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Review Article

Circular economy barriers in Australia: How to translate theory into practice?

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ABSTRACT

Australia has many unique features that make the approach to a transition to circular economy different to other countries. There is growing recognition that the current linear economy of 'take-make-waste' is unsustainable, and this has driven research and government policy into attempting to develop a circular economy in Australia. This systematic transformation will result in significant impact on government, business, and consumers, and therefore will be highly complex to achieve without understanding and overcoming the current barriers. The aim of this review is to identify the major barriers to circular economy adoption in Australia through a systematic review using literature that has been published in the last six years. This resulted in 74 studies being included for analysis across a variety of waste streams and Australian States. The authors identified that barriers to circular economy could be segregated into 21 different barriers, with the most frequently occurring ones including current standards and regulations, high cost of transport, lack of government incentive, missing or inaccurate data, and businesses not prioritising the changes needed for circular economy. These barriers were then assigned to a step in the lifecycle (or supply chain) of a material up until material exhaustion or disposal, as this aids in identifying research gaps, successful examples and barriers that are easier to overcome. Using these identified barriers to circular economy as a guideline, we have made recommendations for how Australia can progress to a circular economy.

1. Introduction

The concept of the circular economy is based on the principles of eliminating waste and pollution, recirculating products and materials (at their highest value), regenerating nature and creating social equity for the benefit of current and future generations (Ellen Macarthur Foundation, 2021; Kirchherr et al., 2023). It therefore encompasses economic, environmental, and social benefits and is a systematic transition from our current linear economy of 'take-make-waste'. However, there is currently no uniform definition for circular economy, and this has contributed to varied interpretations of the core principles and resultant confusion in what can be considered as circular economy (Kirchherr et al., 2023). In particular, the triple-bottom-line approach intended for circular economy has often been neglected in favour of focusing on a singular dimension such as economic prosperity or environmental benefit (Kirchherr et al., 2017; Bjørnbet et al., 2021; Corvellec et al., 2022).

Achieving circular economy will require transformation across the supply chain, with significant involvement from all stakeholders, including governments, businesses, researchers, and consumers. New models, infrastructure and practices must be developed that are centred on emergent principles with flexibility to adapt to location specific barriers. Whilst there is general agreement and enthusiasm by these stakeholders that a circular economy would be beneficial (Lakatos et al., 2016; Giorgi et al., 2022; Shooshtarian et al., 2022b), there is a growing critique that circular economy has become more of an ideological notion rather than being a concrete solution to actual problems (Corvellec et al., 2022).

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The first mention of a circular economy can be traced back to 1990 (Pearce and Turner, 1990); however, there has since been constant evolution and exploration of this concept for how it can be applied to a variety of supply chains (Kirchherr et al., 2023). This interest in circular economy in Australia has increased significantly in recent years due to the Sustainable Development Goals (SDG), and the growing awareness of the need for environmental sustainability (Halog et al., 2021).

This is because the circular economy is closely tied to the United Nations 2030 agenda for sustainable development and the 17 SDG (Schroeder et al., 2019). Australia's SDG progress is ranked below the OECD country average (33rd out of 38), and in particular there are major challenges towards achieving Zero Hunger (SDG 2), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), Life on Land (SDG 15), and Partnership for the Goals (SDG 17) (Sachs et al., 2023). Of even greater concern is that none of the SDGs are on track towards being achieved by 2030 (Sachs et al., 2023). The Australian rates of recovery of several of the major waste type streams have stagnated or decreased in recent years (Fig. 1), and as a country we are at danger of not reaching the 2030 target of an 80 % average recovery rate from all waste streams by 2030 (Australian Government, 2019).

To help understand why Australia is falling behind other G20 countries in this respect, it is important to first acknowledge that Australia is quite different to other G20 countries (Fig. 2). Australia has a high GDP per capita (nominal) of ~$64,000 (2nd highest of G20), but simultaneously has the lowest manufacturing share of GDP and second highest raw material exports as a share of GDP (The World Bank, 2022). This contributes to Australia having an Economic Complexity Index of −0.55, which led to a rank 93rd out of 133 countries and Australia recently falling behind Uganda in economic complexity (Harvard Growth Lab, 2024). With the manufacturing share of Australia's GDP continuing to steadily fall since data was first collected in 1974, beginning at 15 % and declining to 5.4 % in the latest figures of 2022 (not adjusted for inflation), this Economic Complexity Index is expected to continue to fall (Australian Bureau of Statistics, 2023). Consequently, the path to achieving the SDG and a circular economy is likely to be different for Australia than other countries.

Australia has commenced taking initiatives that encourage a circular economy, such as the introduction of waste levies, product stewardship schemes, export bans of waste plastic, paper, glass and tyres, publication of a national roadmap, phasing out problematic plastics and investigating how to encourage material reuse, repair, remanufacture and recycle (Australian Government, 2019; Bolger and Doyon, 2019; Schandl et al., 2020; Tobin and Zaman, 2022). There has been implementation of circular economy principles by select businesses and industries, such as the eco-industrial park in Kwinana, Western Australia that is successfully closing some loops for waste and by-products; water, energy and material (Halog et al., 2021). However, this success has been fragmented and is not representative of widespread change occurring in Australia, which is supported by the stagnation in waste material recovery.

The aim of this review is to identify the major barriers to circular economy adoption in Australia through a systematic literature review. This systematic review encompasses studies of any product or material type and stakeholder group consulted, and consequently is a high-level summary of the perceived barriers to circular economy in Australia. This will enable determination of whether there are common themes between states, materials and stakeholders present, which would allow for overarching messaging and policies to be developed. This is a new approach compared to other reviews in Australia that have focused on a specific industry or material (Shooshtarian et al., 2021b; Hossain et al., 2022; Salvador et al., 2022). Understanding the barriers in Australia, and what is contributing to them, holds implications for policymaking, development of education programs targeting both the future and existing workforce, and produces a guideline of key considerations for evaluating circular economy strategies. Using these identified barriers to circular economy as a guideline, we have made recommendations for how Australia can progress to a circular economy.

2. Methods

A systematic literature review was conducted to answer the following research question: What are the barriers to circular economy in Australia? Scopus database, Web of Science and Google Scholar were used to identify all title, abstract and keyword mentions of "circular economy" AND "Australi*" OR "supply chain" AND "Australi*". The search strategy differed for Google Scholar, as the search cannot be limited to the abstract or keywords and instead search queries were restricted to the title. The search strategy is shown in Fig. 3 (Salim et al.,

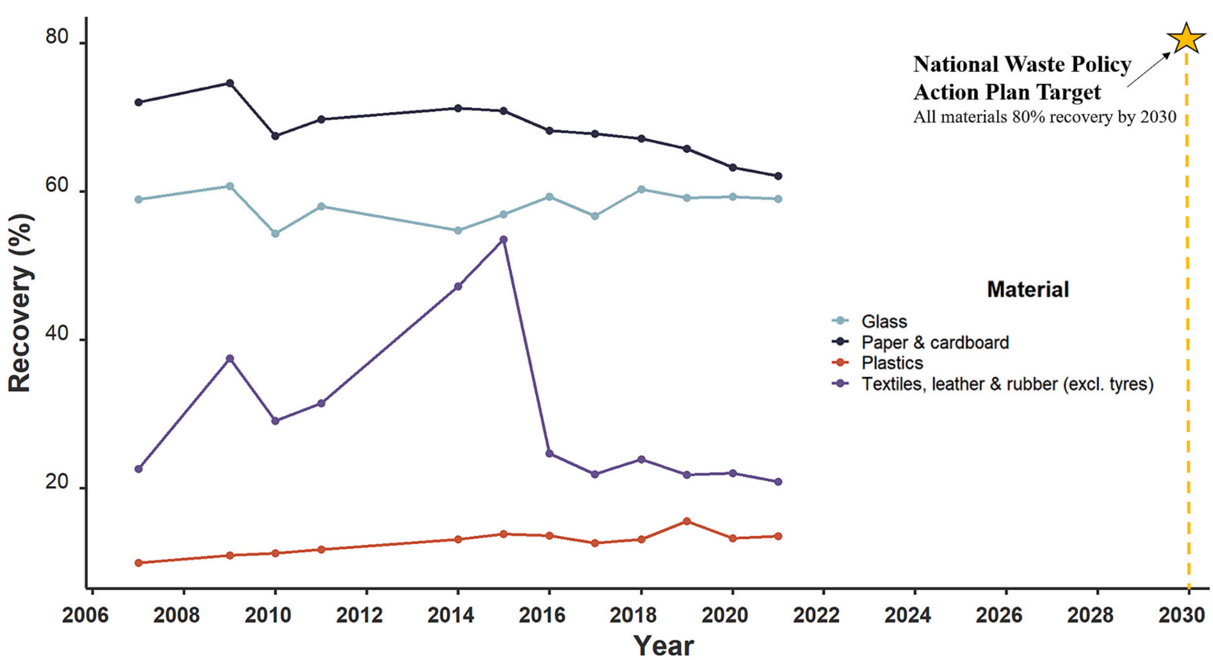

Fig. 1. Rates of resource recovery in Australia from 2007 to 2021. Data used from (Australian Government and Blue Environment, 2022). Resource recovery includes recycling, energy recovery and waste reuse.

