies as part of a broader decarbonisation roadmap (4.3)

- Increasing the traceability, accuracy and granularity of timely end-of-life waste management data to be integrated into accessible state-wide material accounts (4.4)

- Enabling circular and resilient local supply chains by making visible opportunities for closing material loops at regional and local scales using digital tools (4.5)

- Incorporating methods and tools that track material stocks, quantities, qualities and characteristics in the built environment, enabling the concept of 'material banks' to transform buildings into repositories of reusable materials (4.6)

- Monitoring and reporting circular performance at multiple geographical scales, using scientific methods under the perspective of data accessibility and knowledge sharing (4.7)

- Integrating circular economy efforts in a multistakeholder partnership with targeted support from local and State governments to advance towards a unified WA circular economy framework (4.8).

Abbreviations

ABS: Australian Bureau of Statistics
C&D: Construction and Demolition
C&I: Commercial and Industrial
CO_2: Carbon Dioxide
CSIRO: Commonwealth Scientific and Industrial Research Organisation
CMUR: Circular Material Use Rate
DMC: Domestic Material Consumption
DPO: Domestic Processed Output
DPSIR: Drivers, Pressures, State, Impact, and Response model of intervention
EE-IO: Environmentally Extended Input-Output
EF: Emission Factor
EMF: Ellen MacArthur Foundation
ERP: Estimated Resident Population
EPR: Extended Producer Responsibility
EU: European Union
EW-MFA: Economy-Wide Material Flow Analysis
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GRP: Gross Regional Product
GSP: Gross State Product
LCA: Life Cycle Assessment
LGA: Local Government Area
MFA: Material Flow Accounting
MF: Material Footprint
MRIO: Multi-regional Input-Output
MSW: Municipal Solid Waste
NAS: Net Addition to Stocks
NWRIC: National Waste and Recycling Industry Council
OECD: Organisation for Economic Co-operation and Development
PM: Primary Materials
PSUTs: Physical Supply and Use Tables
RMC: Raw Material Consumption
RMI: Raw Material Input
RP: Resource Productivity
SM: Secondary Materials
WA: Western Australia
WATCH: Western Australian Tool for Circular Horizons
WMS: Waste Management Systems

Glossary of terms

Capital Formation: Denotes the cumulation of capital through investment.

Circular Economy (CE): An economic system aimed at eliminating waste and the continual use of resources through principles like reuse, recycling, and remanufacturing.

Circularity Gap Index: A measure of the amount of unrecovered waste that could potentially be reintegrated into the economy.

Circularity Rate: The share of secondary materials in all materials used in the Domestic Material Consumption (DMC).

Circularity Strategies: Approaches within the circular economy that include reducing, reusing, recycling, and recovering materials.

Circularity: The degree to which a system or economy is circular, meaning it minimises waste and maximises resource utility.

Critical Raw Minerals (CRM): Raw materials critical to economic development, considering their scarcity, supply-chain dependencies and environmental consequences.

Downcycling: The process of recycling waste materials into new materials of lower quality and reduced functionality.

Economy-Wide Material Flow Analysis (EW-MFA): A method for assessing the flow of materials through an economy, including extraction, production, consumption, and disposal.

End-of-Life (EoL) Waste: Waste generated when a product reaches the end of its useful life and is discarded.

Extended Producer Responsibility (EPR): A policy approach that makes producers responsible for the entire lifecycle of their products, especially for take-back, recycling, and final disposal.

Green Procurement: The acquisition of products and services that have a reduced environmental impact throughout their lifecycle.

Life Cycle Assessment (LCA): A technique to assess the environmental impacts associated with all stages of a product’s life from cradle to grave.

Material Flow Accounting (MFA): A systematic assessment of the flows and stocks of materials within an economy.

Material Footprint (MF): The total amount of raw materials extracted to meet consumption demands.

Net Addition to Stocks (NAS): The difference between the addition of materials to stocks and the removal of materials from stocks through demolition or deconstruction.

Regenerative: Biophysical processes which restore and renew natural resources and ecosystems.

Resource Productivity (RP): The amount of economic output generated per unit of material input.

Socioeconomic Metabolism: The flow of materials and energy through an economy, reflecting the interaction between human activities and the environment.

System-wide Approach: An approach that considers the entire system, including all interactions and interdependencies, rather than focusing on individual components in isolation.

Value: Financial and/or non-financial gain.

Urban Metabolism: The sum of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste.

Table of Contents

Introduction

Natural resource consumption and waste production are critical challenges in today's economy. In the past 50 years, material use has more than tripled and continues to rise[5]. In an interconnected world, where over 75% of natural resources are consumed in urban areas, which generate over 70% of global waste production[6], transforming linear value chains across multiple levels—national, regional and local—is essential[7]. With half of global greenhouse gas (GHG) emissions resulting from resource extraction and processing, and half from manufacturing and use[8], system-wide approaches are necessary.

The concept of a circular economy has emerged as a response to overcome these challenges. A circular economy is an economic system that addresses fundamental limitations of current economic models. While current economic models assume a linear flow of resources, based on a 'take-make-waste' logic[9], a circular economy takes a systemic approach, emphasising the cyclical and physical basis of our societies. It is widely recognised as an effective model for mitigating waste production, maximising the utility of materials and products, and reducing the dependence on virgin materials—while delivering economic, environmental and social benefits[10].

Enhancing circularity is expected to ease environmental pressures by promoting more sustainable production and consumption patterns and foster economic resilience by creating new opportunities for innovation, job creation, and resource efficiency. Effective circular economies also generate social benefits by encouraging equitable access to resources and promoting cross-sector collaboration to achieve more resilient, prosperous and inclusive societies.

Circular strategies can be implemented at multiple system levels and value chain stages. These strategies include enhanced resource efficiency (narrowing flows), product re-design (slowing flows), closing supply chains and residual waste management (cycling flows), and restoring biophysical processes (regenerating flows)[11]. Practical circular measures include the 3Rs (Reducing, Reusing, Recycling)[12], recently expanded up to 10Rs[13].

Embracing these challenges and opportunities, all of Australia's Environment Ministers have committed to partnering with industry stakeholders to design out waste and pollution, keep materials in use, and foster markets to achieve a circular economy by 2030[14].

Western Australia (WA) is committed to becoming a sustainable, low-waste circular economy, as stated in its Waste Avoidance and Resource Recovery Strategy 2030[15]. However, WA does not currently report progress towards a circular economy at the State and city level, which is essential to informing data-driven decision-making and practical circular solutions.

The absence of a consistent circular economy monitoring framework prevents industry and government leaders from taking clear action. This represents a substantial gap that urgently needs to be addressed since, in the absence of a consistent science-based approach, economy-wide efforts towards practical circular applications cannot be measured accurately or effectively progressed.

Although waste and end-of-life indicators (e.g., waste generation, landfill diversion rates, recycling rates) are helpful, they do not capture a systemic circular economy approach that encompasses elements of sustainable development (economic, social, environmental), multiple levels (e.g., national, regional, local), multiple actors (e.g., institutional sectors, industrial sectors, organisational), and different strategies.

Furthermore, enhancing circularity at the product or industry level alone does not ensure environmental sustainability[16], highlighting the importance of a system-wide approach that goes beyond waste management strategies[17]. Such an approach must monitor and integrate indicators with a clear understanding of the circularity mechanism concerning economic activity and environmental performance[18, 19].

To address these gaps, this project proposes a system-wide perspective that goes beyond waste management by applying integrated assessment methods to provide a comprehensive understanding of material flows and environmental impacts—from extraction and production stages, to final use and end-of-life. Supported by a consistent performance indicator framework within a digital circular monitor, this approach is expected to drive effective circular outcomes across the State.

This report presents the first results of a multi-stage research project, providing insights into resource inflows, built stocks, and waste outflows—the socioeconomic metabolism—at the State, Greater Perth and municipal level. Though a multi-stakeholder effort, the project connects waste management, resource efficiency, and digital transformation to minimise environmental impact and effectively support the monitoring and implementation of a circular economy in WA. It provides businesses, governments and communities with insights to support evidence-based decision-making and positions WA as a global leader in integrating circular economy and net zero approaches within a digital monitoring framework.

1. Circularity in the global and local context

1.1. Global developments

The circular economy has attracted much attention over the past few years. Several national and regional roadmaps worldwide have committed to decoupling growth from material consumption and transitioning to sustainable, low-carbon societies. The connection between material use, waste generation and GHG emissions is increasingly recognised in the context of the Paris Agreement, as 27% of Nationally Determined Contributions (NDCs) refer to circular economy as part of their mitigation strategies[20]. Estimates suggest that circular strategies can reduce up to 39% of global GHG emissions while reducing virgin material demand by 28%[21].

Nevertheless, recent figures show that global circularity is decreasing. The 2024 circularity gap report by Circle Economy Foundation[21] revealed that a significant share of material inflows into the economy is virgin, while secondary materials decreased. Global circularity declined from 9.1% in 2018 to 7.2% in 2023, whereas material consumption peaked. In simple words, 92.8% of the materials used in the global economy on an annual basis are virgin materials.

While this global circularity metric delivers discouraging results, the degree of progress between countries varies considerably, possibly explained by disparities in resource allocation, capacities, and strategies adopted. Furthermore, assessment methods and indicators for measuring material circularity and recovery differ between countries[22, 23] and indeed, several nations do not report any progress. Therefore, these statistics should be carefully interpreted.

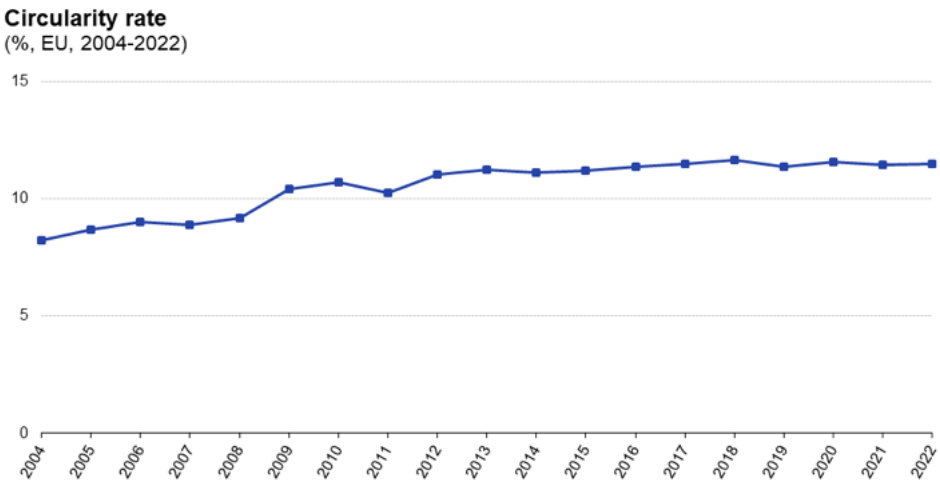

Figure 1. EU's Circularity Rate (%) from 2004 to 2022
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The EU members benchmark their waste management and circularity performances against waste generation per capita, recycling rate, and 'circular material use rate' (CMUR) metrics. In 2022, the EU's municipal solid waste (MSW) generation per capita was 513 kg, the MSW recycling rate was 48.6%, while the CMUR (referred to as the share of material resources from recycled waste materials) reached 11.5%. This reflects that 11.5% of the material inputs in the EU came from recycled materials[2, 24-26]. As shown in Figure 1, the EU's CMUR has remained almost steady since 2010 (10.7%), illustrating the complexities of increasing the uptake of secondary materials.

The Netherlands, Belgium, France, and Italy excel in CMUR scores, which are well over the EU average at 28, 22, 19, and 18%, respectively. Concerning recycling rates, Germany, Slovenia, and the Netherlands stood out at 69, 63, and 58%, respectively. Municipal waste statistics in the EU show that despite an increase in waste generation, less waste is being sent into landfill, as reflected by a 56% drop since 1995. When expressed as the landfilling rate (as a share of waste generation), it decreased from

61 % in 1995 to 23 % in 2022[27]. The different CMURs of EU members result from different recycling performances and structural economic mechanisms. On a disaggregated basis by main material groups (following the economic-wide material low accounting approach), as shown in Figure 2, values were 23.9% for metal ores, 13.7% for non-metallic minerals, 10% for biomass, 10.0%, and 3.2% for fossil energy materials/carriers, illustrating a remarkably stable trajectory.

The Netherlands has effectively reduced landfill usage and increased recycling through policies such as high landfill taxation and the 2nd National Waste Management Plan (NWMP). By 2007, only 2% of municipal solid waste (MSW) was sent to landfill, down from 9% in 2000, largely possible through increased incineration. The OECD recognises the Netherlands as a leader in waste management as the country has combined political, economic, financial and information mechanisms to reduce MSW generation from 9.45 tonnes per capita in 2004 to 8.85 tonnes in 2016, along with higher recovery rates and high-quality waste traceability. However, there is still work to be done to lower unavoidable incineration rates in upstream processes.

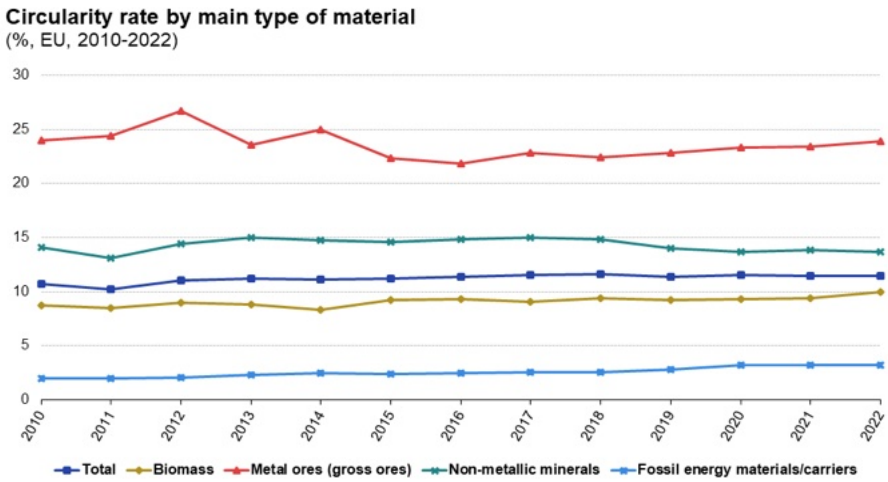

Figure 2. EU's Circularity Rate (%) from 2010 to 2022 by main material groups
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Legislation and policy tools have been critical for advancing a circular economy by creating incentives and setting targets to produce systemic changes. The EU's new circular economy action plan has set a precedent for transitioning to a cleaner and more competitive Europe through a bottom-up approach[28]. The statistical framework developed by the EU is underpinned by the EW-MFA, which captures the interaction between national economies, the natural environment, and other economic regions in terms of flows of materials[29]. On the other hand, China, through its circular economy promotion law, has been raised as an example of a top-down approach[12, 30].

These nuances become more pronounced when practical strategies are adopted. Most policy frameworks for transitioning towards a circular economy embody the circularity strategies represented by the 3R principles of reduce, reuse, and recycle[31]. Recently, these approaches have been expanded to include the 4R, 5R, 6R, 9R and even 10R principles[22] to better represent the range of alternatives available for management. Figure 3 shows the 10R framework with the definition of each of the circular economy strategies: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover. According to this model, the higher up the pyramid, the greater the contribution to the principles of the circular economy.

However, these approaches are usually applied within end-of-life management, focusing on the waste hierarchy (see Appendix A) while overlooking material resource efficiency[32]. Interestingly, the EU roadmap was updated to include resource efficiency as one of the core elements[28]. As such, its successful outcome will rely on deploying meaningful policy instruments to promote resource efficiency in resource-intensive sectors[33].

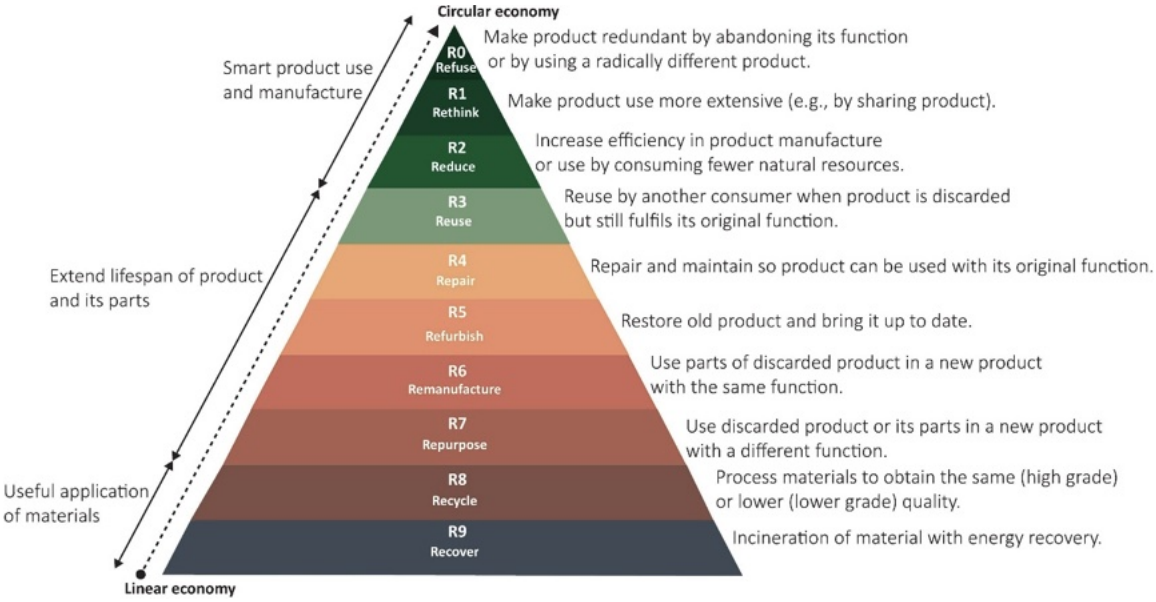

Figure 3. The 10R framework
Reproduced under a CC-BY 4.0 licence from Muñoz et al. (2023)[4].

In this global context, transitioning to a circular economy demands structured and harmonised approaches that ease policymaking. Hartley et al. (2020) developed a comprehensive policy framework applicable to the European context[30]. This work recommended eight potential circular economy policies targeting different stages of a product life cycle: 1) adoption of circular design standards, 2) expansion of circular purchasing, 3) tax incentives on circular economy-based products, 4) free trades of waste, 5) enabling of circular trading mechanisms, 6) building of eco-industrial parks, 7) circular economy marketing and promotion, and 8) creation of an MFA database and monitoring tools. Other academic work highlighted three policy axes to be prioritised: 1) policies for reuse, repair and remanufacturing; 2) sustainable public procurement and innovative purchasing; and 3) policies for strengthening secondary resources markets[32]. These contributions shed light on potential policy reforms tailored to the context of Australia and its states.