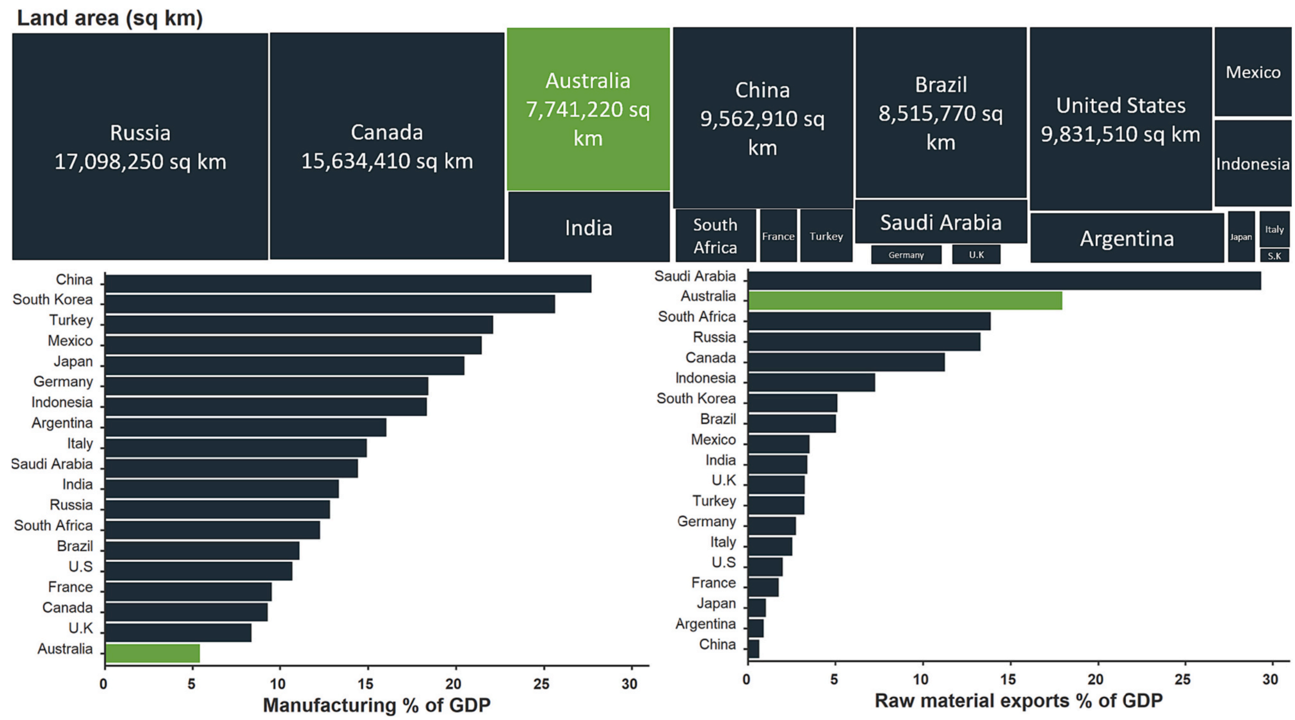

Fig. 2. Comparison of Australia to other G20 countries. Data from Worldbank (The World Bank, 2022).

2019).

To ensure that barriers to circular economy are recent and therefore relevant to current experience, only papers published in the last six years were included in this systematic review. The cut-off of January 2018 was selected, as this marked the start of the China National Sword Policy that restricted the importation of recycled materials. This greatly impacted Australia, as in 2016–17, a total of 1.25 million tonnes of recycled material was sent to China and the ceasing of this going forward caused major disruptions to waste management in the country (NSW Environment Protection Authority, 2018). The National Waste Policy was also published in 2018, which marked the start of number of targets and actions to complete by 2030.

Using the defined search strategy in Fig. 3 there was a total of 275 results. There were a large number of duplicates identified and removed (103), and other results were excluded due to the following exclusion criteria:

- *Language:* Articles not written in English were excluded.
- *Grey literature:* Results that were not peer-reviewed, including reports, theses, unpublished scientific work, and industry magazine publications were excluded.
- *Screening (title, abstract):* Articles were removed if they did not focus on Australia, or if they focused only on highly specific technical data rather than circular economy.
- *Screening (full text):* Articles were excluded if they did not discuss identifiable barriers to circular economy in Australia. However, articles that discussed multiple countries were included, as long as it was identifiable which barriers were associated with Australia.

In this systematic review, a barrier was defined as any contributing factor negatively affecting circular economy progress that the authors from each paper raised in response to their results or identified directly in survey/interview responses from other stakeholders. These were only included if they were specific to the Australian context. Following the completion of the systematic review, the identified negative contributing factors were analysed to allow classification into the 21 barriers used in this study. This classification into barriers was done by identifying common themes in the descriptions and associated context of each negative contributing factor. To prevent double counting of barriers, the same barriers listed by the same author in repeat papers are not included unless the stakeholder type that was consulted or state of focus varied. The publishing year, Australian state of focus, industry sector, stakeholders consulted, and barriers to circular economy were identified within each included paper and compiled in a data summary file. The 21 barriers were then grouped into seven categories, informed by previous research in the Australian context (Corder et al., 2014) and based on the most suitable match.

The 21 barriers were assigned to a step in the lifecycle (or supply chain) of a material up until material exhaustion or disposal. This included raw material, manufacturing, sale, product, collection and sorting, end-of-life treatment, recovered material market and disposal. Whilst the barriers can affect multiple steps in the lifecycle of a material, a barrier was assigned to the stage of the lifecycle where it most negatively impacted the progression to a circular economy. This was determined based on the literature findings in the systematic review. Recommendations to overcome or mitigate these barriers were then devised based on barriers that had a high frequency of appearance in the systematic review and were also able to be directly modified.

3. Results

3.1. Publication trends

A total of 74 papers were included in the analysis. It can be observed in Fig. 4 that publications focused on Australian circular economy have dramatically increased in number in 2021 and 2022, which may be attributed to the shifted priorities following the COVID-19 disruptions (Wang et al., 2022). With the exclusion of Tasmania and Western Australia, the number of papers focusing on specific Australian states is relatively uniform and the majority of papers have focused on Australia as a whole. Only one paper focusing on the Northern Territory, and none on the Australian Capital Territory were identified, likely due to lower population (1 % of Australian population) and embedment within New South Wales, respectively.

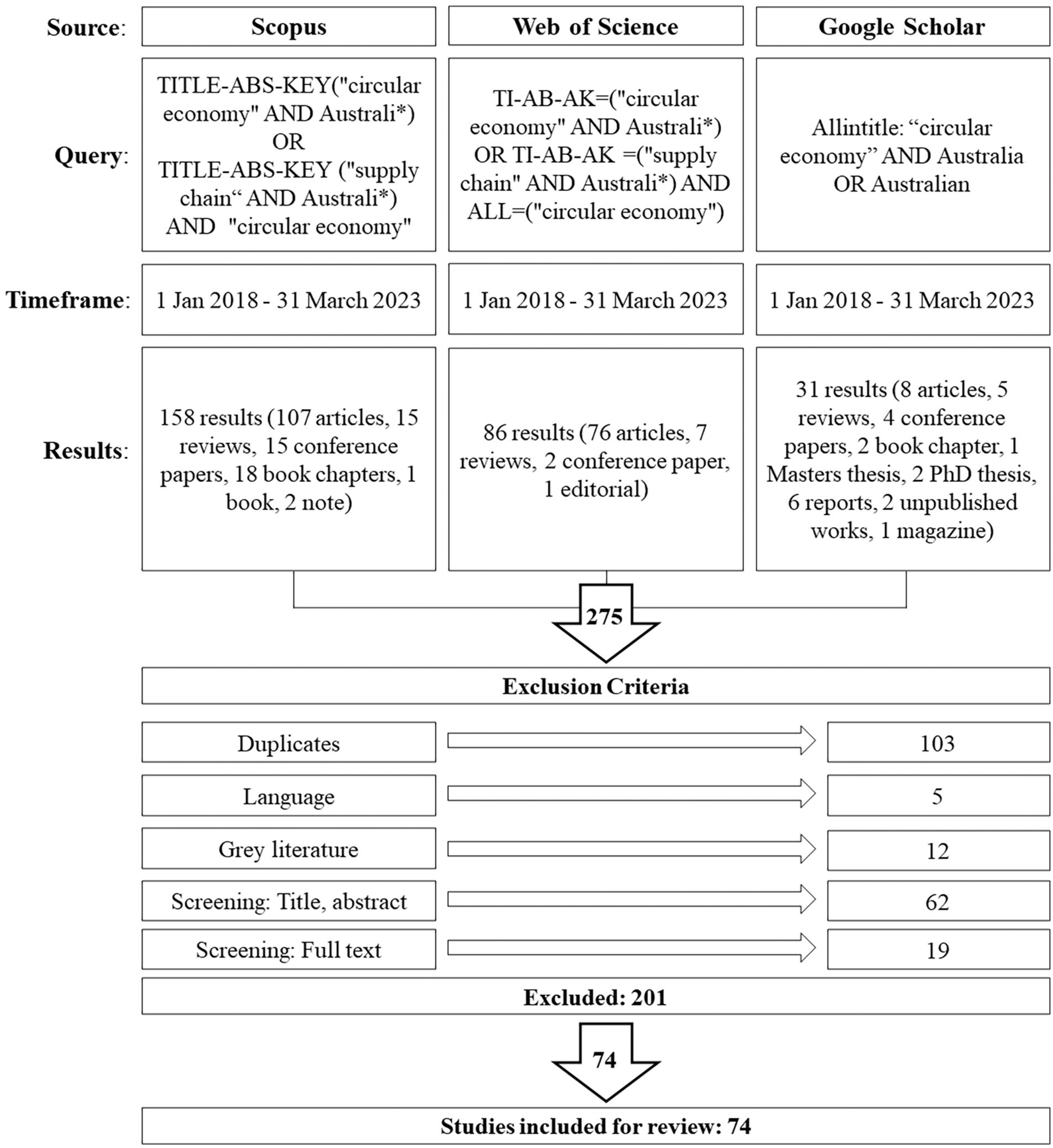

Fig. 3. Overview of systematic review search strategy.

3.2. Australian barriers to circular economy

There was a total of 21 barriers identified across the 74 papers in this systematic review (Table 1).

Further analysis was conducted to determine the occurrence of these barriers in relation to the different industry sectors that had at least 4 papers focusing on that industry in this systematic review (Fig. 5). This highlighted that whilst there are common themes across all product and material types, there are specific barriers that are consistently reported in some industries.

The barriers were then grouped into seven categories, informed by previous research in the Australian context (Corder et al., 2014) to determine the key intervention (Fig. 6). The most frequent type of barriers were economic, regulation, information and lack of commitment.

The importance of lifecycle thinking rather than waste or EOL focused approaches has been previously highlighted as enabling the complete picture to be understood and ensuring coverage of all aspects of circular economy principles (Desing et al., 2020). Whilst some of these barriers are applicable to multiple 'life stages' of the material, they have been attributed to the step most critical in preventing development of a circular economy (Fig. 7). Assigning these barriers to a particular 'life stage' enables future initiatives or studies to be targeted at overcoming the relevant barriers identified. The barrier requiring government incentive has been placed next to disposal, as it could be applied at any 'life stage' and is likely to be instrumental for transition to a circular economy and diverting waste from landfill. The following sections describe the results for each of the eight lifecycle stages supported by relevant articles from the systematic review.

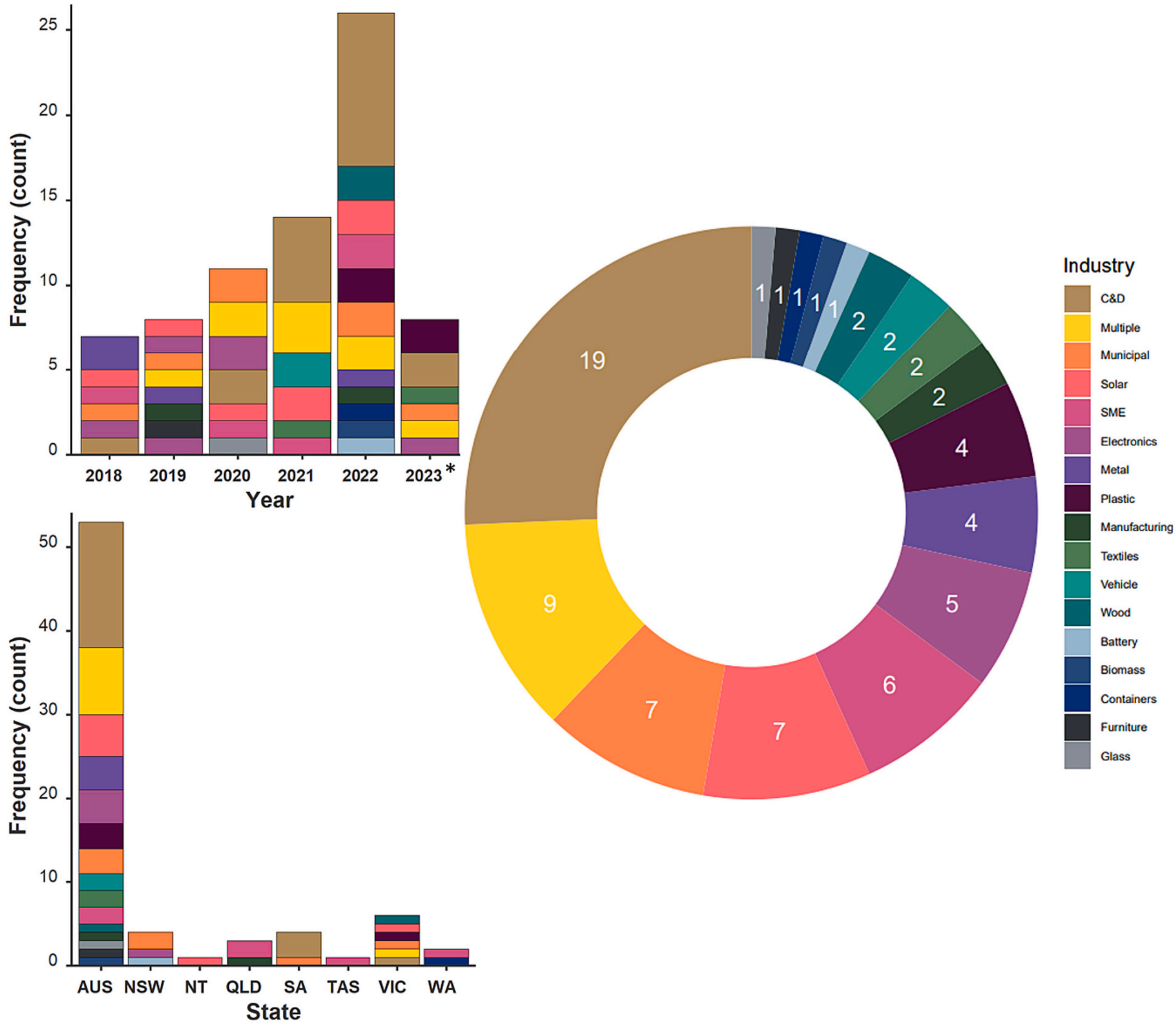

Fig. 4. Characterisation of papers included in systematic review by year, state, and focus area (*publications for 2023 are only up until end of March 2023). C&D; construction and demolition, SME; small and medium enterprises.

3.2.1. *Raw material*

The two barriers assigned to the raw material stage, are reliance on imported goods and supply chain coordination. Whilst these barriers begin at this stage, they have significant influence and impact across the whole supply chain. The reliance on imported goods includes raw materials for manufacturing or products direct for market. One article compared Australia to other G20 countries, and found Australia simultaneously had the largest per-capita levels of raw material exports and the highest reliance on foreign low-paid workforce to produce materials such as textiles and plastics for import to Australia (Cabernard et al., 2022). Concerningly, this amounted to “three full-time workers being needed to supply the consumption of two people in Australia in 2015”. Therefore, Australia is not just selecting imported goods due to lower cost and is instead currently reliant on them. Higher Australian labour costs and previous policy changes, particularly in the automotive industry which is largely absent in Australia, have been cited as the reason for this cost difference (Free and Hecimovic, 2021). Addressing the barrier of reliance on imported products will assist with overcoming the problem of missing or inaccurate data needed in later stages within the life cycle. For example, it has been suggested that imported polymers are greatly contributing to the consumption of unknown polymers, which can be processed by limited facilities in Australia and have a recovery rate of only 5 % (Hossain et al., 2022). This exemplifies why supply chain coordination needs to begin at the raw material stage.

The barrier of supply chain coordination refers to the need to collaborate between suppliers, businesses, and consumers to facilitate knowledge and data sharing and encourage collective waste management strategies such as waste trading. Supply chain coordination can also help governments in regional areas to overcome the economy of scale issues that are present due to smaller populations and consequently less feedstock material and infrastructure (Mathur et al., 2022). In general, it is evident that there are a large number of different stakeholders that a material can pass through from product design to material exhaustion. Decisions made by one stakeholder during the material life cycle can impact the ability of other stakeholders to continue using that material within a circular economy.

Supply chain coordination is a more complex barrier to overcome, as there are inherent risks involved including potential loss of intellectual property and to a certain extent being reliant on other stakeholders. In particular, businesses are reliant on suppliers for data on raw materials and this is not always feasible to obtain due to the supplier being unwilling to share information or adjust their practices (Piller, 2023). Another barrier is that by nature companies are competing, and this competition can lead to a less cooperative approach (Adams et al., 2022). Despite these challenges, there have been successful examples of supply chain coordination within Australia such as the collaborations facilitated through digital waste trading platforms like ASPIRE (King et al., 2020). Waste trading platforms cover just the beginning of the

Table 1
Identified barriers in the systematic review.