1.2. Adoption in Australia

As one of the countries with the highest consumption rates, Australia endeavours to incorporate circular economy approaches while sustaining economic growth and productivity. It ranks among the top 10 countries globally for natural resource extraction[34]. Except for Canada and Chile, Australia consumes more materials per capita than any other OECD or Asian-Pacific country. It also has lower material productivity and supply chain autonomy than most OECD and regional countries. In 2022, Australia consumed 46 tonnes of resources per capita yearly (as DMC[5]), more than twice the average of OECD countries[35], while our material footprint[6] was 32 tonnes per person. Figure 4 benchmarks Australia's material footprint per capita with the OECD and global averages.

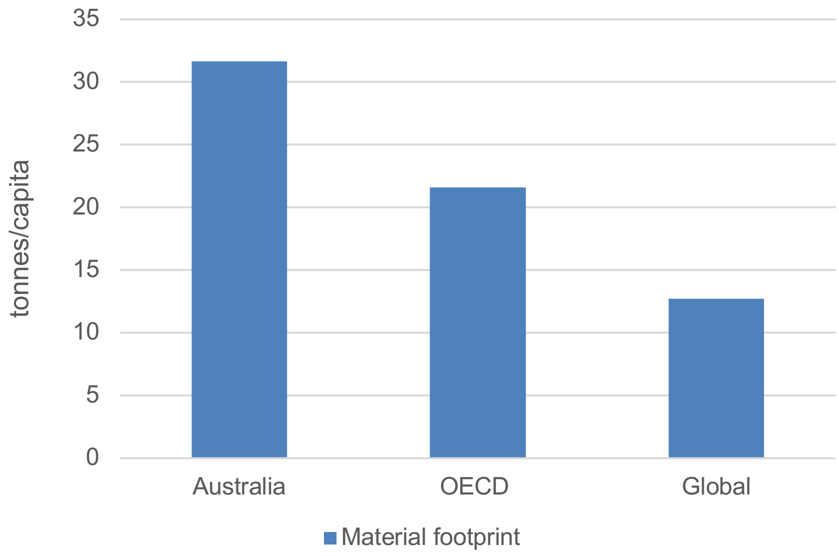

Figure 4. Australia, OECD and global material footprints in tonnes per capita.

The national material productivity stood at 1.1 USD for every kilogram of material consumed, less than half of the OECD average[36], and considerably lower than 5-6 USD values for comparable countries such as the UK, Netherlands, and Switzerland. In terms of material self-sufficiency, Australia is ranked last among the OECD (self-sufficiency ratio of 71.5%) in the context of global supply chains impeding Australia's security[37].

Australia also faces challenges regarding waste management. The country generates 543 kg of municipal waste per capita, which is comparable to Germany, Switzerland, the Netherlands, and Austria, but has considerably lower recycling rates[38]. Australia disposes of ~30% of its total waste to landfill[39], which is markedly higher than comparable economies such as the Netherlands, where just 2% of the Dutch waste volume is sent to landfill[40].

Nationally, there is growing enthusiasm to transition towards a circular economy in response to internal and external factors such as the national waste crisis[41, 42], international trade pressures[43], and climate change and biodiversity impacts[44]. In addition, unlocking Australia's circularity potential can significantly contribute to achieving decarbonisation targets. The 2024 Sector Pathways Review by the Climate Change Authority highlights a circular economy as a key emission reduction strategy through waste minimisation, material value retention and reduced virgin material demand[45].

The National Waste Policy 2018 and action plan embrace a circular approach in which the value of resources is preserved for as long as possible[46]. The National Waste Policy Action Plan 2019 set a target of an 80% average resource recovery rate from all waste streams by 2030, following the waste

[5] Domestic material consumption (DMC) is the amount of materials (in terms of weight) used in an economy.
[6] The total amount of raw materials required to meet final demand.

hierarchy[47]. From this national agenda, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) was assigned to develop a National Circular Economy Roadmap, of which the first stage provided a high-level roadmap for plastics, tyres, glass, and paper[17]. While the policy landscape has a history that reflects tensions between federal and state-level actions[48], these developments represented a change of paradigm that catalysed circular economy research and development initiatives[49], as well as state-level policy reforms that support the transition to the circular economy[50, 51].

In 2021, the Recycling Modernisation Fund (RMF) was deployed with the aim of increasing recycling capacities and waste processing infrastructure across Australia. However, despite the significance of the RMF, the National Waste and Recycling Industry Council (NWRIC) asks for actions to be implemented upstream in the supply chain to address the whole lifecycle of goods and services. This shift towards a lifecycle focus is reflected in several recent developments, including the Sustainable Procurement Guide[52], which seeks to leverage the government's purchasing power to increase the demand for sustainable goods. Likewise, the new mandatory climate-related financial disclosures require large businesses and financial entities to report information related to governance, risks and management, including Scope 1, 2 (1st year), and 3 (2nd year) emissions, from January 2025[53], further stressing a lifecycle perspective.

Sectoral opportunities for a circular economy are also becoming more evident. As stated by a CSIRO report to the Office of the Chief Scientist[54], a circular economy could unlock substantial economic benefits while addressing environmental impacts on a sectoral basis. Critical sectors such as mining, construction, manufacturing, agriculture, and waste management are well-positioned to leverage the country's abundant natural resources. The Critical Minerals Strategy 2023–2030, the main framework guiding the growth of Australia's critical minerals sector, echoes this and acknowledges the opportunities offered by a circular economy to realise the full lifecycle potential of critical raw minerals (CRM)[55]. The strategy outlines CRMs that are important for Australia's modern technologies, economies and national security, and highlights the structural changes required to position Australia as a resilient, low-carbon export-orientated economy, as well as the critical role of cross-sector collaboration in this transition.

Infrastructure Australia's "Embodied Carbon Projections for Australian Infrastructure and Buildings" report[56] further highlights the importance of adopting a lifecycle approach. This report established a baseline for embodied carbon in Australia's built environment by estimating carbon emissions associated with the building and infrastructure construction pipeline from 2022–23 to 2026–27. It revealed that the built environment is directly responsible for 30% of Australia's emissions and indirectly for about 50% of all emissions. Moreover, construction activities over the next five years are projected to produce between 37 and 64 million tonnes of CO_2-e per year. Implementing practical decarbonisation strategies, such as using alternative materials, could reduce a significant portion of these emissions without incurring additional costs.

This growing interest in a circular economy can be seen in practice at the precinct level. The Parkes Special Activation Precinct in NSW, Australia's first UNIDO eco-industrial park, offers sustainable alternatives to businesses, including waste and water reuse and clean energy generation[57]. The Tonsley Innovation District in Adelaide is a leader in green urban development, featuring renewable energy solutions, smart lighting systems, and sustainable water management[58]. The Bega Circular Valley in NSW aims to transform the region into a model for regional Australia by accelerating and supporting enabling initiatives, including a National Centre for Circularity[59].

However, from a system-wide perspective, the level of objective progress towards a circular economy is only beginning to emerge. A consistent, system-wide indicator framework to monitor the state of circularity in Australia is in the early stages of development, although significant contributions have been made. Circular Australia and The University of Technology Sydney conducted a review of circular economy metrics, emphasising the essential role of concise measurement in accelerating circularity. The report discussed a shortlist of 31 circular economy metrics, with a focus on data availability and applicability in the NSW state context[60].

More recently, CSIRO published the results of a material flow analysis of the Australian economy as of 2019, showing a circularity rate of 3.7%, nearly half of the global average[61], and far below the

Netherlands (24.5%)[62]. Following this research, the Australian Bureau of Statistics (ABS) has updated the Measuring What Matters framework to include metrics related to the circular economy based on data from the Department of Climate Change, Energy, the Environment, and Water (DCCEEW) and CSIRO[63]. This publication includes several key indicators: waste generation per person, the proportion of waste recovered for reuse, recycling, or energy, the circularity rate, material footprint per capita, and material productivity. While not yet fully comprehensive (see Section 1.4), these leading indicators underscore the challenges and opportunities for Australia in moving towards a less resource-intensive and low-waste economy.

In 2023, the Circular Economy Ministerial Advisory Group was formed to advise the Australian Government on transitioning to a circular economy[64]. Recently, the Advisory Group released its first interim report with recommendations in six core areas: national policy setting, targets and indicators, economics, net zero, product design and consumption, and the built environment[65]. Three main insights emerge from this report. First, despite progress, more can be done to drive Australia towards a circular economy. Two, there is a need to better understand how resource efficiency supports productivity, prompting the recently formed Productivity Commission to launch a public inquiry on the opportunities in a circular economy[66]. Three, more consistent standards for measuring and benchmarking material flow and circularity in Australia and its territories are required. The joint work of the Advisory Group and CSIRO is expected to form the basis of the upcoming national circular economy framework currently being developed by DCCEEW[67].

1.3. Progress in WA

At the state level, WA is exploring policy mechanisms to upgrade the waste management framework and support the transition towards a circular economy, as demonstrated through a public consultation paper about potential waste reforms[68]. The Waste Avoidance and Resource Recovery Act 2007, the central State waste legislation, establishes the requirement for developing a long-term waste management strategy, which must be reviewed and periodically updated. The latest update, the ‘Waste Avoidance and Resource Recovery Strategy 2030’, envisions achieving a sustainable and low-waste society based on a circular economy[15]. This framework is further supported by the Waste Avoidance and Resource Strategy Action Plan 2022-23[15, 69], which sets three critical targets by 2030: 1) a 20% reduction in waste generation per capita; 2) at least 75% of recovered waste; 3) less than 15% of waste generated in the Perth and Peel regions disposed of in landfill. The action plan supports the deployment of industry-led and public projects promoting a circular economy, while other legislative instruments further reinforce this direction.

An example of successful mandatory State policies was the Plan for Plastics launched in 2021 that, through a two-stage regulatory framework, banned single-use plastic from 2023 in WA[70]. Likewise, the container deposit scheme, Containers for Change, aims to increase the recovery and recycling of empty beverage containers while reducing their disposal in landfill[71]. On the other hand, voluntary approaches relying on industry-led actions, such as the 2025 National Packaging Target, have recently reported modest progress[72]. These conflicting results highlight the circular economy's reliance on finding a balance between cross-sectoral and industry collaboration, and mandatory government regulation.

In line with WA’s economic development framework, the Diversify WA—Supply Chain Development Plan 2021-22 seeks to support WA’s supply chains in building a more diverse and resilient economy while raising the demand for products with lower environmental impact[73]. This strategic plan recognises the dependence of WA’s economy on global trade, which exposes it to potential risks in external supply chains, thereby underscoring the need for system-wide circular approaches. Western Australia’s Battery and Critical Minerals Strategy 2024-2030 further points in this direction, acknowledging the role of the circular economy in maximising environmental, social and corporate governance outcomes in the context of CRM[74].

As circular economy strategies are critical in reducing GHG emissions[75], their contribution is increasingly receiving recognition within WA’s decarbonisation roadmaps. A dedicated circular economy framework is expected to unlock this potential, acting synergistically with the Western Australia Climate Policy[76] and the recently announced Sectoral Emissions Reduction Strategy for Western Australia[77], which assigns a central role to circular economy strategies to achieve net zero emissions. In contrast to all other Australian states and territories, WA's territorial emissions have continued to rise[78], positioning circular approaches as a potential response to curb this trend, and further strengthen commitments towards economy-wide targets.

Sector-specific policy development and circular initiatives are emerging, with a growing interest from State and non-state actors in integrating circular approaches within internal processes. However, few have mandates to demonstrate evidence-based contributions. The Department of Transport stands out as a leader in this respect within the public sector, integrating circular strategies through the Sustainable Infrastructure Policy framework, a commitment to strengthening sustainable resource use and reducing lifecycle impacts across transport infrastructure and assets[79]. Western Australia has seen past success as a leader in industrial symbiosis, as demonstrated by the Kwinana Industrial Area, where over 150 products, by-products and utilities are exchanged within a complex network of synergies between 34 participating companies. This multi-industry-led collaboration is highlighted as a concrete example of circular economies at the industrial precinct level[80, 81].

At the local level, several local government authorities, including the City of Melville, City of Cockburn, and Town of East Fremantle, are pioneers in local and small-scale circular initiatives, aiming to encourage residents to adopt circular economy principles[82, 83]. These initiatives are further bolstered through the WasteSorted Community Education program administered by the Waste Authority[84]. Although these initiatives are very valuable in the context of education programmes focused on household waste, actions with a system-wide focus are necessary. This has been further highlighted in the recent 'Regional Circular Economy Horizon Scan' report, which calls for further transdisciplinary research, multi-sector collaboration and capacity building, and material-focused roadmaps for a circular economy[85].

While WA has significant potential for circularity, beyond clear mandates to improve waste management processes, practical circular frameworks and actions are fragmented at the State, regional and municipal level. Notably, while interest in circular approaches is at an all-time high, WA lacks a comprehensive policy framework dedicated to circular economy foundations. Moreover, a consistent, system-wide approach for measuring progress towards a circular economy is yet to be piloted in WA's jurisdictions. Beyond macro indicators on solid waste generation, recycling and resource recovery, key measures of circularity are lacking at all levels.

1.4. Circular economy monitoring: a system-wide perspective

Circular economy monitoring frameworks can inform evidence-based decision-making, building capacity for continuous improvement through high-quality information and processes[22]. Given the multidimensional nature of the circular economy, no single indicator sufficiently captures all of the circular economy's foundations. Different indicators focus on specific strategies at each scale—micro (products, businesses), meso (supply chains, industry sectors) and macro (cities, regions, nations)—thus, the search for systemic cross- and multi-scale indicator system is a widely held long-term aspiration[23].

Research has suggested that a systemic perspective to monitoring national, regional, and city metabolisms is critical to deriving actionable, evidence-based insights[86]. Such an approach must integrate indicators with a clear understanding of the circularity mechanism concerning economic activity and environmental performance[18, 19]. A comprehensive, system-wide circular monitoring framework should consider thirteen critical aspects.

First, it should represent the contribution of the circular economy to all **sustainability dimensions** —environmental, economic, and social—allowing for a holistic assessment. This requires measuring the biophysical basis of the circular economy (i.e., mass), including energy and material stocks and flows, as well as the role of natural systems in buffering environmental pressures (e.g., emissions)[87, 88]. Simultaneously, stocks and flows within the socioeconomic system should be evaluated in monetary terms (e.g., AUD) alongside metrics for societal outcomes. Integrating these dimensions is vital for effectively monitoring core circular objectives, such as resource efficiency, economic development, environmental sustainability and social wellbeing.

Second, it should aim for **completeness**, capturing the total scale and composition of the socioeconomic system under assessment[89, 90]. This allows for evaluating the structural evolution of the system and its relation to its biophysical substrate, delivering whole-system insight.

Third, it should monitor **narrowing loops** (i.e., the physical scale of inputs and outputs) and the capacity for the socioeconomic system to maximise utility and value with fewer resources[91]. Material productivity and intensity per unit of value added should be evaluated to better understand the potential for decoupling value creation and preservation from total resource demands.

Fourth, it should monitor **slowing material and energy cycles** to determine the effectiveness of circular approaches in extending the use and reuse of materials over time[91]. A distinction should be made on the ultimate use of final products—whether investment in long-lived stocks or consumption of short-lived goods—to better understand progress and advance circular strategies for slowing material loops[92].

Fifth, it should monitor **loop-closing** for all material and energy cycles to understand progress and advance circular strategies for narrowing loops[92]. This includes the mass and quality of secondary materials embodied within internal and external value chains with respect to system boundaries, including trade, making a clear distinction between upstream and downstream contributions to circularity rates. Cycled materials should be understood in terms of their technical properties to determine their potential for closing loops and offsetting raw material inputs.[93] This provides insight into the effectiveness of introducing recovered materials back into production systems.

Sixth, it should monitor the **regenerative capacity** of the natural environment and the socioeconomic system's contribution to environmental impacts. Reductions in resource extraction, waste and emissions are expected to reduce pressures on natural resources and ecosystems, thereby restoring biophysical processes that regulate the stability and resilience of the Earth system[94, 95]. This establishes the critical link between socioeconomic drivers, environmental pressures, and the state of natural systems, allowing for the assessment of circular approaches towards environmental sustainability.

Seventh, it should traverse multiple **geographical and administrative boundaries**, establishing a clear relationship between the state of circularity and circular-related goals at the national, regional and municipal level [23]. This enables the cross-scale propagation of information critical to delivering system-wide insights and building multi-stakeholder capacity to drive circular outcomes at the scale where action is most effective.

Eighth, it should integrate state and non-state **actor perspectives** into geographical and administrative boundaries (e.g., national, regional, and municipal level) to connect system-wide insights to specific actor-oriented actions. It is expected that a multi-actor framework enables accountability across value chains, promoting multi-stakeholder collaboration towards solution-oriented outcomes[96].

Ninth, it should cover all **value chain stages**, providing insight into societal systems of production, consumption, and end-of-life management, with a breakdown by institutional sector (e.g., government, households, corporations) and industrial sector to support specific targets and drive actions within particular actor subsystems[65].

Tenth, it should allow for the **traceability of impacts** along complex supply chains[97, 98], which is pivotal for understanding the direct and indirect effects of circular response measures across regions, actors and value chains. Lifecycle impacts associated with resource extraction, processing and manufacturing, consumption and use, and end-of-life processes should be systematically quantified. This provides a comprehensive understanding of not only the physical weight and impacts of final goods, but also the total raw materials requirements and associated impacts along supply chains that produce and consume such goods.

Eleventh, it must be **actionable**, connecting the full range of circular economy strategies[22, 23]. It should clearly enable insight into drivers, pressures, the state of the system, and impacts on resources, ecosystems, and human wellbeing (as per the DPSIR framework—see Appendix A), allowing for the identification of specific circular responses across regions, actors, and value chains.

Twelve, it should be **comparable** across spatial and temporal scales, providing consistency at the regional and national level and the ability to benchmark with international headline metrics[99]. This is critical for enabling a shared context, building cross-scale and multi-sector capacity for evidence-based decision-making, and monitoring the potential impacts of circular responses over time.

Lastly, it should have **predictive** power, allowing for dynamic scenario analysis to anticipate potential trade-offs, synergies, and rebound effects across regions, actors, and value chains[99]. Measures of uncertainty should be transparently reported whenever feasible.

Given these functional requirements for a system-wide monitoring framework identified in the literature, we aspire to further this research through the implementation of a consistent cross-scale, multi-level, and multi-actor indicator framework within a digital circular monitor. These developments are expected to inform evidence-based decision-making and build capacity for circular outcomes across cities and regions in WA.