Barrier	Associated descriptions	References
Capital funds	• Capital/initial investment costs too expensive	(Caldera et al., 2019; Cother, 2020; She et al., 2020; Shooshtarian et al., 2021a; Chakraborty et al., 2022; Salvador et al., 2022; Zaman, 2022; Zaman et al., 2023)
Current consumer habits	• Consumer education and consumption habits not supportive of a circular economy	(Dominish et al., 2018; Sharp et al., 2018; Bolger and Doyon, 2019; Islam and Huda, 2019; Ramirez, 2019; Islam et al., 2020; Jones, 2020; Stephan et al., 2020; Payne et al., 2021; Cabernard et al., 2022; Chakraborty et al., 2022; Ghafoor et al., 2022; Hossain et al., 2022; Islam et al., 2022; Jayasinghe et al., 2022; Li et al., 2022; Luo et al., 2022; O'Dwyer et al., 2022; Shooshtarian et al., 2022a; Sohal and De Vass, 2022; Bernardo et al., 2023; Kourabas and Nagtzaam, 2023; Piller, 2023; Zaman et al., 2023)
Circular economy is complex and hard to understand	• How to implement circular economy is not understood • Lacking technical expertise	(Elmualim et al., 2018; Bolger and Doyon, 2019; Caldera et al., 2019; Fleischmann, 2019; Cother, 2020; She et al., 2020; Fiedler et al., 2021; Melles, 2021; Payne et al., 2021; Ratnasabapathy et al., 2021b; Salim et al., 2021; Chakraborty et al., 2022; Jahan et al., 2022; O'Dwyer et al., 2022; Shooshtarian et al., 2022b; Shooshtarian et al., 2022a; Tobin and Zaman, 2022; van Bueren et al., 2022; Kourabas and Nagtzaam, 2023; Zaman et al., 2023)
Currently not cost viable	• Comparable products/ materials are cheaper • Concerns that it would not be cost-viable	(Dominish et al., 2018; Elmualim et al., 2018; Werner et al., 2018; Ramirez, 2019; Mahmoudi et al., 2020; Daljit Singh et al., 2021; Ratnasabapathy et al., 2021a, 2021b; Salim et al., 2021; Shooshtarian et al., 2021b; Shooshtarian et al., 2021a; Adams et al., 2022; Jahan et al., 2022; Jayasinghe et al., 2022; Mathur et al., 2022; Mejame et al., 2022; Salvador et al., 2022; Soonsawad et al., 2022; Zahraee et al., 2022; Frangioudakis Khatib et al., 2023; Piller, 2023)
Current standards and regulations are not supporting circular economy	• Lacking standards or government regulations for circular economy • Current standards or regulations do not support circular economy either due to inconsistency or are not aligned with circular economy goals	(Dominish et al., 2018; Hancock et al., 2018; Lane and Gumley, 2018; Islam and Huda, 2019; Madden et al., 2019; Ramirez, 2019; Wiseman and Kariyawasam, 2020; Daljit Singh et al., 2021; Fiedler et al., 2021; Halog et al., 2021; Melles, 2021; Payne et al., 2021; Ratnasabapathy et al., 2021b; Shooshtarian et al., 2021b; Soo et al., 2021; Adams et al., 2022; Hossain et al., 2022; Jahan et al., 2022; Jayasinghe et al., 2022; Li et al., 2022; Mathur et al., 2022; Mejame et al., 2022; O'Dwyer et al., 2022; Salvador et al., 2022; Schuyler et al., 2022; Tan et al., 2022; Mairizal et al., 2023; Piller, 2023; Zaman et al., 2023)
Government legislation is not harmonious	• Legislation varies between state governments • Local government reliant on others to be able to make change	(Bolger and Doyon, 2019; Fleischmann, 2019; Jones, 2020; Melles, 2021; Ng et al., 2021; Shooshtarian et al., 2021b; Shooshtarian et al., 2021a; Chakraborty et al., 2022; Mathur et al., 2022; Salvador et al., 2022; Schuyler et al., 2022; Tobin and Zaman, 2022; Kourabas and Nagtzaam, 2023; Zaman et al., 2023)
Health and safety concerns	• Circular economy strategies discouraged due to health and safety concerns • Business or consumers unwilling to handle materials or products due to safety concerns	(Mahmoudi et al., 2019; Islam and Huda, 2020; Daljit Singh et al., 2021; Oughton et al., 2021; Salim et al., 2021; Shooshtarian et al., 2021a; Jayasinghe et al., 2022; Mejame et al., 2022; Zaman, 2022; Frangioudakis Khatib et al., 2023; Piller, 2023)
Lack of collaboration and sharing	• Stakeholders unwilling to share IP • Difficult to set up collaborative groups • Lacking collaboration needed for circular economy	(Dominish et al., 2018; Bolger and Doyon, 2019; Islam and Huda, 2019; Jones, 2020; Mahmoudi et al., 2020; Wiseman and Kariyawasam, 2020; Halog et al., 2021; Ratnasabapathy et al., 2021a, 2021b; Shooshtarian et al., 2021a; Soo et al., 2021; Adams et al., 2022; Hossain et al., 2022; Jahan et al., 2022; Mathur et al., 2022; Shooshtarian et al., 2022c; Tobin and Zaman, 2022; Frangioudakis Khatib et al., 2023; Henry et al., 2023)
Lack of testing and certification	• Lacking stakeholder confidence in products/ material • Inconsistent products from recycled or recovered material.	(Elmualim et al., 2018; Lane and Gumley, 2018; Argus et al., 2020; Ratnasabapathy et al., 2021b; Shooshtarian et al., 2021b; Chakraborty et al., 2022; Hossain et al., 2022; Jahan et al., 2022; Jayasinghe et al., 2022; Li et al., 2022; Shooshtarian et al., 2022a; Piller, 2023)
Limited market for recovered material	• Limited market • Small manufacturing industry	(Dominish et al., 2018; Werner et al., 2018; Graedel et al., 2019; Islam and Huda, 2019; Jones, 2020; Free and Hecimovic,

(continued on next page)

Table 1 (*continued*)

Barrier	Associated descriptions	References
	• High exports of material to be recycled/reused elsewhere	2021; Ndukwe et al., 2021; Ng et al., 2021; Soo et al., 2021; Li et al., 2022; Shooshtarian et al., 2022c; Soonsawad et al., 2022; van Bueren et al., 2022; Kourabas and Nagtzaam, 2023; Mairizal et al., 2023; Piller, 2023)
Missing or inaccurate data	• Data needed is not available or is inaccurate	(Elmualim et al., 2018; Hancock et al., 2018; Graedel et al., 2019; Islam and Huda, 2019; Argus et al., 2020; He et al., 2020; Jones, 2020; Mahmoudi et al., 2020; Stephan et al., 2020; Halog et al., 2021; Payne et al., 2021; Ratnasabapathy et al., 2021a, 2021b; Salim et al., 2021; Shooshtarian et al., 2021a; Soo et al., 2021; Adams et al., 2022; Chakraborty et al., 2022; Hossain et al., 2022; Jayasinghe et al., 2022; Li et al., 2022; Tan et al., 2022; Zaman, 2022; Bernardo et al., 2023; Mairizal et al., 2023; Piller, 2023)
Need more examples of circular economy success	• Lacking enough successful examples or frameworks to follow to encourage more change • Fear of being first	(Fleischmann, 2019; Argus et al., 2020; Melles, 2021; Chakraborty et al., 2022; de Klerk et al., 2022; Salvador et al., 2022; Shooshtarian et al., 2022c; Frangioudakis Khatib et al., 2023)
No one accountable/ responsible	• No one responsible/ accountable • Unclear who should be responsible	(Caldera et al., 2019; Islam and Huda, 2019; Jones, 2020; Daljit Singh et al., 2021; Salim et al., 2021; Shooshtarian et al., 2021b; Shooshtarian et al., 2021a; Islam et al., 2022; Mejame et al., 2022; Shooshtarian et al., 2022c; Sohal and De Vass, 2022; Soonsawad et al., 2022; Piller, 2023)
Not a business priority	• Business time constraints • Rigid organisational structure • Risk averse	(Dominish et al., 2018; Elmualim et al., 2018; Fleischmann, 2018; Lane and Gumley, 2018; Caldera et al., 2019; Fleischmann, 2019; Mahmoudi et al., 2019; Argus et al., 2020; Cother, 2020; She et al., 2020; Halog et al., 2021; Melles, 2021; Ratnasabapathy et al., 2021b; Shooshtarian et al., 2021b; Shooshtarian et al., 2021a; Adams et al., 2022; Jahan et al., 2022; Li et al., 2022; Luo et al., 2022; Salvador et al., 2022; Sohal and De Vass, 2022; Soonsawad et al., 2022; Tobin and Zaman, 2022; Henry et al., 2023; Piller, 2023; Zaman et al., 2023)
Not enough government incentive	• Tax relief/financial incentive/penalties required	(Mahmoudi et al., 2019; Ramirez, 2019; Islam et al., 2020; Jones, 2020; Wiseman and Kariyawasam, 2020; Fiedler et al., 2021; Free and Hecimovic, 2021; Halog et al., 2021; Payne et al., 2021; Ratnasabapathy et al., 2021a, 2021b; Salim et al., 2021; Shooshtarian et al., 2021a; Adams et al., 2022; Chakraborty et al., 2022; de Klerk et al., 2022; Jahan et al., 2022; Jayasinghe et al., 2022; Li et al., 2022; Luo et al., 2022; Mejame et al., 2022; Salvador et al., 2022; Shooshtarian et al., 2022c; Sohal and De Vass, 2022; Piller, 2023; Zaman et al., 2023)
Product design limiting end of life options	• Product not designed for end of life • Product design results in unnecessary resource wastage	(Dominish et al., 2018; Elmualim et al., 2018; Argus et al., 2020; Islam et al., 2020; Islam and Huda, 2020; Wiseman and Kariyawasam, 2020; Daljit Singh et al., 2021; Fiedler et al., 2021; Ratnasabapathy et al., 2021b; Salim et al., 2021; Shooshtarian et al., 2021a; Soo et al., 2021; Hossain et al., 2022; Jahan et al., 2022; Mejame et al., 2022; Schuyler et al., 2022; Piller, 2023; Zaman et al., 2023)
Reliance on imported products	• Inability to produce in Australia • Transparency issues for imported products	(Islam and Huda, 2019; Flood et al., 2020; Free and Hecimovic, 2021; Ndukwe et al., 2021; Cabernard et al., 2022; Hossain et al., 2022; Kourabas and Nagtzaam, 2023)
Technology and research gap	• Technology/ understanding needed is not yet available • Ineffective sorting or separation methods	(Graedel et al., 2019; Mahmoudi et al., 2019; Flood et al., 2020; Islam and Huda, 2020; Daljit Singh et al., 2021; Fiedler et al., 2021; Free and Hecimovic, 2021; Halog et al., 2021; Ng et al., 2021; Shooshtarian et al., 2021b; Adams et al., 2022; Jayasinghe et al., 2022; Mejame et al., 2022; Shooshtarian et al., 2022a; Zahraee et al., 2022; Zaman, 2022; Frangioudakis Khatib et al., 2023; Piller, 2023)
Time delay for benefit after change	• Australia slow to change (behind other countries) • Waste is a future problem • Business' prefer short term benefits	(Fleischmann, 2019; She et al., 2020; Halog et al., 2021; Melles, 2021; Shooshtarian et al., 2021a; Hossain et al., 2022; Bernardo et al., 2023; Kourabas and Nagtzaam, 2023)
Transport distances and spread of infrastructure	• Transport costs/distance • Lack of nearby waste infrastructure	(Werner et al., 2018; Bolger and Doyon, 2019; Fleischmann, 2019; Islam and Huda, 2019; Madden et al., 2019; Mahmoudi et al., 2019; Cother, 2020; Islam et al., 2020; Daljit

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Table 1 (*continued*)

Barrier	Associated descriptions	References
		Singh et al., 2021; Halog et al., 2021; Ng et al., 2021; Payne et al., 2021; Ratnasabapathy et al., 2021b; Shooshtarian et al., 2021b; Hossain et al., 2022; Islam et al., 2022; Li et al., 2022; Luo et al., 2022; Mathur et al., 2022; Mejame et al., 2022; O'Dwyer et al., 2022; Shooshtarian et al., 2022a; Zahraee et al., 2022; Bernardo et al., 2023; Frangioudakis Khatib et al., 2023; Mairizal et al., 2023; Piller, 2023)
Variable waste volume and quality	• Volume, composition, or quality of waste is variable	(Dominish et al., 2018; Elmualim et al., 2018; Graedel et al., 2019; Islam and Huda, 2019; Mahmoudi et al., 2019; Ratnasabapathy et al., 2021b; Shooshtarian et al., 2021b; Shooshtarian et al., 2021a; Soo et al., 2021; Jahan et al., 2022; Mejame et al., 2022)

potential of supply chain coordination, as the benefits of knowledge and equipment sharing between businesses is also well regarded (Bolger and Doyon, 2019). However, changes like knowledge and equipment sharing require significant change to how a business operates and this is another major barrier to circular economy.

3.2.2. *Manufacturing*

The three barriers identified at the manufacturing stage include circular economy not being a business priority, product design limiting EOL options, and the lack of examples of success. Circular economy changes to manufacturing and later steps within the material life cycle will require transformation to how a business operates. This business change will require greater priority to be placed on innovation and research and development, and modification of normal practice and organisational structure (Caldera et al., 2019; Fleischmann, 2019; Cother, 2020). In a study that interviewed Queensland SMEs, it was reported that the main reasons for not pursuing circular economy changes were a combination of lack of technical expertise within the business, time constraints, large capital costs, and absence of recognisable short-term benefits (Caldera et al., 2019). There are several drivers that will contribute to improvement in this area, including both a greater commitment to circular economy and providing more information and education. Caldera et al. (2019), recognised that there needed to be better understanding that adopting circular economy changes to manufacturing would also have immediate benefits such as water and energy saving, and there needed to be education on how to effectively make these changes across the whole organisation. Another benefit of a business adopting circular economy changes is that it can aid employee job satisfaction and organisational commitment, and consequently lead to employee retention and attraction (Harrach et al., 2020). Improving consumer education will also help as products containing waste materials have variable consumer approval and this can cause business hesitancy in adopting these new practices (Li et al., 2022).

A closely related barrier is that current product design often doesn't consider end-of-life (EOL) (Wiseman and Kariyawasam, 2020; Daljit Singh et al., 2021). This means that at EOL, it is more likely that a product will be disposed in landfill or downcycled rather than continuing as part of a circular economy. This is particularly evident for electrical products, as there is business pressure to focus on producing

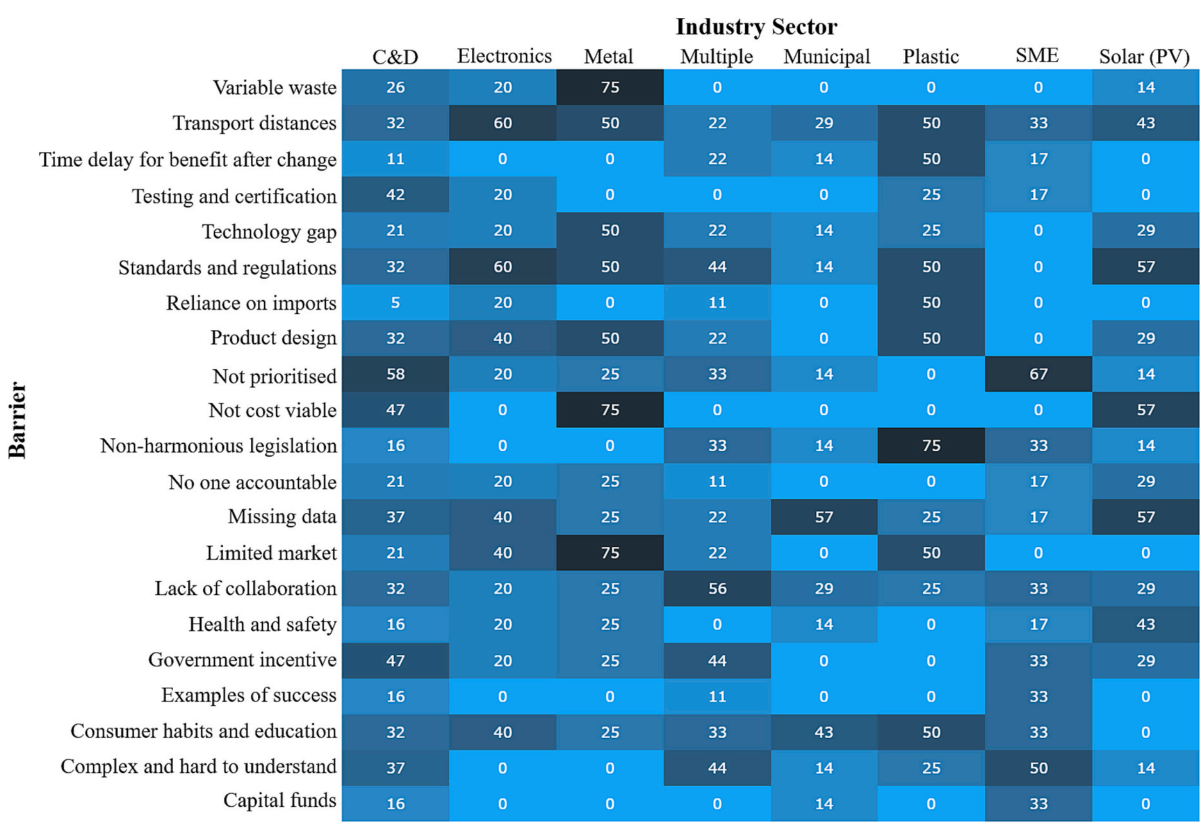

Fig. 5. Occurrence of barriers by industry sector. The values are the percentage of total papers focusing on each industry sector that reported that barrier. C&D; construction and demolition, SME; small and medium enterprises.