2. Mapping the circular economy

2.1. Project overview

This project takes a whole system approach to building multi-stakeholder capacity and informing smart circular practices through evidence-based insights and digital transformation, with the aim of promoting innovation, community wellbeing and environmental sustainability (Figure 5). Together with local and regional councils, State departments, and industry partners, this project further enhances our understanding of circularity in WA with the long-term aim of providing a critical performance indicator framework within a digital circular monitor for effectively monitoring and driving circular outcomes at the city and regional level.

Assessment tools are essential in understanding socioeconomic metabolisms and supporting cross-sector collaboration towards enhanced resource efficiency and environmental performance. This project seeks to position WA as a leader in integrating circular economic and net zero approaches within a digital monitoring framework. These innovative tools and processes provide governments, industry, investors, and communities with the conceptual and empirical backbone to support circular planning and decision-making regarding practical circular applications within WA[100].

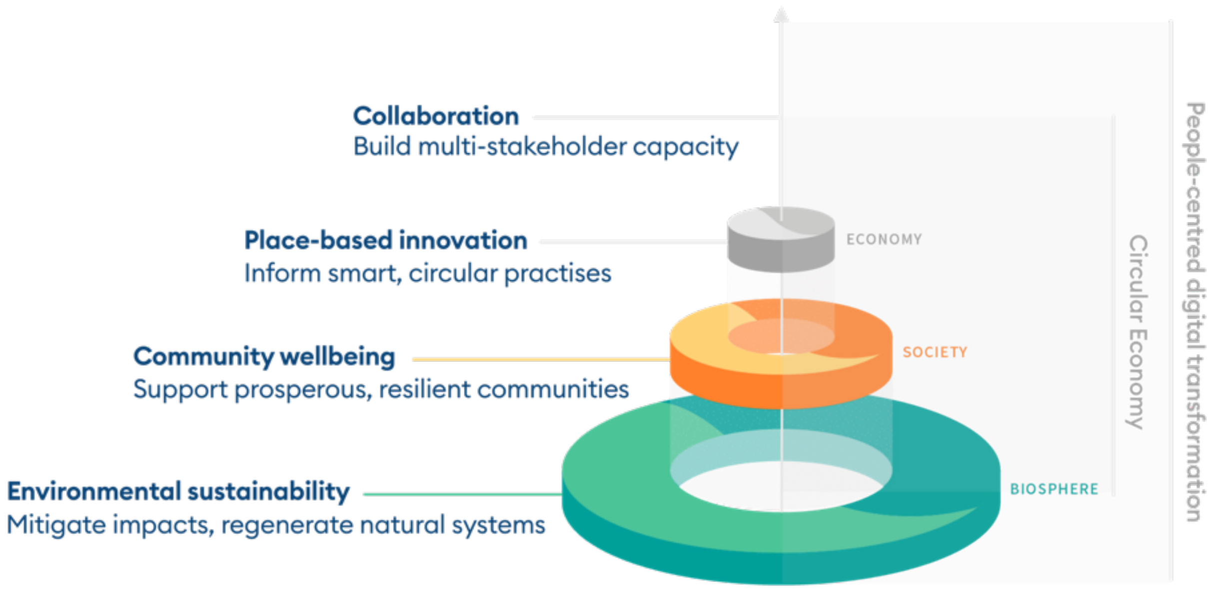

Figure 5. Whole system approach
Reproduced with permission from Open Corridor (2023)[1].

The project offers tangible methods and tools for WA state and non-state actors to measure, monitor and report on enhanced material flows (including narrowing, slowing, cycling and regenerating) and assess progress towards decoupling raw material use and environmental impacts from economic activity and societal needs. Through State and local demonstrations, we aim to inform resource strategies (including enhanced resource efficiency, closing supply chains, product lifetime extension, and residual waste management) and enable scale-up plans at the city and regional level. These goals align with international, national and state regulatory frameworks (see Section 1) that recognise the relevance of circular economy approaches in the transition to sustainable, low-carbon and low-waste societies.

2.2. Project objectives

This is the first stage in developing WA's digital circular economy monitoring framework, WATCH (Western Australian Tool for Circular Horizon). The objectives for Stage 1 are:

- To determine the state of play in circular economy research and policy internationally and locally.
- To quantify and visualise the resource inflows and waste outflows linked to intermediate and final computation demands across WA and Greater Perth, and case study regions.
- To estimate, map and visualise the material stocks and flows within the administrative boundaries of WA and Greater Perth.
- To disseminate results and make recommendations for further research stages.

2.3. Research approach

This project consists of three key research steps to assess material and environmental flows within Greater Perth and WA. In Step 1, the project quantifies material inflows, waste outflows, and embodied environmental flows (such as energy use and GHG emissions) to establish a baseline for socioeconomic metabolism. This step incorporates the cities of Bunbury and Canning as case studies, providing insights into local consumption and potential circular economy solutions. Step 2 builds on these initial measurements by focusing on the built environment and conducting a detailed material flow analysis. This step integrates various data sources and visualises material flows through Sankey diagrams to better understand Perth's socioeconomic metabolism. Finally, Step 3 synthesises the findings, assesses policy implications, and provides actionable recommendations to support the transition to a circular economy. The project also outlines future steps, including expanding case studies, improving data collection, and developing decision support tools for government and industry.

Measuring the footprint

During this initial step, we quantify the material (minerals, ores, biomass, fuels, and water) inflows and waste outflows within city and regional boundaries[101]. Alongside material flows, we account for embodied environmental flows (e.g., energy use and GHG emissions) generated along supply-chains supporting the production of all goods and services consumed within the administrative boundaries of WA, Greater Perth, and two municipal case study regions. This includes household and government consumption of short-lived goods, private and public capital investment, and the total supply required to meet final demand, domestically and abroad.

We prepare a functional framework by linking systems of provision to systems of functional demand. This provides a crucial link between micro and macro systems, essential for informing a holistic understanding of urban metabolism. Together with sector-based categorisation, this framework supports the identification of potential supply and demand-side solutions towards enhanced circularity. In addition, an indicator framework is provided to enable footprint baseline assessment, hotspot analysis, and the monitoring of changes over time.

Two local case studies, Bunbury (regional) and Canning (metropolitan), are conducted to validate the approach and provide more significant insights into local decision-making at the municipal level. The resulting city material footprints and associated environmental impacts are graphically visualised to facilitate a shared understanding of the quantities of material handling and use and identify circular solutions at the city scale.

Mapping stocks and flows

Building on the material footprint measures from Step 1, which quantifies the total (supply-chain inclusive) material demands, Step 2 prepares localised stock and flow accounts of actual material and energy use. These physical accounts are structured around key components: domestic extraction, imports, additions to stocks, exports, and outflows as waste. Figure 6 illustrates the conceptual Material Flow Accounting (MFA)[102] framework employed in this research, highlighting how material inputs into the economy result in changes to stocks and generate outputs to other economies or the natural environment.

To comprehensively analyse the physical structure of the WA economy, we adopt an integrated methodology that combines top-down and bottom-up approaches. A bespoke Australian, multi-scale, nested Multi-Regional Input-Output (MRIO) model is advanced, integrating interregional trade statistics and Physical Supply and Use Tables (PSUTs) where possible. Detailed physical accounts are integrated, including resource extraction and energy use, sourced from national and state government agencies, utilities providers, production facilities, and industry partners. These statistics serve as input and output data used for material flow analysis, which is used to assess material stocks and flows and evaluate the socioeconomic metabolism of the selected cities and regions. For greater granularity and accuracy, material stocks within the built environment are quantified using bottom-up LCA-MFA methods. This integrated approach offers local and regional insights consistent with state and national statistics, and alignment with the System of Environmental-Economic Accounting (SEEA) framework. To effectively communicate the findings, we visualise results using Sankey diagrams, offering clear and intuitive depictions of material and resource flows.

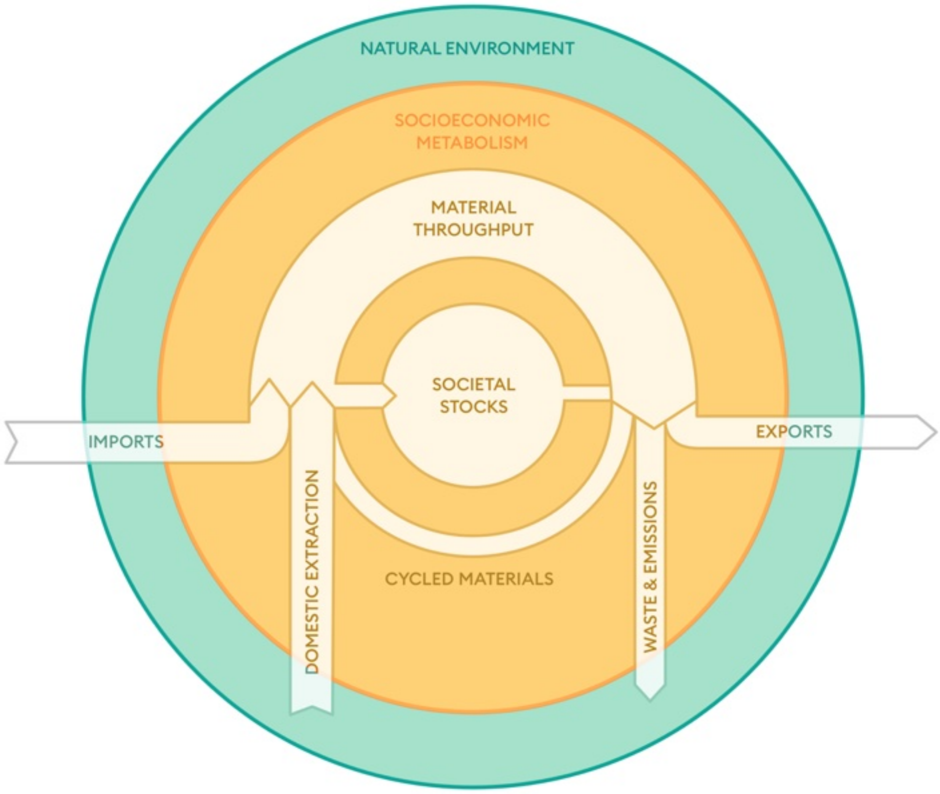

Figure 6. Scope of system-wide material flow accounting Reproduced with permission from Open Corridor (2024)[1].

Reporting and Recommendations

Finally, we assess policy implications and make recommendations for enabling the transition towards a circular economy in the context of net zero pathways. We critically analyse the significance of the findings, identify the approach's strengths and limitations, and determine its value and relevance to different levels of government policy (local/regional/state) and broader industry opportunities. Building upon the findings, we provide actionable policy recommendations and directions for further research.

3. State of circularity

Western Australia is characterised by significant material consumption and high levels of domestic extraction, underscoring both the challenges and opportunities for advancing a circular economy within the State. In 2021, total raw material consumption across WA amounts to 114.1 Mt (42 tonnes per capita), twice the OECD average (21.6 t/capita) and more than three times the global average (12.7 t/capita). Of this, about 80% (90.7 Mt) of demand occurs in Greater Perth, associated with 79% (50 Mt) of WA's emission footprint. This level of resource use highlights the domestic material demands of the State's economy and emphasises the need for more circular practices in industrial and end-use sectors.

Material productivity, which measures the efficiency of raw material consumption relative to the Gross State Product (GSP), stands at 3.2 billion AUD per Mt[7]. This ratio indicates the State's ability to generate economic value from material inputs but also points to areas where circularity improvements can be made to decouple economic growth from non-critical resource use.

Western Australia is the top exporter among all Australian states and territories, contributing 56% of the total value of Australia's goods exports[103]. In 2021, domestic extraction in WA totals 1,068 Mt, reflecting the State's reliance on natural resource extraction to support its export-orientated economy. This domestic extraction exceeds alone that of several OECD countries such as, Chile (1,005 Mt) Germany (970 Mt), France (707 Mt), and Poland (686 Mt)[104].

When factoring raw material imports (193.7 Mt), this translates to a material intensity of 3.1 Mt per billion AUD of GSP[8]. Of this, the raw material consumption required to produce one unit of GSP was 0.3 Mt, underscoring the extensive input of natural resources into the State's economic output. If WA were a country, it would rank as the most materially intense economy in the world, surpassing world leading extractors such as Chile (2.66), Brazil (1.83), Russia (1.60 Mt), China (1.53), Germany (0.45), and USA (0.36)[104].

When it comes to stock formation, WA's in-use building stock is estimated to be 288 Mt, with a net addition of 8.4 Mt for the year 2021, given associated solid waste outflows of 2.0 Mt. Total solid waste generation amounts to 6.6 Mt (2.5 tonnes per capita), at a 62% end-of-life recovery rate. This recovery performance stands below countries such as Singapore (96%), Norway (74%) and Hungary (70%) and the USA (68%)[38], although WA incinerates considerably less waste. Consumption-based emissions[9] amounted to 63.5 Mt, while net-territorial emissions are estimated to be 73.7 Gt, highlighting opportunities for decarbonisation through circular strategies on both the demand and supply side.

Municipal-level case studies show a dependency on external supply, with only 4.7% (0.22 Mt) of the total raw material input originating from WA. This indicates that a significant portion of the cities' environmental impact is embedded in upstream value chains, highlighting the importance of a lifecycle approach to informing circularity at the city scale.

These headline indicators (Table 1) collectively provide a snapshot of the state of circularity in WA, emphasising the need for systemic shifts to improve material efficiency, reduce waste, and transition to a more circular and sustainable economic model. See Appendix C for the complete table. The following chapter focuses on distinct but interconnected aspects of the circular economy–material inflows, built stocks, and material outflows–at the State, Greater Capital and municipal level.

[7] Material Productivity is presented on a raw material consumption basis. The efficiency of material consumption in the production of goods destined for export is not included.
[8] Material Intensity of raw material inputs is equal to RMI/GSP. Here the area covered for materials inputs completely overlaps with that in which added value is generated.
[9] Lifecycle emissions include direct (scope 1), indirect (scope 2) and supply-chain emissions (scope 3).

Table 1. WA's circular economy heading indicators derived from WATCH

CE Headline Indicators	**Unit**	**WA, 2021**
Gross State Product	$b	361.8
Domestic Extraction	Mt	1,067.5
Domestic Extraction, per capita	t/capita	401.3
Direct Material Input	Mt	1,082.3
Raw Material Input	Mt	1,134.4
Raw Material Consumption	Mt	114.1
Raw Material Consumption, per capita	t/capita	42.9
Material Productivity, raw material consumption	$b/Mt	3.2
Material Intensity, raw material input	Mt/$b	3.1
Material Intensity, raw material consumption	Mt/$b	0.3
Imports, direct [(a)]	Mt	14.8
Imports, raw material equivalent	Mt	66.9
Exports, direct [(a)]	Mt	999.8
Exports, raw material equivalent	Mt	1,114.6
Gross stock, buildings [(b)]	Mt	288.9
Net addition to stock, buildings [(b)]	Mt	8.4
Consumption-based emissions	Mt	63.5
Terrestrial emissions, net	Mt	73.4
Solid waste generation, total	Mt	6.6
Solid waste generation, per capita	t/capita	2.5
Resource recovery rate [(c)]	%	62

a. Direct international trade flows only

b. Initial estimates

c. Recovery rate is defined here as resources diverted from landfill

3.1. Material footprints

Material footprints (MF) serve as a crucial metric for advancing the circular economy by providing a detailed measure of resource use and environmental impact. They quantify the total raw materials—biomass, fossil fuels, metal ores, and non-metal ores—extracted to meet intermediate and final consumption demands, offering a holistic view of the resources embedded in production and consumption cycles. By identifying areas where materials can be used more efficiently, MFs support the circular economy's goal of minimising waste and maximising resource utility. This helps businesses and policymakers develop strategies to optimise resource use by pinpointing inefficiencies, thereby reducing the overall MF.

The work described here quantifies the material (minerals, ores, biomass, fuels) inflows – the material footprints – within administrative boundaries[101]. Alongside material flows, we account for embodied environmental flows generated along supply-chains supporting the production of all goods and services.

The methods utilise Environmentally-Extended Input-Output Analysis (EE-IOA), a method to quantify the life-cycle of products and services and the associated environmental impacts[105], together with local activity data, to estimate the material and GHG emission footprints of WA, Greater Perth, and local government case study regions. This considers household and government consumption, private and public investment activity, and the total supply required to meet final demand, domestically and abroad.

3.1.1. Western Australia and Greater Perth

Western Australia plays a pivotal role in both domestic and global material flows. With its resource-rich economy, the State's footprints are heavily influenced by primary industry, while final consumption drives significant impacts embodied in external value chains. The interplay between domestic extraction, consumption demands, and trade reveals a unique economic structure that presents both challenges and opportunities for circularity. This section delves into WA's material inflows and outflows, as well as associated GHG emissions flows—providing a baseline for circularity and underscoring the potential for enhanced circularity and decarbonisation in both metropolitan and regional WA.

Material flows

The Sankey diagram below (Figure 7) presents a disaggregated view of the WA material footprint, showing material inputs from domestic extraction and imports, through to initial processing, final products, and final destination—whether it be Greater Perth, Rest of WA, or exports. Intermediate flows are mapped based on supply-chain stages and value-adding activities[106]. Not surprisingly, by far, the major component of the WA material footprint when exports are included revolves around the extraction and export of materials.