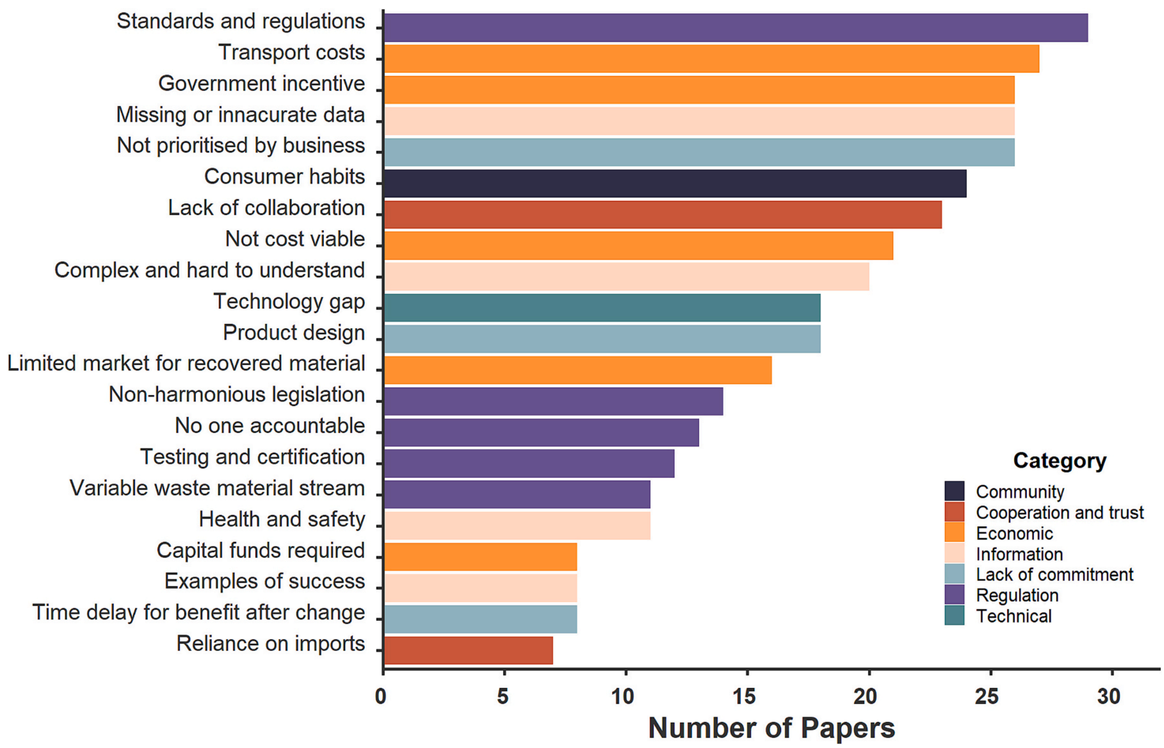

Fig. 6. Barriers identified in the systematic review.

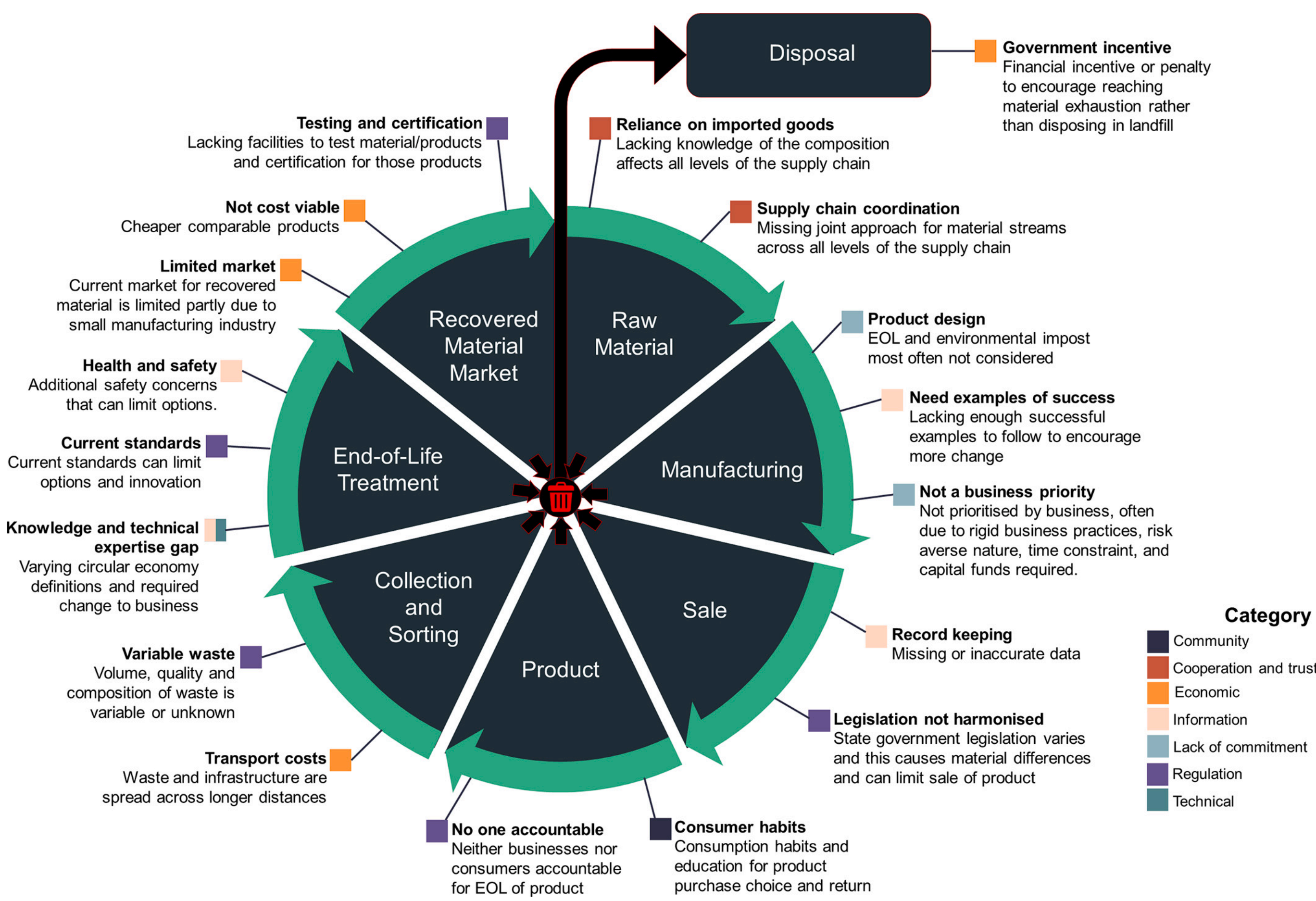

Fig. 7. Factors in Australia affecting the adoption of a circular economy.

new products to keep pace with technological advancement and market competition (Dominish et al., 2018). Simultaneously, there is economic disincentive to design for remanufacturing and component reuse as this would be done by another company and reduce profits for sale of new electrical products (Dominish et al., 2018).

Another common theme apparent in the literature was the importance of the design phase in reducing environmental impact and unnecessary waste generation (Jahan et al., 2022; Piller, 2023). An interview with construction industry participants from Melbourne, Australia, highlighted that design was the largest contributor to construction waste, due to excess ordering, poor understanding of construction practices, design inflexibility, and lack of waste management plans (Jahan et al., 2022). Concerningly, 70 % of participants did not consider waste management to be an important consideration, and around 58 % of participants were not using recycled materials in their projects. This was despite 70 % of participants receiving education, either through university or industry workshops, and suggests that there needs to be a greater focus within these courses on waste management practices particularly for designers.

One of the barriers to circular economy in Australia that was experienced by business in particular, was the lack of successful examples that model how to make circular economy changes (Argus et al., 2020; Frangioudakis Khatib et al., 2023). This barrier is closely connected to the 'not a business priority' barrier, as without successful examples the perceived risk and time investment needed is even greater.

For Australia to achieve repeated cycles, inspiration should be drawn from countries such as the Netherlands, who are considered one of the leaders in circular economy (Mazur-Wierzbicka, 2021). A successful example of this is the sustainable coffee and timber industry developed in the Netherlands partially due to government intervention (Vermeulen and Kok, 2012). These government initiatives taken during the early development and implementation of self-governance organisations in these industries were analysed in 2012 (Vermeulen and Kok, 2012). It was noted that in 1990 the government started to promote consumer awareness and also selectively procured from sustainable organisations. This was followed by direct regulation in the form of defining minimal standards and special tax arrangements, financed interactive regulation and internalisation and creating networks, up until 2009 when sustainability became the standard. This example demonstrates the considerable time for government intervention to impact the supply chain in the Netherlands and suggests that Australia may see similar success given enough time for businesses to transition, the education gap to be closed and new standards to be developed. It should be noted that also around the period of 2007–13, leading sustainable Dutch companies adopted practices such as supply chain analysis, monitoring of suppliers to ensure compliance, and training for suppliers (preferentially local ones) (van Lakerveld and van Tulder, 2017). This has not yet become widespread practice in Australia, particularly due to the reliance on imported products that do not have a high degree of transparency regarding the production process as discussed earlier.

3.2.3. Point of sale

The two barriers identified at point of sale include information about the product not being retained and shared to facilitate record keeping, and the variation in stage government legislation. In addition to product design changes, another improvement would be to have an accurate bill of materials (BOM) at point of sale to facilitate correct sorting and EOL treatment, as this would improve waste material quality and prevent health and safety concerns. Missing or inaccurate data was identified as one of the largest barriers to circular economy in this systematic review, and this begins at the first transfer from supplier to manufacturer, potentially manufacturer to manufacturer (multi-component products), and then applies again in transfer to consumer. As discussed in 3.2.1 Raw material, it is not always possible for manufacturers to obtain material data from suppliers, but it is also very rare that a BOM is provided to consumers (Babbitt et al., 2020). Not providing a complete BOM for products is understandable due to intellectual property concerns, but this should be made available for construction projects so that waste can be accurately managed at the demolition stage (Shooshtarian et al., 2021a). Some alternatives to providing a manufacturer BOM for products have already been suggested, including transforming the BOM into a maintenance version of the BOM (Liu et al., 2014) or industry- or researcher-provided databases of disassembly-based BOM (Babbitt et al., 2020). Regardless of solution, having this data publicly available would provide data essential for waste management and business investment cases.

If new legislation such as requiring a maintenance BOM is introduced, it should be harmonised across Australia as there is already criticism that state government differences are causing problems in EOL treatment and creating difficulties in understanding how to conform to varying standards (Shooshtarian et al., 2021a). Furthermore, this can disadvantage businesses in certain states or localities who have to pay higher costs to comply with regulations that national competitors do not have to adhere to (Kourabas and Nagtzaam, 2023). The state government is responsible for driving circular economy through providing funding and legislation, however in many cases it is the local government that is required to instigate that change (Melles, 2021). This can create problems if the local and state government agendas are not aligned, but furthermore, there can be challenges when local councils are expected to work together but are not in agreement (Fleischmann, 2019; Tobin and Zaman, 2022). The pressures of these expectations on local councils and likelihood of differing priorities is compounded by the fact that local government is only peripherally involved in the decision-making process of state and federal government (Jones, 2020). Despite these challenges being identified in the systematic review, there has still been only limited discussion on the implications of this barrier within these papers. This suggests that there needs to be further research into understanding the impacts of non-harmonious legislation on circular economy progress.

3.2.4. Product use

The two barriers identified at the product stage include current consumer habits and lack of education, and accountability for EOL of a product. Consumers are a major stakeholder in progression to a circular economy and in most cases, the business and government changes discussed previously require consumers to adopt new practices (Islam et al., 2020). These include changing consumption and disposal habits, and the main driver for addressing this barrier is education. Despite this acknowledged barrier, it is promising that consumer perspectives towards becoming more sustainable are increasing. The EY Future Consumer Index reported in 2021, that 44 % of global consumers are willing to support organisations that benefit society even if their products cost more, and within Australia, 37 % are willing to pay a premium for these products (Nijssen-Smith and L'Huillier, 2021).

This change in mindset could enable sustainable initiatives that were previously not economically viable to see success and encourage more companies to reduce their environmental impact either by changing raw materials, changing processing, or implementing schemes such as take-backs (return of product to business). This consumer drive will be important, as on average across 2022, the cost to purchase blow moulding grade recycled high-density polyethylene (HDPE) was USD $600/t more expensive than virgin HDPE in North America and USD $240/t more expensive in Europe (ChemAnalyst, 2022b; ChemAnalyst, 2022a). Ensuring that consumers understand the benefits of circular economy products is key for increasing willingness to pay higher premiums such as these. However, a challenge is that 56 % of consumers in Australia reported that they found identifying sustainable companies too time consuming or difficult and this is challenged even further by the pandemic of 'greenwashing' that is occurring globally (Nijssen-Smith and L'Huillier, 2021). Consequently, there is growing awareness amongst consumers for the need to move away from what constitutes a linear economy, but this is currently hindered by both lack of education and lack of certification.

Currently, for most products in Australia, each business and consumer have no obligation to be accountable for the next stage in the material life cycle, and consequently decisions made can have immediate or delayed effects in the success of re-processing and recovery efforts. These stakeholders may be entirely new entities in future cycles the material passes through, particularly if the material changes state/country. The current lack of accountability in Australia for the entire product lifestyle is particularly evident when you compare the Australian e-waste management system to that of Europe. In comparison to Europe who has included all 6 categories, Australia has only included 2 out of the 6 waste electrical and electronic equipment categories within the extended producer responsibility recycling scheme (Islam and Huda, 2020). This excludes a large number of electronics containing toxic compounds as well as precious and less-common metals, that are consequently less likely to be diverted from landfill due to lack of accountability. Introducing other categories to the extended producer responsibility scheme is complicated by the lack of technical expertise, advanced technology and infrastructure needed to recycle certain products such as photovoltaic panels (Islam and Huda, 2020). Research and development, and government influence are therefore critical, as without financial or legislated incentive or penalty, the rate of change for accountability is unlikely to improve. The Australian Government has indicated greater future regulation with the recently released, revised and expanded list of priority product stewardship products (Australian Government, 2022b).

3.2.5. Collection and sorting

The two barriers assigned to the collection and sorting stage include high transport costs and variable waste stream. A major feature of Australia, and also in other countries such as Canada, is the spread of the population across land mass. Large distances result in high transport costs, significant carbon emissions and increased maintenance requirements for transportation infrastructure. In addition, storage costs are incurred before transport, and limited space on-site restricts collection options (Ratnasabapathy et al., 2021b). On the other side, consumer engagement in recycling schemes such as container exchange programs or other initiatives, is also negatively impacted by inconvenient drop-off locations due to long transport distances (O'Dwyer et al., 2022). These factors culminate in a 'tyranny of distance', a challenge to the transition to a circular economy. The impact on regional areas is that it limits which types of processing technologies are commercially viable. For example, a pyrolysis plant for plastic solid waste needs to have a minimum processing capacity of 6250 t/month to be economically viable (Dai et al., 2022). An Australian regional city with a population of ~175,000 collects about 56–85 t/month of plastic on average (Australian Government and Blue Environment, 2020; Queensland Government, 2021), which excludes recovery technologies requiring economies of scale. However, research and development could lead to new technology such as modular processing operations that could change this current cost constraint for regional areas.

The second barrier that is further contributing to downcycling of material into low-value applications, or in worse cases leading to disposal in landfill, is that waste material quality, volume and composition is variable (Ratnasabapathy et al., 2021b; Soo et al., 2021). This is complicated by the uncertain effects of material degradation due to recycling, which is an issue that will increase in importance as more and more material passes through multiple cycles (Soo et al., 2021). A solution that has been suggested for minimising this barrier, is to enforce a standardised process for assembling products that are hard to disassemble, such as photovoltaic panels. This would mean that recycling and disassembly would follow a consistent process and technology, and the recovered material would be reasonably consistent in quality and composition (Daljit Singh et al., 2021).

3.2.6. End-of-life treatment

The three barriers identified at the EOL treatment stage include knowledge and technical gaps, current standards and health and safety concerns. EOL treatment refers to any processing or beneficiation of waste material required before it can be sold again, either as a complete product or as a recovered material. As discussed in previous sections, stakeholder education on sustainability and circular economy is needed and it should not be expected that the end-goal circular economy practices can be achieved in a single step change (Shooshtarian et al., 2022b). For example, in a survey of key stakeholders in the Australian architectural, engineering, and construction industry it was found that 70 % of participants understood circular economy but only 13 % had the knowledge and confidence to implement circular economy practices in their business (Shooshtarian et al., 2022b). This is despite 86 % of those participants responding that they were highly interested in adopting circular economy principles.

The current standards and policies within Australia can also limit options and innovation at EOL, for example Australia's focus on recycling, ahead of other strategies such as reuse and repair, has been criticised by several authors (Lane and Gumley, 2018; Melles, 2021; Schuyler et al., 2022). However, a successful blueprint for how to increase rates of reuse and repair is not yet available in Australia. Sweden reduced the tax burden for repair in 2017, and whilst this was lauded as a great step in the right direction, a 2020 follow-up study with key stakeholders discovered that this change had not made any impact on rates of repair (Dalhammar et al., 2020). It was noted that consumer education and business capacity for repair still needed to increase. This consumer education is needed for both understanding that repair had been made cheaper, but also in general for the preconception that second-hand goods are lower quality (Li et al., 2022). This education gap needs to be closed at the same time as the policy gap, as without understanding how to conform to and follow new policies there will not be significant change.

A goal of the circular economy is to ultimately either slow resource loops or close resource loops by creating a circular flow of material, and this by nature reduces the input of virgin resources. Consequently, there will be a growing disparity in circulating material quality and composition over reuse cycles, as well as a potential build-up of toxins within the systems. For example, it is recognised that the mechanical properties of HDPE are deteriorated after 10 cycles (Oblak et al., 2015), and the presence of contaminants like detergent can further accelerate this degradation and may build-up over time despite industrial washing (Mylläri et al., 2016). Of further concern, HDPE exposed detergent was found to have an increasing concentration of human carcinogen after every repeated extrusion cycle (Mylläri et al., 2016). Another example found in this systematic review, was the difficulties in treating photovoltaic panels due to the presence of toxic compounds such as lead, tin, gallium or cadmium telluride, which vary between module types (Mahmoudi et al., 2020). The uncertainty created by factors such as these would require increased quality control measures to be used by manufacturers and potentially more rigorous cleaning and pre-processing of material, which would have flow on economic and environmental effects. For example it was found that for a treatment plant to be economically viable for recycling photovoltaic panels in Australia, there would need to be at least ~20,000 t of waste panels per year (Mahmoudi et al., 2020).

Further research and development is required to understand this process for more materials, which would lead to generation of data and education material to support businesses in investing in capability to use more waste material.