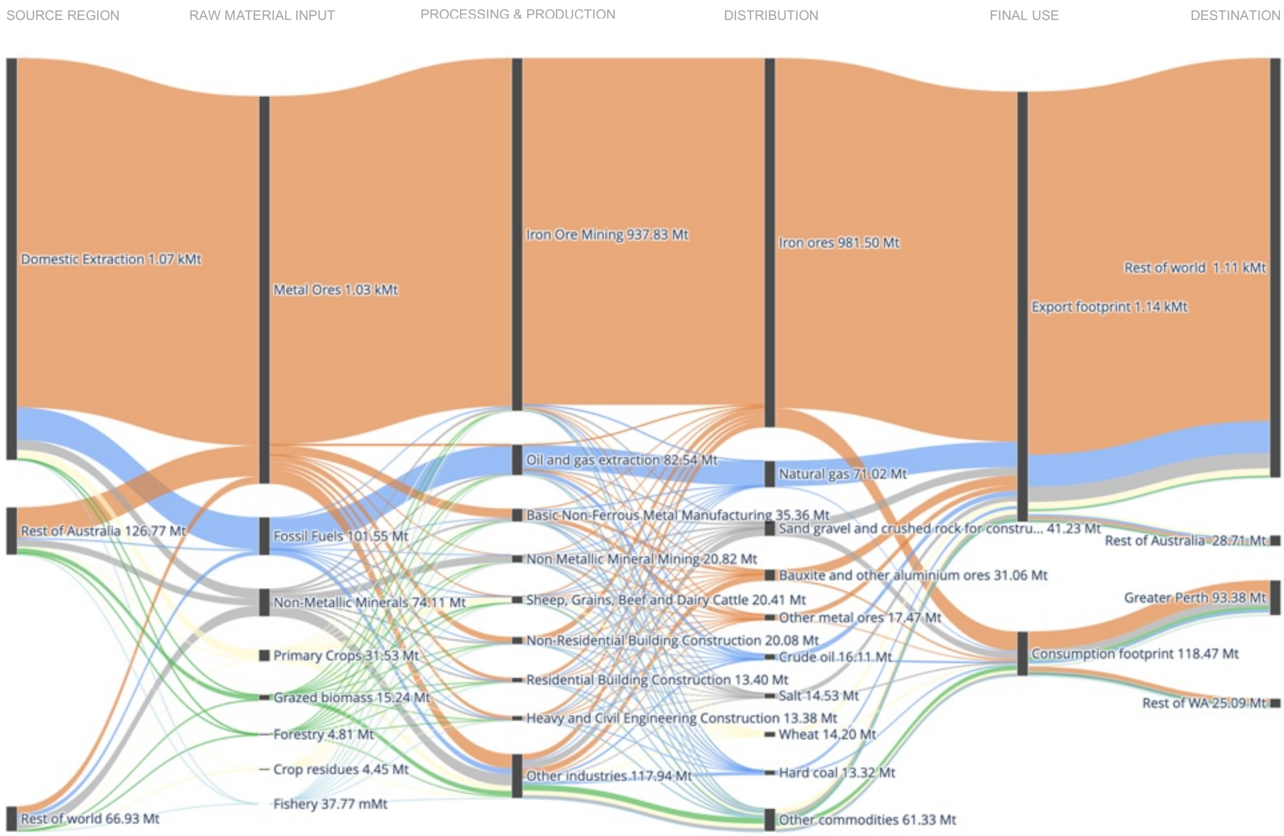

Figure 7. Sankey diagram showing the throughput of materials from source to final products for WA, 2020-21

One of the most significant contributors to these results is material footprints due to iron ore extraction. Western Australia exports significant ore, however, it is dependent on the import of products (vehicles, structural steel for buildings, etc.) that are produced in other countries and other states. While WA clearly plays a critical role in the sustainability of iron ore production in the global marketplace, without significant investment in green steel and remanufacturing, it has limited leverage to increase circularity within such production chains. Other major exports include liquid natural gas (LNG), with a relatively small fraction of domestically extracted fuels being consumed domestically, raising concerns about impacts external to WA. Consequently, these dominating features have led to WA being regarded as one of the world's simplest economies from an economic complexity perspective[17]. This has potential implications for the long-term resilience of the State's economy within the international context.

One aspect that the Sankey draws attention to is the significant contributions of manufacturing, non-residential and residential building construction, and "other industries" (which are mainly non-primary or service sectors). Product lifetime extension, recycling, and other CE policies to slow and close loops can likely have the greatest impact in these areas from a final-use perspective.

A deeper understanding of local drivers within WA is achieved by further disaggregating the material footprints into systems of functional demand. This provides a crucial link between micro and macro systems, essential to informing a holistic understanding of societal needs, systems of provision and potential circular responses. Below (Figure 8), focuses on the domestic footprint (i.e. excluding exports) on a per capita basis. These results point to common areas of significance across the regions and systems, dominated by housing, food, and furnishings and equipment.

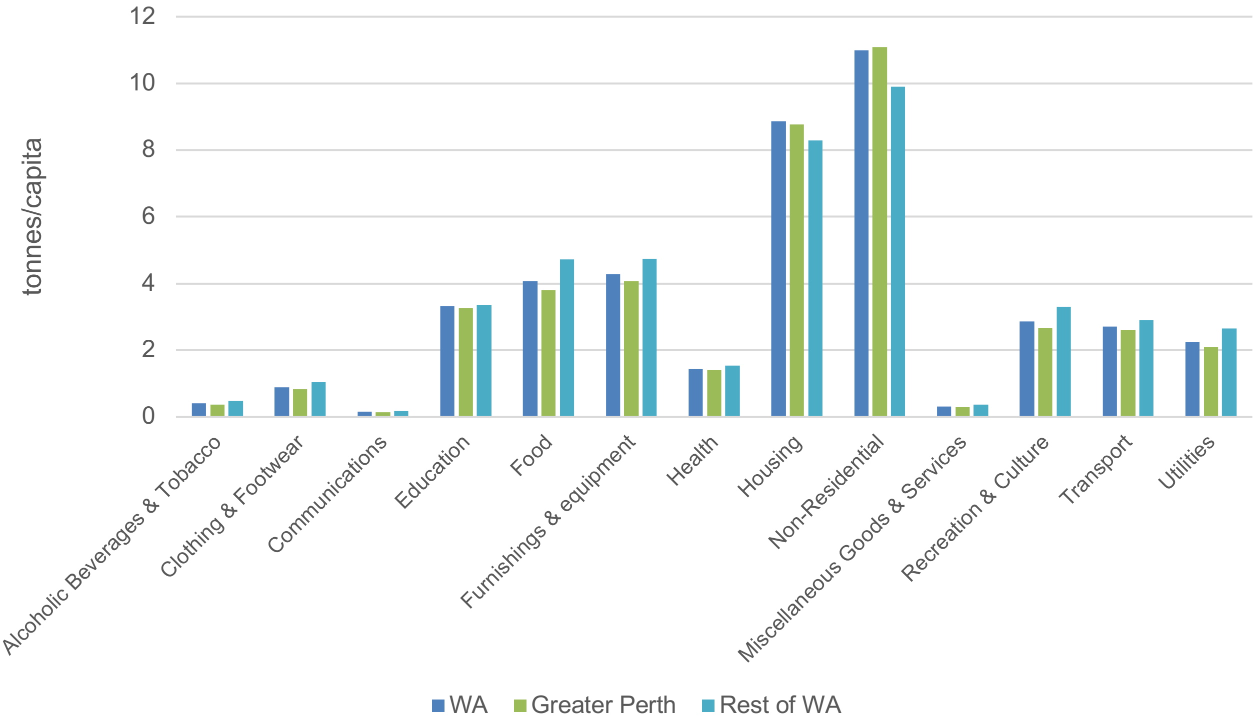

Figure 8. Material footprints by system of functional demand for WA and greater capital regions

Benchmarking footprints and drivers

In Figure 9, results are broken down into the types of drivers – whether it be households, government (national, state and local), public corporations, or private and public capital investment. The export footprint is excluded from these figures to focus on the material footprint of residential activities.

Key results show that WA's material footprints are 43 tonnes per capita. For material footprints, contributions are evenly distributed across household consumption and investments. This means that for circular economy considerations, roughly half of the material footprint is driven by consumption – which relates to the consumption of short-lived products with lifetimes of less than a year, whilst the other half of the material footprint is driven by investments in long-lived stocks (construction, machinery, etc.) with lifetimes of longer than a year. Western Australia has relatively lower per-capita material footprints than the main eastern states of NSW and VIC, with footprints similar to those of QLD and SA. On the investment side, this is mainly driven by lower levels of construction in the 2020-21 financial year. On the consumption side, there is lower housing and governmental expenses.

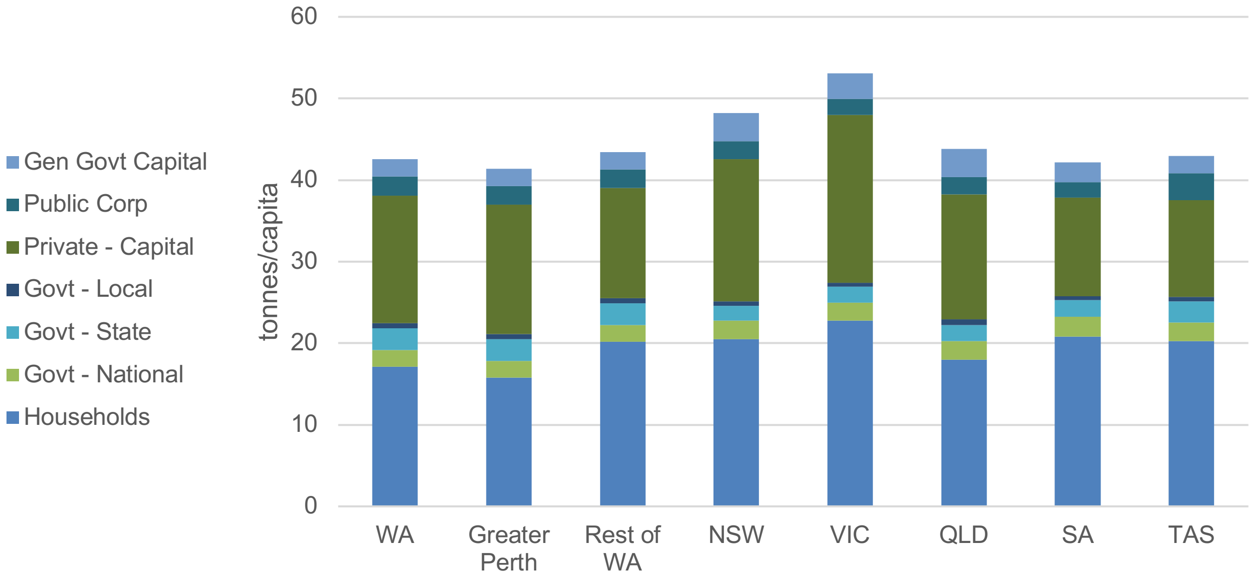

Figure 9. Comparison of material footprints by final demand category across regions

GHG emissions flows

Figure 10 illustrates WA's greenhouse gas emissions for 2020-21, segmented by source region, sector, industry, and destination. It provides a clear breakdown of emission flows across various emission scopes and highlights state, interstate and international components of WA's emission footprint. From a circular economy perspective, analysing these flows can inform targeted strategies to reduce emissions through resource circularity, improved efficiency, and rethinking production and consumption patterns.

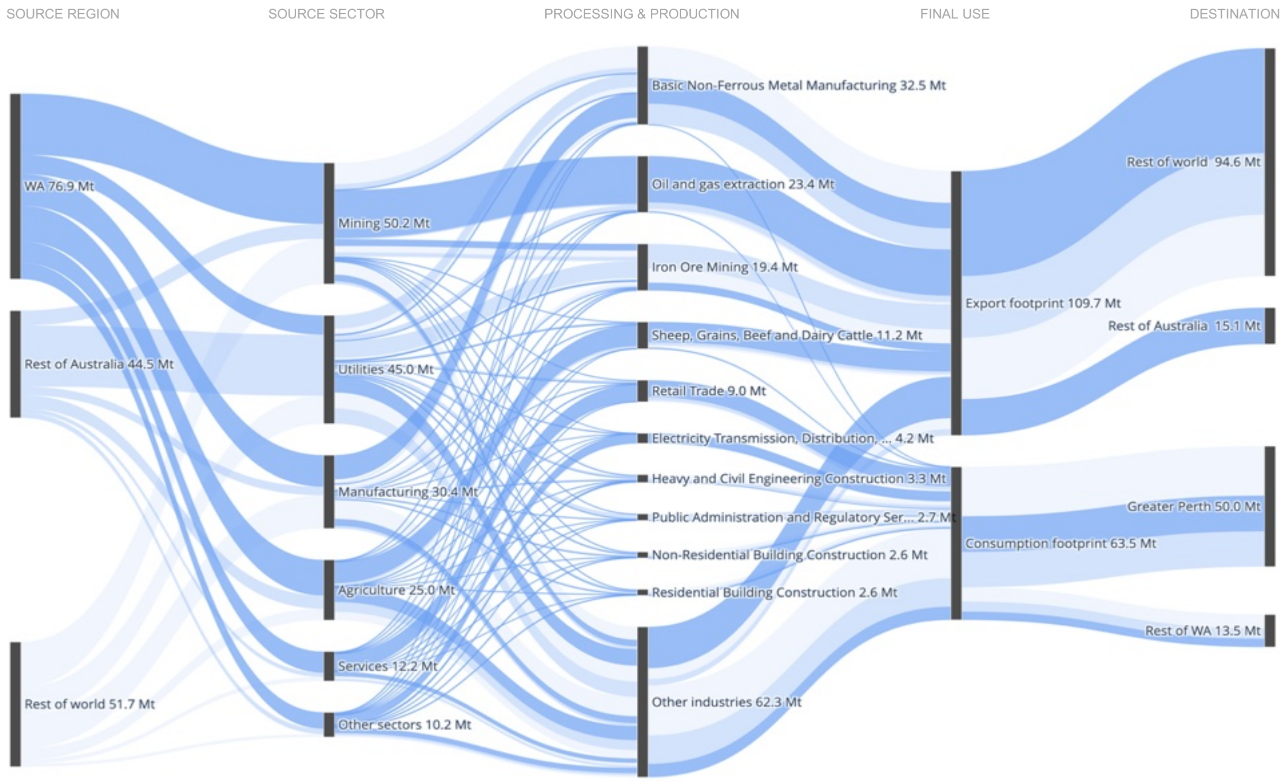

Figure 10. Sankey diagram showing emission flows of WA by source, sector, industry and destination, 2020-21

Emissions flows are categorised into three main sources: 1) direct emissions from sources within WA (76.9 Mt[10]), 2) indirect emissions from goods and services produced in other states but consumed in WA (Rest of Australia, 44.5 Mt), and 3) indirect emissions embodied in international imports (Rest of World, 51.7 Mt). Total emissions related to final consumption in WA amount to 63.5 Mt, with 79% (50 Mt) driven by demand in Greater Perth.

Several key observations can be made. Firstly, the composition of WA's consumption footprint indicates that a significant portion of its environmental impact is embedded in upstream value chains, highlighting where shifts in demand may be an effective mitigation strategy. Secondly, WA's export footprint (109.7 Mt) is substantially higher than its consumption footprint (63.5 Mt), indicating that WA is a net exporter of emissions. This is common in regions with resource-intensive industries, which are typically emission-intensive. Addressing these emissions requires transitioning towards cleaner production practices, alongside efforts to enhance the circularity of materials exported from the region.

The composition of emission sources – whether direct or indirect – is critical, as it shapes industries' decarbonisation strategies and their capacity to adopt circular approaches. On a sectoral basis, mining emerges as the largest contributor to emissions, followed by utilities. Within individual industries, non-ferrous metal manufacturing, oil and gas extraction, and iron ore mining account for the majority of emissions. For emissions linked to final demand in WA, the construction, service, and retail industries dominate.

Figure 11 shows the emission footprints broken down by system of functional demand, focusing on the domestic footprint (i.e. excluding exports) on a per capita basis. While housing and non-residential construction dominate in terms of raw material use (Figure 8), utilities and transport emerge as primary drivers of emissions across regions. Systems showing the strongest correlation between raw material demands and GHG emissions include food, clothing and footwear, as well as furnishings and equipment.

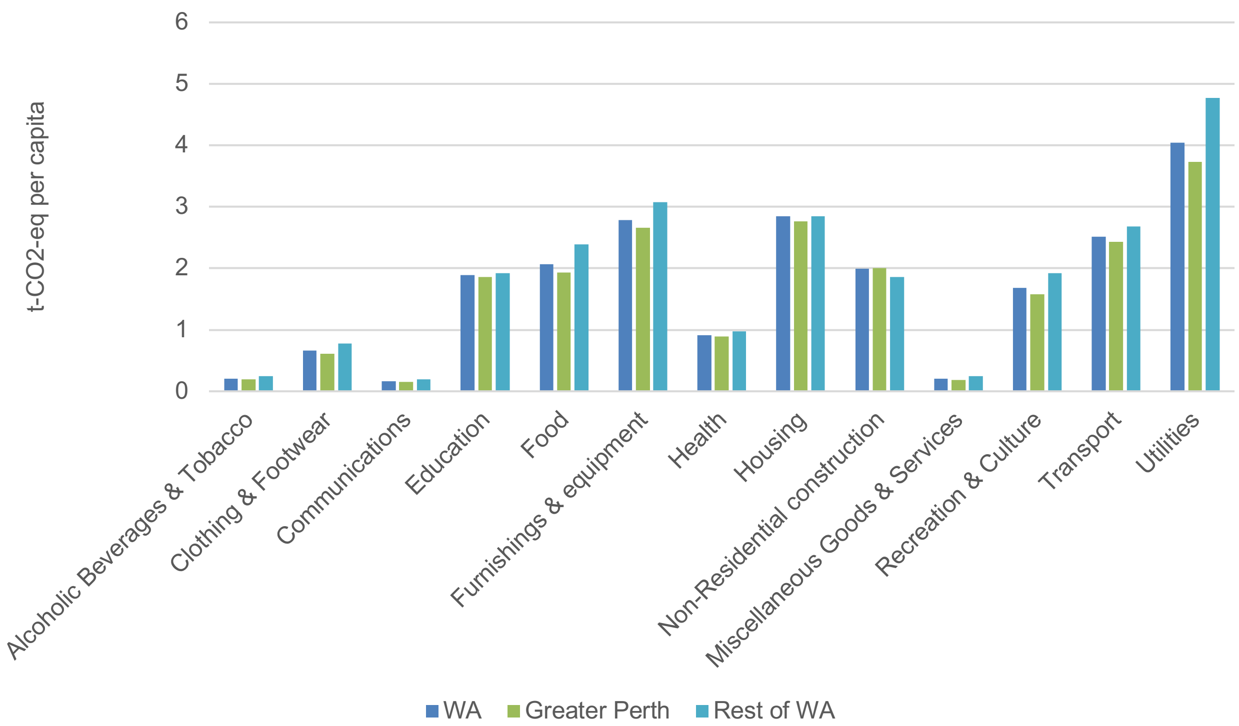

Figure 11. Emission footprints by system of functional demand for WA and greater capital regions

[10] Does not include negative emissions from land use and land use change.

Benchmarking footprints

Figure 12 shows emission footprints of households. Here, explicit identification of scope 1, 2, and 3 emissions for WA and Greater Perth is visible, highlighting variation in consumption patterns across regional and metro WA.

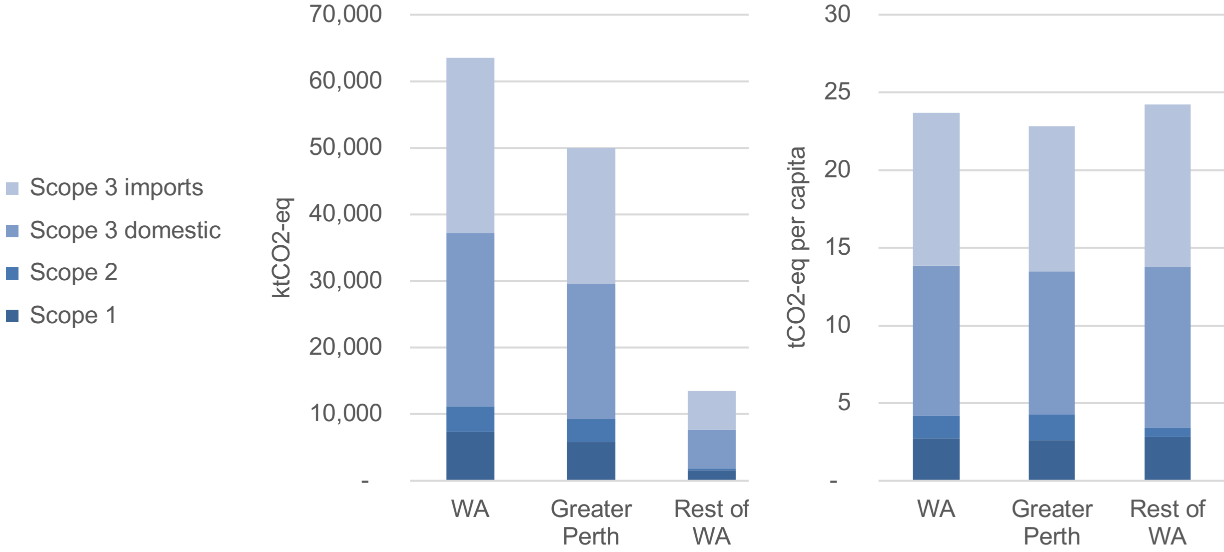

Figure 12. Emission footprints of households, including explicit identification of scope 1, 2 and 3 emissions for WA and Greater Perth. Absolute (left) and per capita (right)

In Figure 13, results are broken down into the types of drivers – whether it be households, government (national, state and local), public corporations, or private and public capital investment. Key results show that WA's GHG footprints are 22 tonnes per capita. Note that in this visualisation, direct (scope 1) emissions of households are excluded due to differences in data availability across states. Greenhouse gas emission footprints are mainly driven by household consumption and only to a lesser extent by investments.

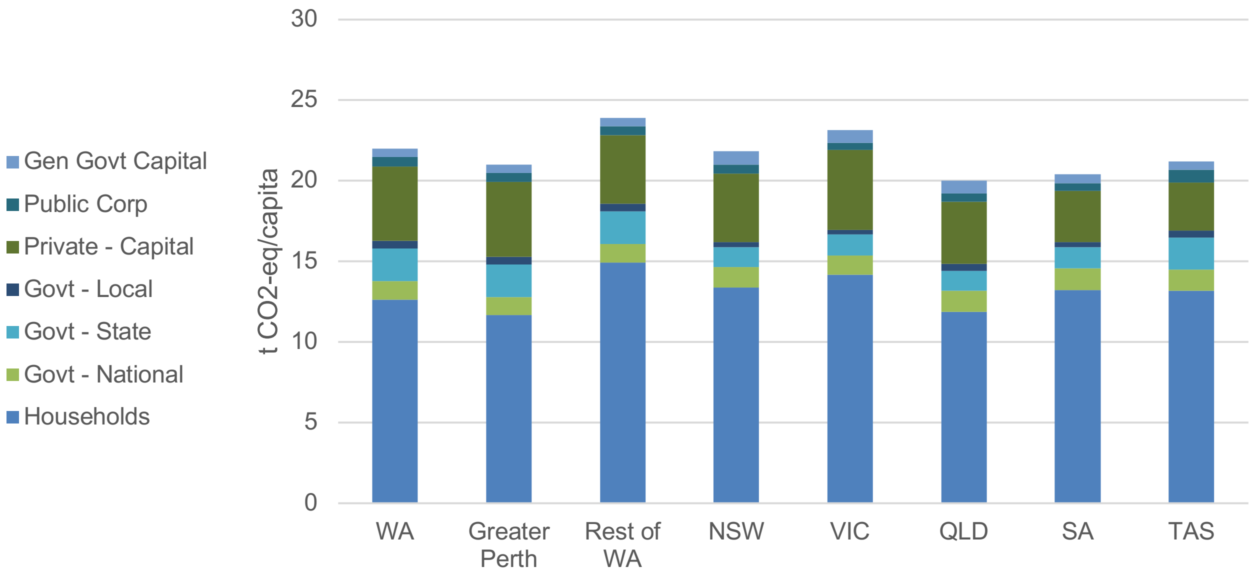

Figure 13. Comparison of GHG emission footprints by final demand category across regions

Material footprints include all materials used along supply chains. A certain proportion occurs within WA, other states, and the remainder in foreign countries. Including exports in material footprints results in the domination of state-specific resources (principally iron ore and fossil fuels) that are exported directly. The right side of Figure 14 shows emissions and material footprints by source, excluding exports. Here, it becomes clear that most of the WA material footprint does not occur within WA but in foreign countries and other states.

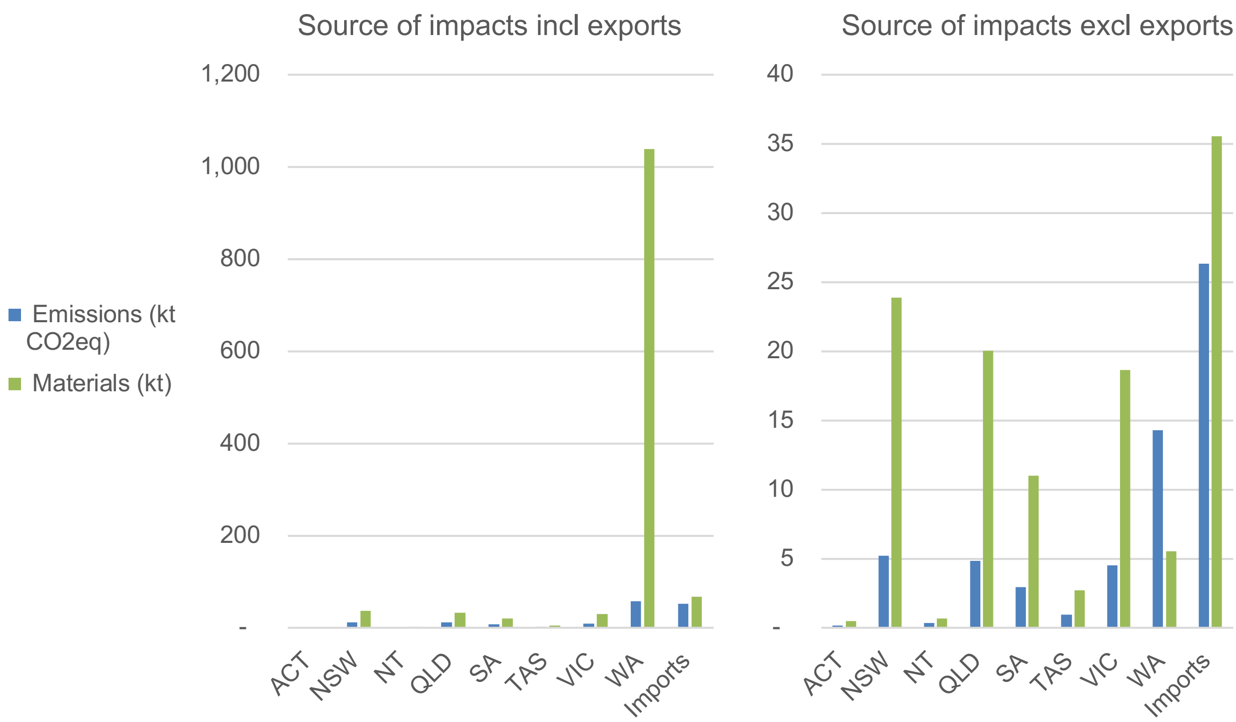

Figure 14. WA material and GHG emission footprints by regional source of extraction or emission

Waste outflows

The Sankey diagram below (Figure 15) illustrates solid waste outflows in WA for 2020-21. A novel aspect of our analysis is the connection between the main material groups identified through the MFA, the waste-producing region and sector, material composition, and the final waste treatment.

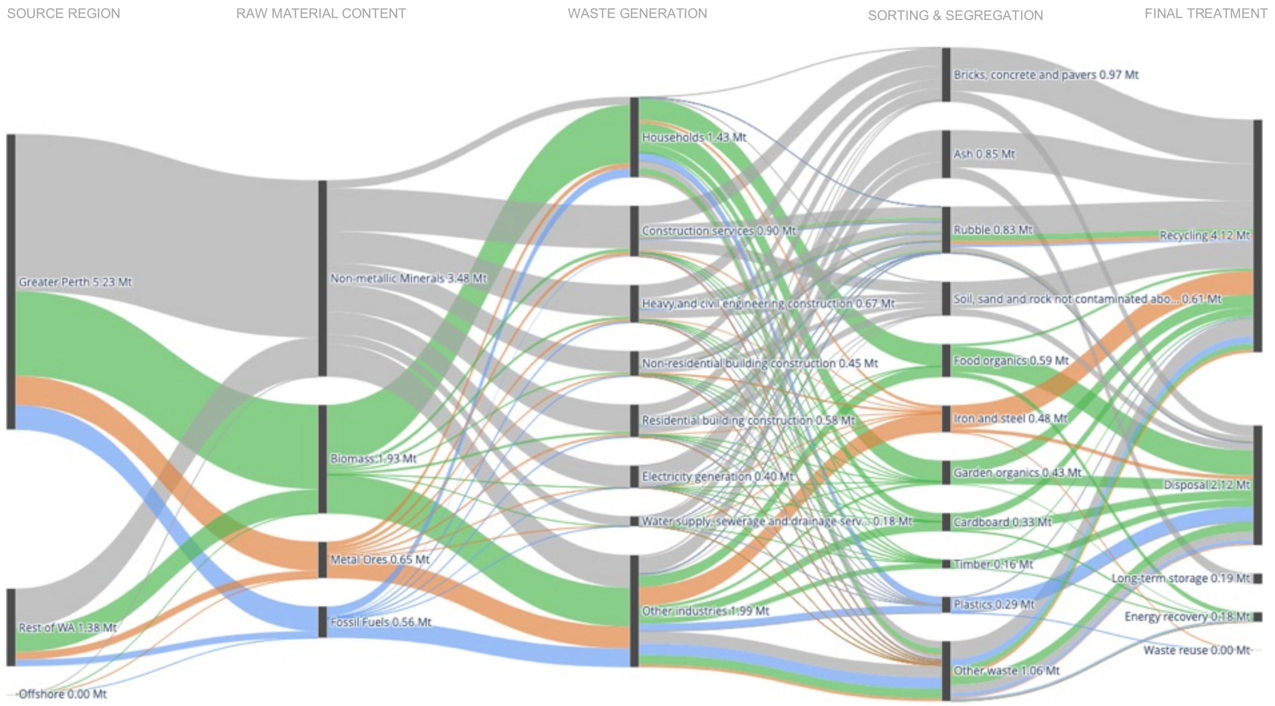

Figure 15. Sankey diagram of waste outflows in WA, 2020-21

It is important to note that the figures presented here may differ slightly from those reported by the Waste Authority WA for several reasons. First, we have harmonised waste data from various sources, including DWER, DCCEEW, and the ABS. Second, we allocated waste to specific waste-generating industries instead of using broad waste streams and categories. Third, we estimated the material composition of landfilled waste based on a variety of sources, including peer-reviewed literature, surveys and economic data. Finally, we accounted for differences in waste classifications between data sources and jurisdictions.

The view is primarily shaped by a significantly larger waste throughput from Greater Perth compared to the rest of WA, with values of 5.23 Mt versus 1.38 Mt. A significant proportion of the 3.48 Mt of non-metallic minerals from construction services, residential and non-residential building construction, and engineering projects is eventually processed as recycled C&D waste, which aligns with the data reported by national and state agencies. Nonetheless, much of the recovered C&D waste is likely recirculated within lower-quality applications (downcycling), which limits its effectiveness in displacing virgin materials in production processes[107], suggesting that circular strategies should be focused upstream in the construction lifecycle.

Waste generated by households and various industries in Greater Perth is largely composed of biomass. A significant portion of this biomass ends up in landfill, especially in the form of garden waste, food scraps, and paper and cardboard, suggesting a need for advancing organic waste recycling initiatives, such as waste-to-energy projects. Experiences at the local level are emerging, as in the case of a Bioenergy plant in Jandakot[108].

Fossil fuel-related waste (0.56 Mt), mainly from the industrial and household sectors in Greater Perth, are sent to landfill in the form of plastics or mixed waste, highlighting the difficulties in the plastic recycling value chain. Issues such as incorrect segregation, contamination, problematic blends, and losses in recycling facilities (including sorting and technological limitations) account for only 14% of national plastic waste being diverted from landfill[109]. These findings are far from new and are consistent with the urgency raised by the National Plastics Plan.

Finally, metal-containing waste outflows are consistent with global and national trends, which point to high rates of material recovery with minimal quality losses. Specifically, 0.48 Mt of iron and steel, mostly generated by 'other industries', are recycled.

3.1.2. Local government case studies

Cities offer a significant opportunity for addressing circularity, as the global population is rapidly urbanising. In 2021, 90% of Australian residents lived in cities, jumping from 58% in 1911, concentrating many of Australia's sustainability challenges in urban areas[110]. This urbanisation presents a chance to reduce environmental pressures by developing more sustainable urban spaces. However, the concept of circular cities leads to the need to observe and understand cities from a systems perspective with inputs, internal processes and outputs of resources and waste.

Understanding the urban metabolism

The concept of 'urban metabolism' is not new in the literature, and some case studies have been conducted in Perth[111]. Metabolism refers to how materials and energy flow through living systems, supporting life activities while converting resources into waste and heat. Urban metabolism expands this concept, focusing on how cities consume resources and produce waste (see Figure 16).

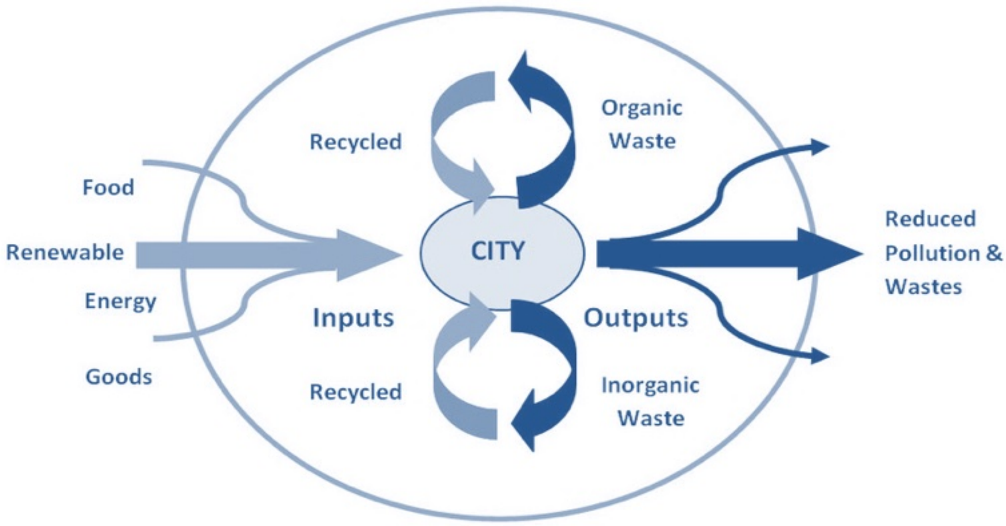

Figure 16. Circular urban metabolism in theory
Reproduced under a CC-BY 4.0 licence from Newman, Beatley and Boyer (2017)[3].

The theory of circular urban metabolism suggests that evidence-based policy and multi-level governance are essential for fostering sustainable urban infrastructure that promotes a circular metabolism in cities. This approach leads to lower emissions, reduced water and materials demand, cleaner energy, local food production, efficient waste recovery, and improved liveability. A theoretically circular metabolism uses resources efficiently, reducing the dependency on external sources while regenerating both the economy and the community, enhancing sustainability at multiple levels[3].

As demonstrated by numerous effective transitions to a circular economy, engaging across multiple jurisdictional levels—state, greater capital region, and municipal—is essential due to each level's distinct roles in facilitating and supporting circularity. The state-level offers overarching governance, including policy, regulation, and resource coordination. At the same time, the greater capital region serves as an economic and innovation hub, presenting high-impact opportunities in densely populated urban areas.

With their proximity to communities, municipalities can tailor initiatives to local needs and encourage grassroots innovation. This loosely coupled, multi-level approach facilitates strategic alignment while building multi-sector capacity for response measure design and effective circular actions, therefore maximising the overall impact of circular economy initiatives across diverse regions.

The results presented in this section make visible the urban metabolism of two selected case studies. At this level, the quantification and visualisation of upstream material requirements, local drivers, material outflows, and associated environmental pressures are particularly useful. From here, local governments and local communities can gain a deeper understanding of their city's metabolism, moving beyond the narrow focus of municipal waste and local environmental management.

Case study regions

Canning was selected as the metropolitan case study based on data availability and the City’s circular economy aspirations. The city is in Perth's south-eastern suburbs, about 10 kilometres from the Perth CBD. According to the ABS data, Canning has an Estimated Resident Population (ERP) of 103,691 distributed over 64,95 square km, reaching a population density of 1,597 persons per square km[112]. Manufacturing excels as the largest industry in the city based on employment figures, which provides opportunities for circular interventions. The estimated Gross Regional Product of Canning is $12.68 billion, accounting for 3.02% of WA’s Gross State Product (GSP)[113]. The city provides 78,176 local jobs across 10,711 businesses[113].

Bunbury was selected as the regional case study based on data availability and the city’s commitment to advancing circularity. The latest census revealed that Bunbury has a population of about 33,000 people[114]. Located 180 km south of Perth, Bunbury is an important economic hub of the South West region, positioned as the State’s second major city. Bunbury’s Gross Regional Product is $5.37 billion and supports 26,364 jobs. The construction sector is the most significant contributor to the region's economic output, accounting for $2.0 billion, which constitutes 17.04% of the overall output. The Health Care and Social Assistance sector, employing 5,509 individuals or 20.9% of total employment, is the region's largest employer[115]

Material flows

The Sankey diagram below (Figure 17) breaks down the flow of raw materials from global and domestic extraction to final demand within the cities of Bunbury and Canning for 2020-21. Here, consumption occurring within the cities is broken down by system of functional demand, linking State, national and global impacts to local drivers and societal needs.

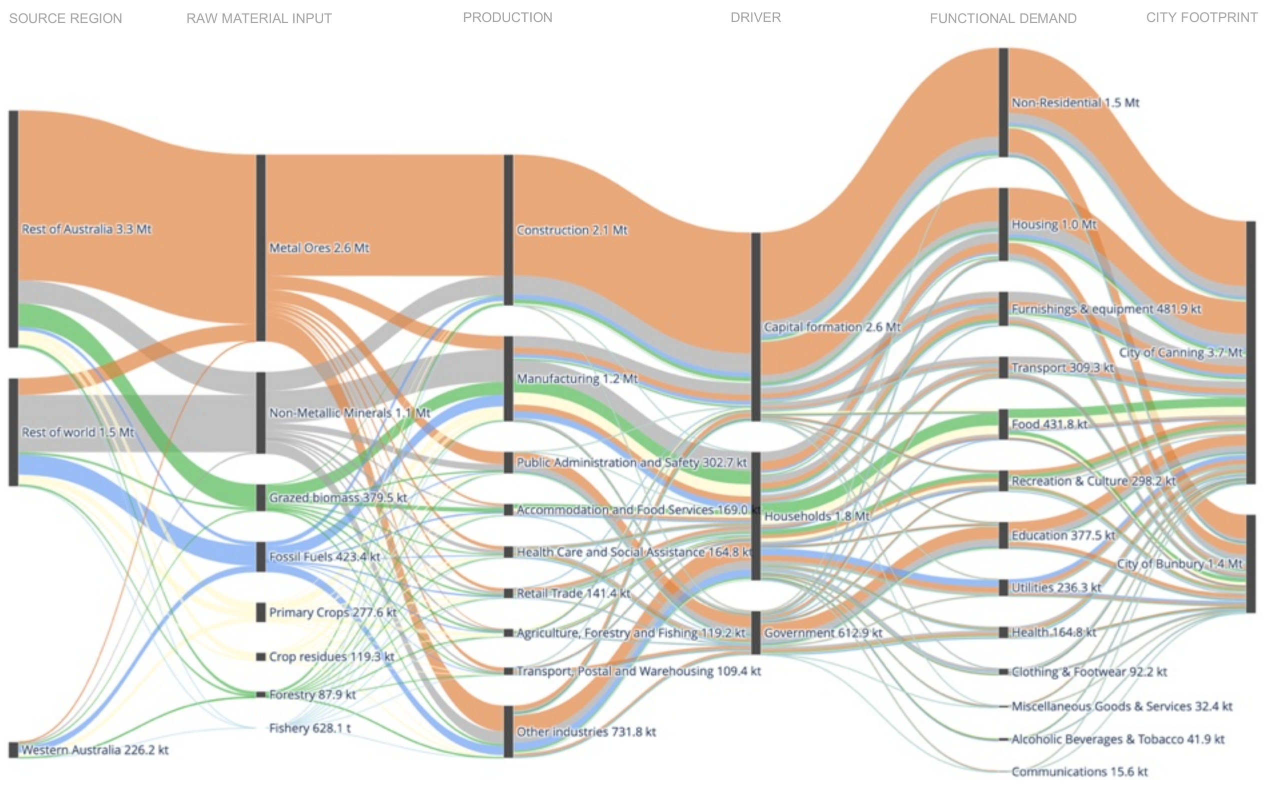

Figure 17. Sankey diagram of material flows in the cities of Bunbury and Canning regions, 2020-21

The prevalence of external supply is a distinctive feature of the cities' material inflows. Interstate supply dominates (3.3 Mt), followed by international sources (1.5 Mt), with only 4.7% (0.22 Mt) of total raw material inputs originating from WA. Imports of metal ores are particularly relevant for both cities, while non-metallic minerals are more relevant in Canning. Grazed biomass and primary crops stand out as important for both cities, with the majority of food-related supply originating from interstate sources. Notably, most of Canning and Bunbury's demand for fossil fuels is met through international imports, underscoring the State's reliance on imported secondary fuels.

A considerable share of extracted resources is destined for manufacturing activities distributed across a cluster of industries, with a noticeable participation of construction sectors. The net accumulation of long-lived capital stocks (capital formation) within these sectors is the most relevant final destination of material flows, followed by household and government consumption of short-lived products. From a functional demand perspective, non-residential buildings and housing dominates, followed by furnishing and equipment, food, and transport.

Canning's material footprint (3.7 Mt) is approximately twice that of Bunbury's (1.4 Mt). This is consistent with both city's resident population and economic output described above, suggesting a coupling of resource consumption and economic output. However, additional investigation is required to validate these assumptions.

Benchmarking footprints

Error! Reference source not found. shows emission footprints of households at the city level. Here, an explicit identification of scope 1, 2, and 3 emissions for Canning and Bunbury is shown, highlighting variation in consumption patterns across local government areas.

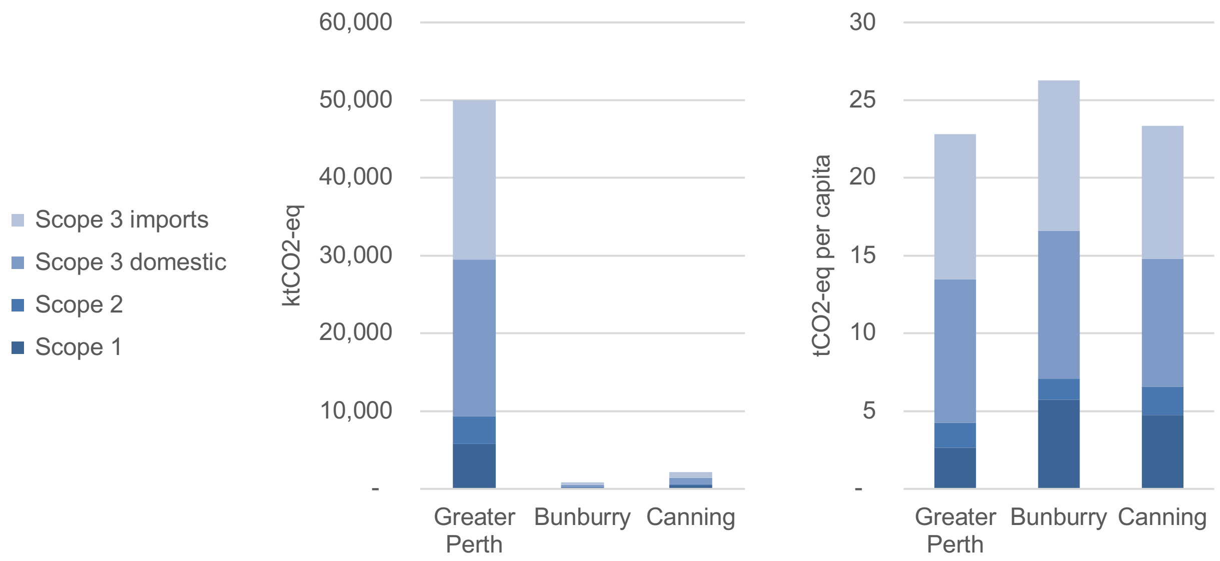

Figure 18. Emission footprints of households, including explicitly identifying scope 1, 2, and 3 emissions for case study regions. Absolute (left) and per capita (right)

Figure 19 shows two key indicators—material footprint and emission footprint—for Bunbury, Canning, and Greater Perth on a per capita basis. As per our analysis of WA and Greater Perth (Section 3.2.1), each footprint is broken down by final demand categories—households, different levels of government (local, state, national), public corporations, and private and public capital investment. Across all regions, the largest contributor to the material footprint is the household sector, followed by private and public investments.

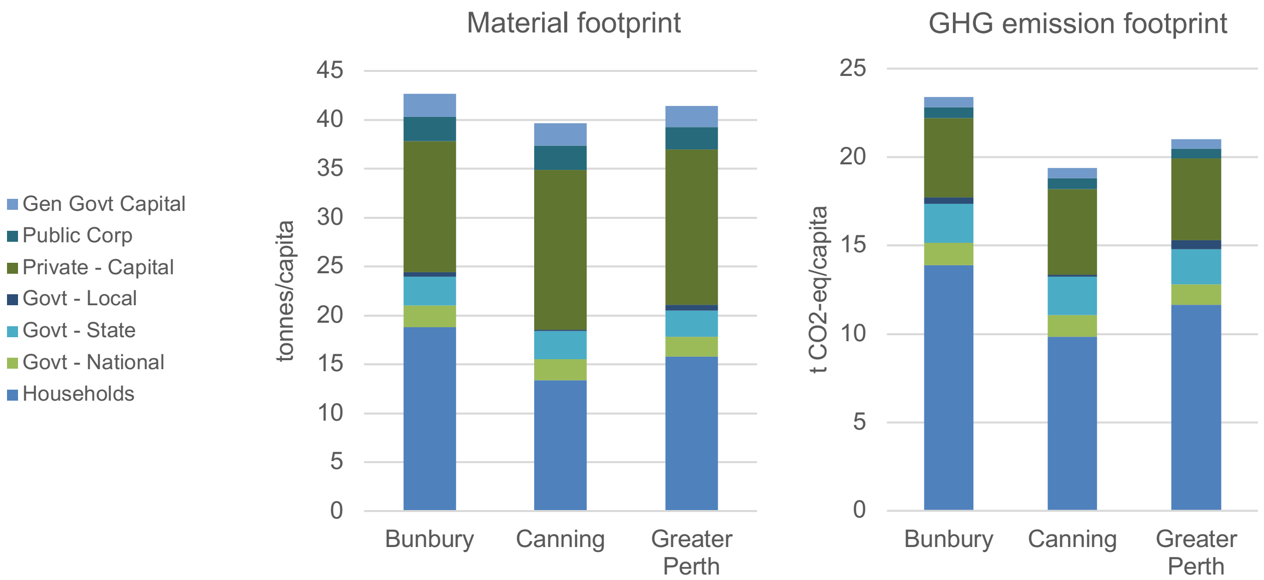

Figure 19. Material and GHG emission footprints by final demand category for case study regions, per capita[11]

[11] As per interstate figures, the GHG emission footprints focus only on industrial emissions and exclude scope 1.

Municipal waste outflows

Figure 20 represents MSW outflows in Canning and Bunbury for 2020-21. A novel aspect of our approach is the ability to link MFA material groups, the type of municipal service, material composition, and the final treatment of waste. This process is the result of the reconciliation of waste data from multiple sources (see Appendix B for further details).

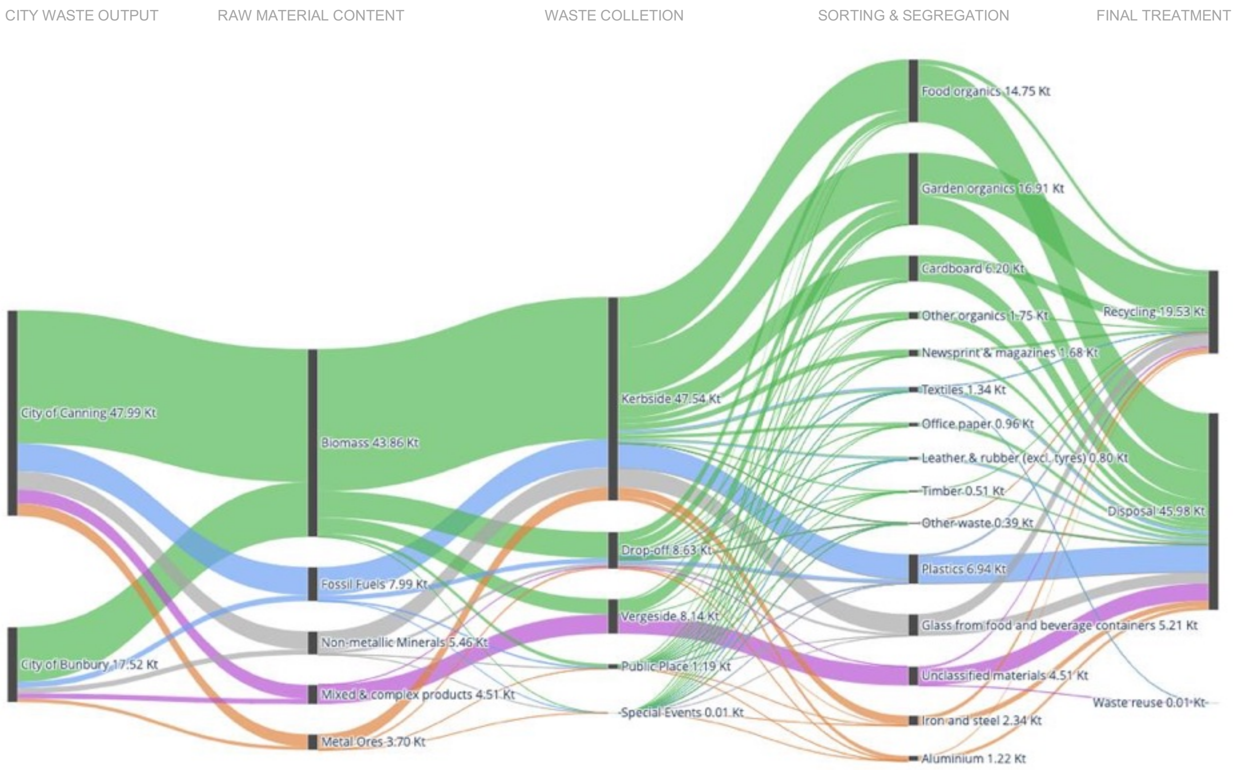

Figure 20. Municipal waste outflows in the cities of Bunbury and Canning regions, 2020-21

The Sankey shows that the waste throughput in Canning is nearly three times that of Bunbury (47.99 Kt versus 17.52 Kt). Overall, recycling rates from both cities at 29.8% (19.53 Kt out of 65.52 Kt of waste generated) remain low with the national average at 42% informed in the National Waste Report[38].

Biomass-related waste (43.86 Kt), mainly as food organics and paper and cardboard, largely ends up in landfill. Due to its great energy potential, this represents an opportunity for LGAs to see this waste as a resource. On the other hand, garden organics go primarily for recycling, possibly as municipal compost.

Similar to the state-wide analysis, plastics are predominantly disposed of in landfill. This highlights the complexities of the plastic recycling value chain and underscores the need for further developments at the local level to reduce losses and inefficiencies while increasing community awareness and capacity.

It is surprising that in contrast to metals found in C&D and C&I waste, recovery rates for iron and aluminium are relatively low, particularly in the forms of aluminium cans and metal-containing food packages. Likewise, verge-side collection yields complex waste outflows (i.e. heavy and hard waste) that end up disposed of in landfill. This stream is inherently complex to manage due to its mixed composition and difficult component recovery. Despite glass being associated with high recyclability with minor quality loss, there is a low performance of glass recycling as 5.21 Kt were disposed of in landfill, which calls for reforms to increase its recovery.

Although Figure 20 shows a very low value of reuse, this number only reflects waste reuse. We define "reuse" as the process of recirculating resources and second-hand products that remain in-use within social stocks. However, this can include recovered products from the waste management system (WMS) that retain some degree of functionality and, therefore, are diverted prior to treatment, as seen above. While there is a lack of product traceability within the use phase, we speculate product reuse to be much higher than waste reuse, as the second-hand market in WA is increasingly important but somewhat obscured by the lack of information, as thoroughly addressed in our recommendations (see Section 4).

Based on our analysis, we can draw a few observations. First, local initiatives for organic waste recovery, such as waste-to-energy projects and composting at both industrial and household levels, are still in their early stages. Additionally, the limitations of plastic recycling within municipal waste management have become evident. Low recycling rates for plastics stem from problematic plastic compositions, improper segregation, contamination, sorting difficulties, and constraints related to technology and capacity.

Furthermore, the significant amount of mixed and complex products sent to landfill indicates that current product design and waste management processes do not facilitate the easy recovery of materials and components. The recovery rates for aluminium, iron, steel, and glass are lower than anticipated. Therefore, it is essential to analyse their recycling value chains in greater detail to formulate effective responses.

3.1.3. Future work

Significant progress was achieved in stage 1 of the project, with the completion of a fully functioning state-based coupled input-output model in which to investigate the material requirements and emission footprints at the state and local level with the ability to disaggregate by region of production and to integrate regional environmental accounts. The approach to nesting the Australian IO model in a global MRIO model is a multi-step process. This approach ensures that regional insights are consistent with state and national statistics, a key component in building cross-scale and multi-sector capacity for evidence-based decision-making. For details, see Methodology (Appendix B).

The model used here itself could be further extended by a range of aspects. Further work would add to the utility of the model by further incorporating monetary and physical trade flows by industrial sector between regions, by further incorporating the bottom-up physical data into the understanding of the built stock, by endogenising capital dynamics to understand the lifetimes of productive capacity in the economy; and by incorporating scenario analysis into the model.

The year of analysis was based on the most recent available national and state data, which was the 2020-21 financial year, a year affected by COVID lockdowns. Future work should update the model to more recent years and incorporate time-series analysis. A considerable amount of data interpolation is needed for such work, especially in relation to detailed consumption, investment and inter-industry flows. However, by using data integration techniques, it would be possible to understand the progress of the regions towards or away from emission and material goals.

The co-development of counterfactual “what-if” scenarios–together with industry, government and communities–will help identify effective circular strategies considering their local context and potential cascading effects. Analysis of commodities on a mass, value-added, and environmental impact basis would enable greater insights into their circular potential.

A core objective of this project is to provide comprehensive headline indicators for monitoring the circular economy in WA. While we present several leading indicators within stage 1, indicators, such as the Circular Rate, will require additional research to ensure rigorous and consentient results. Essential to this work is the integration of interstate trade flows and interregional freight data, as well as better estimates of secondary materials embedded in domestic production and trade. Furthermore, additional work is required to comprehensibly compile energy accounts in accordance with the System of Environmental-Economic Accounting (SEEA) and the EW-MFA framework. Additional biophysical extensions, such as land, water, and energy, can also be developed, providing further context across the assessment framework.

Future work will focus on expanding the involvement of additional local governments across WA to enhance the scope and effectiveness of circular economy initiatives. Including a broader range of local governments is critical for fostering diverse, community-specific approaches that address regional challenges and opportunities. This expansion will enable the development of tailored solutions that reflect the varying socioeconomic conditions, infrastructure capacities, and resource needs across different areas. Moreover, it can facilitate greater collaboration and knowledge-sharing between local governments and communities, strengthening the overall network of circular practices.

3.2. Built stocks

The built environment represents by far the most significant proportion of in-use stocks globally[116]. WA is no exception. Built stocks can be broadly categorised into buildings and infrastructure assets, with buildings representing the largest component by mass and value.

To understand how to better manage built stocks and all materials within, it is important to quantify both the in-use built stock and the net addition to the built stock. The in-use built stock is the amount of materials in existing buildings and infrastructure assets. The net addition to the built stock for a given year is the number of materials added in the form of new buildings and infrastructure assets, minus those removed through demolition or deconstruction.

Either a bottom-up or a top-down approach can be used to quantify the in-use built stock and net addition to the built stock[117]. A bottom-up approach is more data-intensive but is usually preferred as it provides more detailed information about materials, parent buildings, and urban mining and reuse opportunities.

Here, we focus on building stocks, excluding infrastructure assets, and rely on a bottom-up approach for modelling. We use a set of different building archetypes that represent typical construction typologies in Greater Perth and the rest of WA. Given the scoping nature of the study and the lack of spatialised data building-by-building, we use average material intensities for a total of five building archetypes. Material intensities are derived from using averages of 13,760 individual buildings in the City of Melbourne, Australia[118]. These material intensities are multiplied by the gross floor areas of buildings derived from building attribute data to obtain the material stock. For the net addition to stock, we apply the same multipliers to the gross floor area of new buildings in 2021 received from building approval data[119] and remove the materials resulting from demolition for the same year[120]. The results are presented below.

3.2.1. In-use building stock

Figure 21 enables us to identify the hotspots in WA's in-use building stock. Four major observations can be made, one for each level of the Sankey diagram. Firstly, from a material perspective, concrete represents 58.5% of the in-use stock by mass, followed by ceramics (24.8%), timber (9.7%), plasterboard (3.9%), and steel (2.5%). From a material reuse perspective, this already demonstrates the need to develop deployable technologies and strategies to reuse such materials. From an environmental standpoint, the colossal use of concrete over steel is concerning because, while steel-based materials are more easily reused or recycled, this is certainly not true for concrete or plasterboard.

Secondly, houses alone represent 58.9% of the total in-use mass, ahead of apartment units (17%) and semi-detached houses (4.1%). This might pose challenges in terms of material harvesting since most of the stock is dispersed across multiple units and owners. Additionally, detached homes are demolished on average 95% more frequently than units or apartment buildings in Australia[121], resulting in more related emissions and waste production[122]. Compulsory regulation must be enforced to ensure a robust approach to managing materials in privately owned residential buildings[123]. Thirdly, a logical repercussion of this observation is that residential buildings represent more than 80% of the in-use building stock alone. Finally, most of the stock is concentrated in Greater Perth, where materials weigh 2.3 times more than all buildings across WA. This provides opportunities for localised material harvesting as most of the stock is concentrated in the urban area instead of being spread across an extensive area.

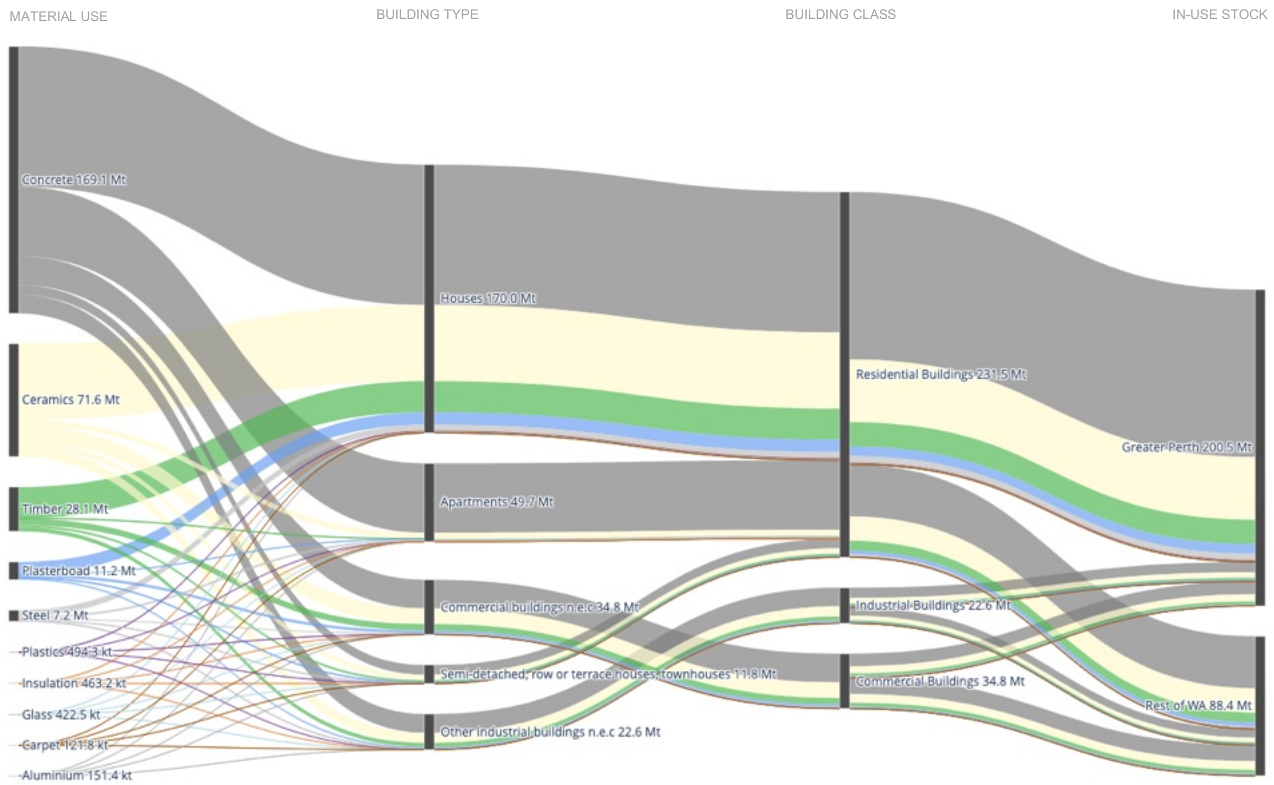

Figure 21. In-use building stock by material, building class and region

3.2.2. Net addition to building stock

While understanding the existing building stock is critical, it is also important to understand its growth or degrowth trajectory, captured through the net addition to stock. Figure 22 shows the inflows of materials for new building construction flowing from the left-hand side and outflows of material waste from Greater Perth and the rest of WA on the right. This results in a net addition to stock of 8.4 Mt for 2020-21. Assuming an average density of 2,000 kg/m^3, this amount of material is enough to cover the City of Perth (19.4 km2) with 21.4 cm of materials every year. That is more than a meter of materials after five years.

Concrete is the most significant material category in terms of inflows (53.8%), followed by ceramics (27.5%) and timber (11.1%). However, the net addition to stock is much more balanced in terms of building types than the existing stock, with residential buildings representing 45.6%, followed by commercial buildings (41.6%) and industrial buildings (12.8%). Greater Perth represents the most inflows (74.5%), similar to the in-use stock. Outflows in terms of waste represent 2.0 Mt per year[12], mostly in the form of sand, masonry, concrete and mixed construction and demolition waste

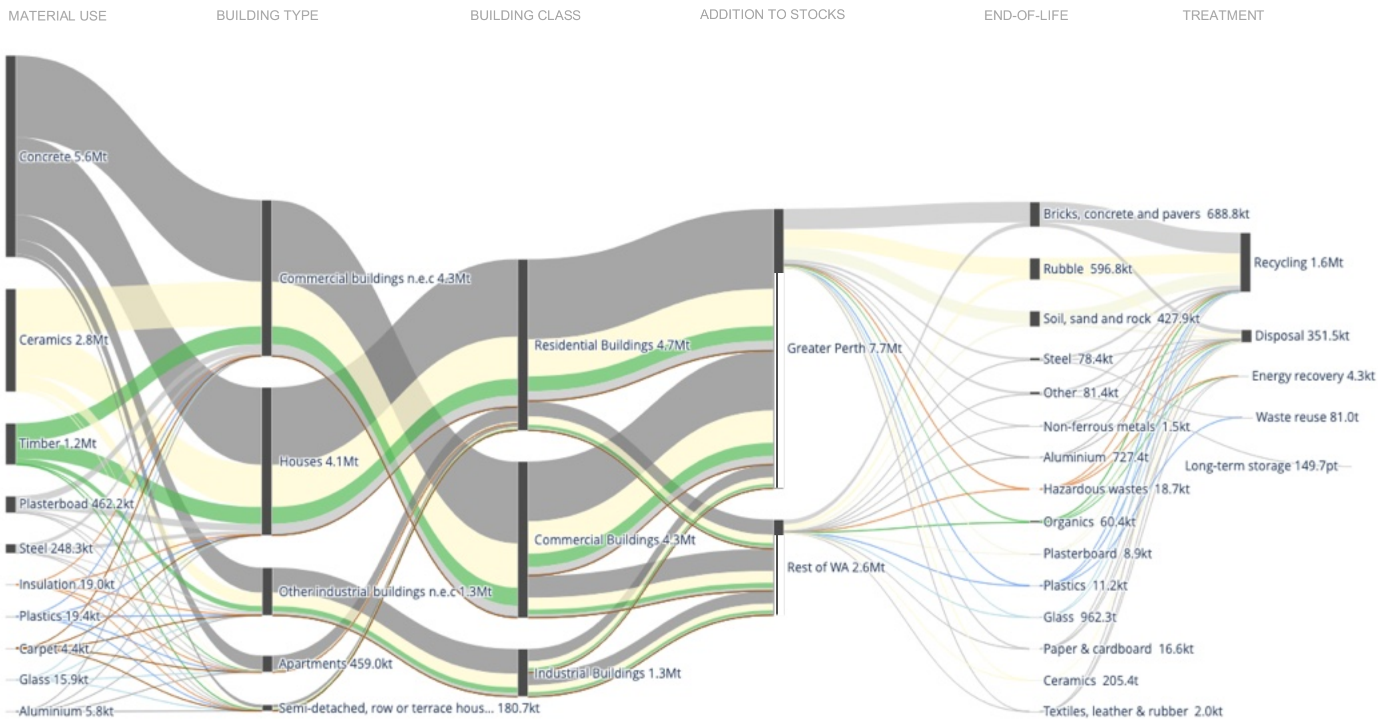

Figure 22. Material inflows, net addition to stock (dashed node) and waste outflows by material, building class, and region, 2020-21*.*

3.2.3. Future work

This initial estimation of the in-use stock and net addition to stock of buildings in WA provides insights into the most significant material flows, the order of magnitude of the stock (hundreds of Mt), the order of magnitude of the net addition to stock (tens of Mt), and the most significant building typologies to focus on. However, as in any research, there is considerable scope for further improvement. Future work can be subdivided into three main aspects. Firstly, a higher archetypal and material resolution specific to WA needs to be developed. This will further disaggregate the results and enable a more nuanced approach to material characterisation and evaluation of their reusability.

[12] Residential and non-residential building construction waste only.

Secondly, spatialising the stock using geographic information systems would provide more insights to better understand where the materials are located and identify opportunities for potential material harvesting and the material intensities of certain growth areas. This spatialised approach requires spatial data in terms of building shapes, construction year and use type. With these parameters, the building stock and net addition to stock can be quantified using automated approaches[124].

Thirdly, infrastructure assets, in addition to buildings, also need to be considered. Given that the 2024-25 to 2027-2028 Asset Investment Program included 42.4 billion for infrastructure, quantifying this stock is of particular importance[125]. This will enable capturing assets that are most often publicly owned and deployed at scale, which, therefore, offer significant opportunities for improvement, either in terms of inflows of material (material efficiency) or of outflows (material reuse and recycling). This can be done using the same archetypal approach and nested computation model used for buildings.

4. Recommendations

This report mainstreams actionable recommendations to drive the circular economy transition in WA. We identify tangible near-term actions across eight systemic themes: policies and governance, economic instruments, supply chain diversification, net zero alignment, end-of-life management, built environment, enabling tools and technologies, and cross-sectoral collaboration (Figure 23). By targeting these cross-cutting themes, WA can seize key opportunities to advance circularity as a cornerstone for reducing emissions, fostering economic diversification, and promoting job creation. Additionally, we emphasise the importance of data-driven tools to support circular outcomes and monitor impact across sectors, align investment with circular goals, and strengthen policy with evidence-based insights.

Figure 23. Summary of recommendations – graphical representation

4.1. Policies and governance

Policies and regulatory frameworks are considered essential foundations for implementing circular economy initiatives. Western Australia has made significant modifications to its waste strategy to tackle the challenges and seize the opportunities presented by a circular economy.

To build upon these strong governance signals, we recommend complementing this framework with three actionable and scalable policy mechanisms: a consistent, economy-wide lifecycle framework, targets focusing on resource productivity, and an annual report to monitor progress towards a circular economy.

4.1.1. Adopt a consistent economy-wide lifecycle framework

The Waste Avoidance and Resource Recovery Strategy 2030[15] and Action Plan[69] set the direction to becoming a low-waste and circular state. It provides a proper environment for developing circular economy-focused actions by articulating a clear vision for waste management. Although there are explicit references to the circular economy, the strategy focuses on actions downstream in the value chain, prioritising end-of-life management interventions and mainly accounting for recycling and landfill diversion rates.

Consistent with insights from the Circular Economy Advisory Committee[65], we advocate for a lifecycle-focused policy framework that considers environmental impacts, lifecycle costs, and trade-offs beyond localised end-of-life management, including the extraction of raw materials, sourcing, product manufacturing, usage and disposal.

Based on lifecycle principles, WATCH provides a consistent and economy-wide framework that can be used as a basis for such policy development. In the first instance, we recommend: 1) the adoption of an economy-wide lifecycle monitoring framework (see Section 4.7.2), and 2) the development of policy guidelines as a basis for benchmarking and evaluating further policy development. These policy guidelines should aid in the transition from a waste management to a resource-oriented perspective and be used to measure the effectiveness of sector and industry-specific policy and reporting framework development.

4.1.2. Set government- and economy-wide targets on resource productivity

Deploying policy mechanisms to improve material productivity could yield significant benefits as the focus shifts away from waste activities to tackling the whole economy. Resource productivity reflects how efficiently an economy transforms resources into value while minimising waste. Higher resource productivity means achieving enhanced economic output with less resource input. It is a critical indicator for assessing the transition to a circular economy, as it encourages practices that optimise resource use, reduce environmental impact, and enhance the long-term viability of ecosystems and economies.

As developed nations and cities set circular economy targets, we urge decision-makers in WA to establish evidence-based and ambitious resource productivity and intensity aspirations. In this context, future WATCH research can help in evaluating the feasibility of these targets by 1) providing a consistent circular assessment framework, 2) developing comprehensive "what if" type scenario analysis (see Section 4.7.1), and 3) enabling sector-based risk and opportunity analysis to better focus on resource-intensive sectors to align expectations[126].

4.1.3. Publish an annual progress report on the state of circularity

Reporting mechanisms are critical to building capacity, transparency, and accountability in the transition to a circular economy[23]. Nonetheless, WA does not report circular economy progress through performance indicators nor benchmark outcomes against an agreed-upon framework beyond the waste-oriented metrics found in the Annual Waste and Recycling Data Report.

To advance WA's leadership towards a circular economy, it is recommended that the State government commission an annual report on the state of the circularity, integrating scientific, traditional, and local knowledge to deliver a holistic assessment of the State's progress. The purpose of the annual report is to help shape evidence-based strategy, policy, and action, support positive demand and supply-side change, and assess WA's progress towards a circular economy.

This initiative should focus on supporting a multi-sector collaboration driven by local researchers and decision-makers and leverage the capabilities of science-based tools to monitor and report progress over time. The report should take a systematic approach at multiple scales, including local, regional, and industry-specific case studies, spotlighting key opportunities in focus sectors to illustrate practical applications and scalable solutions. By building capacity among government, industry, and communities, this initiative has the potential to empower stakeholders to implement effective circular strategies, positioning WA as a global model for circular economy innovation.

The WATCH framework, as presented throughout this work, provides the scientific and technical basis for such an annual report. This framework is expected to be further developed to enable statewide reporting on an annual basis, capturing environmental interactions, responses and actions, and socioeconomic opportunities for a sustainable transition.

4.2. Economic instruments

The government plays a crucial role in establishing economic incentives to promote the adoption of circular practices. The circular economy has the potential to deliver significant financial benefits through more efficient resource use. While funding for innovations and capacity building in the circular economy is essential, it may not be enough to fully realise its potential. In the long-term, investments should be encouraged through fiscal reforms that enhance the competitiveness of secondary raw materials.

Common fiscal mechanisms, such as tax deductions, royalties on resource extraction, and subsidies, have proved to be solutions by creating a more level playing field.

Such instruments should be adjusted and deployed on the basis of comprehensive modelling and analysis (see Section 4.7.1). More directly, a feasible action is the utilisation of government spending power through an integrated circular procurement framework to stimulate the market for secondary materials.

4.2.1. Implement a government-wide circular procurement framework

The government of WA can be a key player in the market by leveraging its purchasing power. Procurement activities by government-dependent institutions can boost the demand for products with recycled content. Specifications with a clause for recycled content (green procurement) can drive new markets and indirectly promote innovation. This WA circular procurement framework should be consistent with the 2024 Sustainable Procurement Guide by DCCEEW (see Section 1), which outlines how to integrate environmental sustainability into procurement in Commonwealth-dependant institutions.

Building on DCCEEW advice, we advocate for a circular procurement framework based on lifecycle approaches (see Section 4.1.1), to provide insight into material requirements and environmental impacts per dollar of expenditure, broken down by different purchasing categories. Financial management and accounting systems utilised by State agencies (e.g., Treasury and Department of Finance) and local governments, can leverage data feeds from WATCH to enable such circular procurement capabilities. In the first instance, screening and benchmarking functionality would help to identify where to focus procurement decisions to mitigate environmental impacts (e.g., within specific material supply chains). In the long-term, product disclosure statements can be incorporated to provide additional context on product and supplier-level contributions to circularity driven by public procurement.

4.3. Net zero emission alignment

As an emission-intensive economy with access to abundant natural and renewable resources, WA is uniquely positioned to reduce emissions across all its production and consumption activities. This includes addressing upstream emissions by shifting demand towards less emission-intensive imports; domestic emissions through advancements in production technologies, employing innovative product design, and enhancing industrial symbiosis and material recovery; and downstream emissions by fostering robust trade partnerships focused on critical minerals and low-emission goods. While ambitious national and state emission targets are vital for progressing and tracking goals related to territorial emissions, adopting circular economy strategies can unlock additional emission reduction opportunities, bolstering interim aspirations, and generating long-term co-benefits across WA's entire value chain.

4.3.1. Identify tangible opportunities for emissions reduction from circular strategies

A comprehensive circular economy strategy can significantly reduce carbon emissions. As reported by the EMF, emerging technologies could reduce carbon emissions by up to 55%. Changing production and consumption and implementing a circular economy could achieve the remaining 45%[75]. PwC reported that a circular economy could save Australia 165 million tonnes of CO2 annually by 2040[127]. Higher material efficiencies, extended product lifetimes and lower material demand can lead to a cascade of energy reductions across supply chains.

However, we recognised the lack of research on concrete pathways for emissions reduction from implementing circular economy approaches in Australia. This evidence can support decision-making and help ensure that circular and decarbonisation strategies are aligned, considering potential trade-offs and rebound effects. Future research and scenario analysis (see Section 4.7.1) should estimate these opportunities from a systems perspective on a sector-by-sector basis.

4.4. Diverse and local supply chains

Localised supply chains are critical for boosting economic complexity, promoting job growth, and enabling a more resilient economy with fewer external dependencies. Western Australia's economy is heavily reliant on global trade to sustain economic development. This is echoed by WA's Supply Chain Development Plan 2021-22[73], which highlights the limitations and risks associated with WA's current economic structure and advocates for supply chain diversification across the State. From a circular economy perspective, locally oriented supply chains can minimise material inputs while reducing waste outputs. Two immediate actions can lay the foundations for stronger local supply chains:

4.4.1. Map local supply chain networks

Circular supply chains require three essential elements: 1) Distributed and interconnected networks to maximise local collaborations with suppliers, customers, and industry partners. 2) Wide flows of information, goods, and finance to facilitate data sharing among partners (e.g., materials' location, composition, and disassembly options). 3) The ability to create and provide value by maintaining products and materials in use[128].

Consistent with these insights, we observe supply chain fragmentation as a barrier to enhanced industrial symbiosis and resource productivity gains in WA. Particularly, the current lack of information linking material flows and regional production prevents a comprehensive understanding of local supply chain networks and interdependencies.

We recommend advancing state and regional production-based accounts, linking inter-industrial and interregional trade. This information can be further integrated with material, energy and emission accounts, informing production-based metrics consistent with economic-environmental accounting practises, as provided by WATCH. These developments will provide relevant information on the magnitude and characteristics of production processes, shedding light on potential synergies at the local and regional scale.

4.4.2. Enhance opportunities for closed material loops

Diverse and resilient productive ecosystems rely on networks that effectively connect local material supply and demand. A material marketplace, a platform connecting buyers and sellers of primary and secondary products, including potential waste from production processes, can enhance opportunities for closed material loops in WA. In the first instance, we advocate for a distributed platform based on open protocols, allowing users to share data on material availability and demand, identify opportunities for reuse, and visualise the logistics involved. In the long-term, bottom-up traceability systems, such as material passports with information on material composition, can be integrated into material marketplaces for further accuracy and transparency.

4.5. End-of-life management

The Waste Authority highlighted the need for improvements in waste data collection and analysis. Further developments in data collection and harmonisation of different accounting systems will allow for a better understanding of circular flows. From there, the integration of Waste Management Systems (WMS) into an economy-wide assessment framework will provide critical insights for understanding downstream environmental impacts and designing circular responses. Below, we focus on two feasible near-term actions.

4.5.1. Improve waste traceability

Since the circular economy seeks to reduce the demand for virgin materials, we speculate that official recycling and circularity figures are overestimated, as a large portion of recovered materials are downcycled[129]. This may be the result of the loss of quality and functionality along the value chain, which is particularly true in the management of C&D waste, which usually involves downcycling processes (e.g., EoL concrete reprocessed into materials for backfilling)[130].

We observed two limitations in current waste data collection preventing the design of better waste management responses:

- WMS usually collect data on waste once they reach treatment facilities, overlooking crucial information about their journey from the generation point.
- The loss of quality or functionality restricts the capacity of a recovered material to offset raw material inputs. However, post-treatment data does not capture these parameters, preventing accurate insights.
- Current data collection systems prevent determining if the recovered materials ultimately offset virgin material inputs in production processes, as the endpoints are not systematically tracked and recorded.

Therefore, we suggest future research should include surveying waste facilities and collaborating with industry, Waste Authority and DWER to provide a clearer understanding of:

- The origin of waste generation (C&I and C&D), including the mass of materials upstream of waste facilities.
- Waste reuse, including the mass of materials redirected before treatment and the sector of final or intermediate demand.
- Recirculation of recovered materials, particularly the mass of recovered material recirculated into the economy and the sector of final or intermediate demand.

Digital tools to trace materials from their production point to their end-of-life can serve these purposes, providing accurate information to supply chains and allowing the identification of barriers to reusing and recycling valuable resources that would otherwise be treated as waste. This is especially important in the context of the National Framework for Recycled Content Traceability by the DCCEEW.

The integration of next-generation protocols and accounting systems will be an important research area in the long-term. In the short term, future developments exploring the hybridisation of existing data sources and approaches will help to more accurately quantify the percentage of secondary materials in traded products (see Section 4.5.2).

4.5.2. Integrate waste management systems into an economy-wide lifecycle framework

In their current form, policy and technical frameworks draw distinct boundaries between waste management and production systems, making it difficult to assess the recirculation of recovered materials back into production processes, referred to as circular rates[2]. Additionally, economy-wide circularity metrics are not equipped to evaluate the quality of recycled materials and their potential to substitute virgin material inputs (i.e., circular potential). Therefore, additional tools are necessary to gather information on the characteristics of end-of-life products.

We recommend integrating the WMS into an extended MFA-LCA framework, a development that is anticipated to be addressed in future WATCH research. This integration would allow for better estimation of environmental performance in regions and cities by considering the flows of secondary resources as a proportion of the economy's total material input and assessing downstream environmental impacts in the waste value chain (e.g., EoL emissions).

The additional insight derived from this integration would be particularly valuable at the municipal level, helping to bridge the gap between the WMS, circular economy strategies, and practical actions. By better understanding and forecasting material release from social stocks–including expected waste generation, material composition, and potential recoverability–municipalities may be better equipped to effectively co-design circular response measures with local businesses and communities. These positive impacts would not occur in isolation, as they will likely trigger transformations at the local level by building capacities and awareness of challenges and opportunities across value chains.

4.6. Built environment

The impact of construction materials has been highlighted in this research. In the built environment, there is a pressing need to better quantify and monitor built assets and material components across the construction project lifecycle. Integrated assessment and traceability tools can provide valuable information about the quantities, qualities, and characteristics of material stocks. In the long-term, these technologies could facilitate material exchanges, enabling efficient and resilient markets for secondary construction materials. Here, we outline two actionable recommendations that can lay the groundwork for further technological advancements:

4.6.1. Dynamic mapping of built stocks

An accurate assessment of built stocks helps identify the quantities and types of materials that can potentially be recycled or reused. Recognising high-demand or high-value materials for future use is expected to encourage their reclamation, promoting practices like "urban mining" or building as material banks (BAMBs), thereby reducing the reliance on virgin materials. This information can also guide construction lifecycle processes, including design choices and material selection with respect to lifespan, performance, cost and environmental impact.

Given that transport infrastructure represents a significant capital investment in WA (see Section 1), modelling the potential for material recovery and reuse of transport infrastructure projects may have a major impact on the value chain. This includes the ease of separating and recycling materials during deconstruction, energy-efficient construction methods, and low-carbon materials. Innovative tools, such as GIS and remote sensing for spatial planning, LCA for assessing lifecycle costs and impacts, BIM for material tracking and management, and digital twins for real-time monitoring of performance and resource usage, can provide relevant insights. The integration of such methods and tools should be considered for future WATCH research.

4.6.2. Forecast material requirements

Efficiently forecasting material requirements is a critical component of modern infrastructure project management. Advancements in data-driven analysis and predictive tools enable more accurate forecasts of future material demands, enhancing resilience against supply chain disruptions and shortages. By accurately estimating material needs, construction projects can more effectively implement circular economy strategies, such as reusing, recycling, or repurposing construction materials, fostering sustainability and resource efficiency in the industry. This is expected to be a focus area of future WATCH research.

4.7. Enabling tools and technologies

Science-based tools are essential for strengthening decision-making capacity across sectors, industries, and regions—supporting effective policymaking, strategic investment, and urban and infrastructure planning. Additionally, integrated accounting frameworks enable actors to measure, monitor, and report changes over time with consistency and transparency. These enabling tools and technologies create a robust foundation for informed, data-driven actions toward a circular economy. Here, we outline three actionable advances.

4.7.1. Scenario analysis and response measure design

Developing counterfactual “what-if” scenarios will be essential to deepening insights into the circular strategies highlighted in this report and better understanding the circular potential for WA. This will help create a clear connection between circular strategies and specific regions, sectors, and actors, informing cost-benefit analysis and the development of response measures.

Establishing consistent benchmarking across regions will be crucial to ensure the comparability and relevance of these insights. Furthermore, linking leading indicators to response measures will be important to ensure transparent, consistent benchmarking and facilitate ongoing impact monitoring.

Scenarios should include a wide range of circular strategies, such as product redesign, residual waste management, closed-loop supply chains, resource efficiency, shifting demand, and economic instruments. Collaboration with industry, government, and community stakeholders is vital to ground these scenarios in the local WA context. Co-development with these groups will help tailor strategies to regional priorities, constraints, and opportunities, thus enhancing the impact and feasibility of circular economy initiatives in WA.

4.7.2. Deploy a circular monitor as a digital public good

Having access to timely, relevant and evidence-based information is essential in building the multi-sector capacity required to effectively navigate the transition to a circular economy. However, during ongoing research and consultation with governments, businesses, and communities across WA, we have identified several reoccurring challenges that state and non-state actors face in this transition:

1. Data fragmentation and lack of interoperability across systems, actors and scales;
2. Misalignment in objectives, with information gaps in policy, science and culture; and
3. Lack of data-driven tools, limiting the capacity for evidence-based action in line with effective circular outcomes.

To address these challenges, we propose WATCH (Western Australian Tool for Circular Horizons), a science-based digital circular monitor offering governments, industries and communities critical insight to support circular planning, monitor and report on enhanced material flows, and promote data-driven decision-making. By providing a comprehensive view of circularity at multiple geographical scales, this digital public good aims to enhance cross-sector collaboration and strengthen WA's capacity for interdisciplinary research and effective circular applications.

We further emphasise the impact of Digital Public Goods[131] in the context of enabling tools and technologies, and urge governments to prioritise the development and maintenance of solutions that adopt open-source-first principles[132]. Open source software, open data, and open artificial intelligence models provide not only essential transparency and traceability but also promote circular strategies, such as reusability and product lifetime extension, presenting new opportunities to accelerate digital and circular transformation. The Open Source Software Guideline, published by the Queensland Government[133], highlights the expected benefits of using and developing open source software within government and provides information for agencies considering adopting a similar approach. Industry and open source community leaders have also published recommendations for stakeholders developing and supporting open source for environmental sustainability[134].

4.7.3. Develop a circular resource hub to enhance community awareness and business capacities

Community-driven circular initiatives play a vital role in co-designing response measures that reflect local context and needs. Establishing a circular resource hub at the city level could greatly enhance community awareness while strengthening the capacities of businesses and local governments. By offering accessible resources, educational tools, and a circular economy dashboard, the hub would empower local businesses, residents, and governments to collaboratively advance circular economy efforts.

This hub should be seamlessly integrated into local government operations to monitor, report, and support both municipal and local cross-sector circular initiatives. Furthermore, integrating data feeds from systems like WATCH would provide insights into the performance of circular initiatives, enabling communities and governments to measure impact effectively. This data-driven approach would support cities in refining policies, enhancing accountability, and fostering continuous improvement through actionable feedback loops.

4.8. Cross-scale and multi-sectoral collaboration

The circular economy thrives on the interconnectedness of systems and processes, emphasising the continuous flow and reuse of resources across sectors, industries, and regions. Achieving true circularity requires collaborative efforts that extend beyond individual businesses or industries to include cross-sectoral partnerships, regional initiatives, and state and national policies. This interconnected approach ensures that materials, products, and resources are cycled effectively, minimising waste and reducing reliance on virgin resources. To close material loops sustainably, multi-level collaboration across scales—from local waste management facilities to global supply chains—is essential. Such cooperation enables the alignment of circular strategies, data integration, and policy coherence, fostering a resilient circular economy that benefits all sectors and levels of society. We draw to immediate steps to foster cross-sectoral, industry and agency collaboration:

4.8.1. Integrate efforts in a multistakeholder partnership

Interorganisational relationships need to be reconsidered to transition from a traditional dual focus (supplier-buyer) to incorporate several government agencies, non-governmental (NGOs) and capacity-building organisations. Cross-sector partnerships between large-scale companies, research institutes, and innovative entrepreneurs can bring sustainability and circular benefits to firms. These relationships can be further supported by external forces such as those exerted by national, state and local governments introducing incentives, standards and policies[135]. A network perspective is critical to unlocking the potential of circular ecosystems[136], the importance of which has been demonstrated in the implementation of eco-industrial parks and industrial symbiosis at the meso level of the circular economy[137]. In many cases, transition brokers can guide and facilitate multistakeholder alliances from a politically neutral standpoint and help create the necessary preconditions for change to emerge across scales and system boundaries[138].

Multistakeholder partnerships are emerging across Australia. Supported by the Australian Government, the Australian Circular Economy Hub led by Planet Ark focuses on delivering knowledge and building capacities to accelerate the transition to a circular economy. Circular Australia[139] has also been a frontrunner in building circular capacities across the country. CSIRO[140] has made a significant contribution at the national level by advancing a national assessment framework and providing comprehensive roadmaps and policy advice.

Nonetheless, WA has not yet established a formal partnership between relevant stakeholders with targeted support from the State government. We advocate for establishing a multistakeholder alliance with the presence of relevant state and non-state actors, representing essential, cross-cutting circular economy functions, including but not limited to:

- **Natural environment**: Department of Water and Environmental Regulation (DWER); Waste Authority WA, Department of Biodiversity, Conservation and Attractions.
- **Economic development**: Department of Jobs, Tourism, Science and Innovation (JTSI); Department of Primary Industries and Regional Development (DPIRD); Department of Mines, Industry Regulation and Safety (DEMIRS); Energy Policy WA.
- **Sustainable finance:** Department of Finance; Department of Treasury.
- **Built environment and infrastructure**: Department of Planning, Lands and Heritage; Department of Transport; Main Roads WA; Development WA; Infrastructure WA; Western Australian Land Information Authority.
- **Community development and local governance**: Department of Communities; Local Government Authorities; Western Australian Local Government Association (WALGA).
- **Research and civic society**: State universities; national research institutes (e.g., CSIRO); and scientific non-profit consortiums (e.g., Open Corridor).

These government and research institutions, alongside innovative industry partners and civic society organisations, can build capacities and deliver high-impact research and practical circular outcomes.

4.8.2. Develop a local circular economy agenda

The critical role of cities in transitioning toward a circular economy has been highlighted throughout this research. Cities translate policies, research and developments into tangible actions on the ground. From a governance standpoint, local government associations are important stakeholders in spreading circular economy strategies at the community level by acting as a bridge between research, policy and communities. By engaging more local authorities, we anticipate an increase in comprehensive data collection, policy alignment, and the scaling of successful circular models, ultimately driving more widespread and sustainable circular transitions across the State.

In WA, municipal partnerships, such as the Western Australian Local Government Association (WALGA), can facilitate the uptake of science-based circular solutions as those informed in WATCH. Municipal alliances can support data-driven decision-making and the co-design of circular responses at the local level, enhancing accountability, transparency and participation. We call for the development of a concrete agenda through municipal associations to bring these developments closer to local administrations and communities.

5. Conclusions and final remarks

This report provided the first comprehensive assessment of the state of circularity in WA. We took a system-wide approach, focussing on several core aspects of a circular economy—resource inflows, built stocks and waste outflows—at the State, Greater Perth and municipal levels. We evaluated WA's capacity for circularity, the policy landscape, and data and conceptual gaps, and highlighted key opportunities for greater circularity and emission reduction across sectors and geographical scales. Finally, we outlined a pathway towards a consistent, multi-scale indicator framework for building cross-sector capacity and monitoring and driving circular outcomes.

Through local and state government demonstrations, we sought to assist WA in capitalising on the opportunities offered by the circular economy. These opportunities include:

- Circularity as a critical enabler to achieving net zero
- Economic diversification and innovation as drivers of job growth and resource efficiency gains
- Preserving the value of products and materials while designing out waste and pollution
- Effectively monitoring and driving circular outcomes across multiple levels and sectors
- Aligning investment and procurement with circular strategies
- Guiding policy development with evidence-based insights
- Positioning WA as a global leader in integrating circular economic and net zero approaches

To understand the current state of circularity in WA, we applied integrated environmental-economic methods to quantify resource inflows, material stocks, and waste outflows across the State and Greater Perth. The framework was further validated through two local government-level case studies. From this assessment, we derived key performance indicators for monitoring progress towards a circular economy. These results were graphically presented and then thoroughly analysed to understand the flows of resources and GHG-related emissions at the State, regional and local level. From there, we identified tangible near-term actions across eight systemic themes that can assist policy and decision-makers in finding the reforms needed to move towards a more circular economy.

Our findings illustrated that WA is one of the world's most resource—and emission-intensive economies. However, we observed that the State is strategically positioned to leverage circular economy opportunities across its value chain, unlocking substantial benefits at multiple levels. Nonetheless, achieving this will require significant advancements in policy, technology, and cross-sector collaboration.

Through this research, we have increased our understanding of circularity in WA, equipping industry, governments, and communities with data-driven insights and key performance indicators to monitor and drive effective circular outcomes. Our work provides valuable lessons for policymakers, industry partners, and communities, raising awareness and capacity for circularity across sectors. A key performance indicator framework, supported by a consistent circular economy assessment model, as developed through this project, places WA at the level of developed economies openly reporting circular performances, resource productivity and environmental pressures. Beyond that, we advanced towards a science-based circular monitoring system that helps to position WA as a global leader in digital transformation, bridging the gap between scientific knowledge and practical circular actions.

Future research stages are focused on operationalising the digital circular monitor and conducting scenario modelling to gather deeper insight on potential circular response measures. Further developments on regional economic-environmental accounts will enable a comprehensive understanding of local supply chain networks for enhanced industrial symbiosis. An increase in the resolution and coverage of materials stocks will support circular responses in the built environment. Time series data will allow for trend analysis. Lastly, better integration of waste management systems into the circular framework will allow for a better estimation of circular material use rates and downstream environmental impacts.

In conclusion, this project has successfully forged a multi-stakeholder effort to connect waste management, resource efficiency, and digital transformation, towards minimising environmental impact and effectively supporting the transition to a circular economy in WA.

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