3.2.7. Recovered material and product market

The three barriers identified at the recovered material and product market stage include the limited market for 'recovered' material, partially due to cheaper comparable products (not cost viable barrier), and also lack of testing and certification. This recovered material would continue the circular loop into the next lifecycle stage, as shown in Fig. 5, and therefore be utilised by the manufacturing industry. Australia's smaller manufacturing industry has further impacts of reducing the market for recovered material/products in Australia, as the cost of long transport distances or export often negates the value of the material as discussed previously (Li et al., 2022). Consequently, businesses are less willing to invest into methods to collect and process waste material due to the limited market for sale (Shooshtarian et al., 2022c).

In recognition of this problem, the Australian government announced the $15 billion National Reconstruction Fund in the 2022–23 budget to support developing the manufacturing industry (Australian Government, 2022a). Another government initiative to encourage development of local industries, is that the state of Victoria has ambitiously mandated that 90 % of content procurement be from Australia or New Zealand for public capital construction projects, where possible (Local Jobs First Policy 2003 (updated 2018)) (Ndukwe et al., 2021). However, growth in manufacturing will still take time despite this government support. Going forward, the location and technology/process used for both waste processing and manufacturing needs to be carefully considered to ensure that there is adequate material volume and quality for the desired application.

There are number of issues that have been raised previously with the current testing and certification system in the construction industry, including absence of third-party verification of claims made by products and insufficient number of available independent inspection services (Argus et al., 2020). The ability to transparently test and certify products, would not only give consumers confidence but also encourage businesses to make circular economy changes (Chakraborty et al., 2022). Another example from the food industry, is the challenge of obtaining approvals for processing of food grade recycled HDPE (rHDPE) as they are given on a case-by-case basis and contain more stringent cleaning requirements than polyethylene terephthalate (Franz and Welle, 2022). Consequently, this increases the start-up costs and investment risks for new businesses. In a recent study, it was found that rHDPE from mixed packaging sources was contaminated with several pesticides and polychlorinated biphenyls, and in general, had considerably more detected substances of concern with higher migration rates than mostly pure milk-bottle rHDPE (Su et al., 2021). Challenges like these have led to only 4 % of HDPE packaging being produced from rHDPE in Australia, which is far from the goal of 20 % rHDPE by 2025 (Australian Packaging Covenant Organisation, 2022). Whilst this is one example, it highlights how the current testing and certification setup is limiting progression to circular economy and changes to this process as well as more facilities/independent bodies need to be developed.

3.2.8. Material disposal

A simple definition of circular economy is that waste is no longer generated; however, in reality that is not yet possible for the majority of materials due to the degradation that occurs in repeat cycles or irreversible changes that are made to the material (Desing et al., 2020). Consequently, at some point in a circular economy the majority of materials or products are going to reach a disposal stage and will either need to be managed or recovered as energy. The goal of circular economy should be to reduce this virgin resource use through extending the life of materials already in circulation through various methods, and nearly all the barriers identified in this systematic review can help towards delaying this stage. However, the lack of government incentives for progressing towards a circular economy is one of the most frequently reported barriers identified in this review and government influence here could be utilised to encourage delaying reaching material exhaustion. For example, the majority of Australia now has waste levies in place to discourage waste disposal and this has led to circular economy approaches becoming more viable due to the costly alternative of disposal (Shooshtarian et al., 2020).

For future incentives/penalties and for the government to be able to effectively lead Australia towards a circular economy, there needs to be thorough analysis conducted to inform these decisions/policies made. This should be a joint contribution from key stakeholders and be facilitated by close working relationships between research and industry/business. As raised in the introduction, a specific material focus and the four scales of change (location, responsibility, magnitude and time) should be considered when attempting to address the complex problem of transitioning to a circular economy.

4. Discussion

This systematic review examined the barriers to circular economy in Australia across all product and material types available in the literature and grouped the findings into 21 barriers to circular economy. Of the 74 papers included in the systematic review, 47 % were focusing on larger waste streams such as construction and demolition (C&D), municipal waste, and waste in general (multiple areas). In particular, C&D waste accounted for 26 % of all papers and has been increasing in rates of publication in recent years. The high rates of urban development in Australia have led to C&D waste increasing by 39 % per capita over the last 15 years, in contrast to municipal, and commercial and industry (C&I) waste which have fallen during the same time period (−13 % and − 21 % per capita respectively) (Australian Government and Blue Environment, 2022). The other concern noted in the National Waste Report for C&D waste is that data collection and resource recovery is generally only from larger C&D projects, and smaller projects often send mixed material directly to landfill. These trends as well as the increasing cost of virgin material and awareness of resource use may have contributed to this recent, accelerated focus in Australia.

This trend of growing interest in managing C&D waste is also occurring globally, as found in a recent systematic review (Wuni, 2022). This global systematic review found that regulatory, financial and knowledge barriers were the most frequently occurring in the literature. In comparison, our Australian systematic review found that the most frequently occurring barrier for C&D waste was that circular economy is not prioritised by business due to factors such as time constraints, rigid organisational structure, and risk averse tendencies. This type of barrier was examined in the global systematic review (classified as organisational barriers) but was ranked only 8th out of 11 barriers. In our review, 67 % of all studies focusing on small-to-medium sized enterprise (business) had the same low business priority barrier similar to other global findings (Takacs et al., 2022). This suggests that an important barrier to address in Australia for targeting both C&D and business waste is to focus on raising organisation awareness and capability. The study by Takacs et al., recommends six management implications to mitigate this barrier including 'strengthening internal awareness for sustainable change' and 'stimulate intertemporal and sustainability-based risk assessment and decision making'. A challenge with circular economy analysis is that this sustainability-based risk assessment and decision making is often complex in operation and interpretation, and this can limit use by and impact on business decisions. A tool to assess economic, environmental, and social benefits that can be transparent and easily understood by business, government and consumers would be ideal in addressing this challenge.

An encouraging finding from this systematic review is that the majority of papers have narrowed the focus area to at minimum a waste stream or industry, with only 10 % focusing on circular economy in general (multiple areas). This can aid in in identifying important challenges and opportunities to include in the analysis and decision-making. For example, 75 % of papers focusing on plastics included the non-harmonious government legislation barrier, suggesting that this is a key area for improving plastics recovery. Whereas, for a metal circular economy, 75 % of all papers mentioned that it is not cost viable due to reasons such as variable waste and limited market, and 0 % of papers mentioned non-harmonious legislation. This indicates that there are barriers unique to select materials or products, but a useful contribution of this systematic review is the identification of barriers that are impacting across multiple supply chains. This includes barriers such as transport costs due to the lack of local infrastructure, circular economy not being prioritised by business, lack of available and accurate data, lack of collaboration to support a circular economy, and consumer habits and education (Fig. 5). Therefore, targeting these barriers could be an effective way to impact multiple industry sectors simultaneously.

Whilst this review has focused on Australia, the barriers and later recommendations made may be relevant to other countries that share some similar characteristics, for example low population density and low economic complexity in particular. Australia has an average population density of 3 persons/km^2, which is followed by other G20 countries Canada with 4 persons/km^2, Russia with 9 persons/km^2, Saudi Arabia with 17 persons/km^2, and Argentina with 17 persons/km^2 (Worldometer, 2024). Consequently, Canada and Russia in particular are more likely to face barriers that are directly caused by low population density such as transport costs, supply chain coordination challenges, and limited market. There may be indirect effects from a low population density that result in Canada and Russia also sharing other barriers identified in this review of Australia. The economic complexity index of Australia is far below other G20 countries, ranking 93rd in comparison to the next lowest G20 country Brazil at rank 70 (Harvard Growth Lab, 2024). This is despite the high GDP per capita (nominal) of Australia, which ranks 2nd out of all the G20 countries and 10th in the world (Worldometer, 2024). Consequently, Australia is quite unusual in these two characteristics and for economic complexity is similar to developing countries, whereas GDP per capita is firmly in the developed country category. Further exploring country characteristics in comparison to circular economy progress and barriers would contribute to understanding why certain circular economy strategies are effective in some countries and are ineffective or underutilised in other countries.

Concerningly, this systematic review highlighted that there has been only limited research into the materials shown in Fig. 1 in the last 6 years in Australia, with only 1 study focusing on glass, 0 on paper and cardboard, 4 on plastics, and 2 on textiles. The recovery rates for these materials are either stagnating or declining in recent years and are therefore not on track towards achieving the goal of 80 % recovery by 2030. In particular, there needs to be more research into plastics and textiles as they currently only have a recovery rate of 13.5 % and 20.8 % respectively. This is a research gap that should be explored further.

4.1. Recommendations

When these barriers were divided into the 7 different categories, economic barriers were most frequently cited as the barrier to circular economy, followed closely by regulation, information and the requirement for a commitment to circular economy. The economic barriers are more difficult to directly influence, excluding government incentive or penalty. Focus should instead be placed on overcoming regulation and information barriers to circular economy, as this has flow on effects to many other barriers and has impacts across many 'life stages' of a material. Taking the results of this review, we propose the following five recommendations to address the identified barriers and enable Australia to progress to a circular economy:

1. Increase government financial incentive or penalty for businesses to engage and commit to circular economy strategies. This could be at any point along the 'lifecycle' of a material. This barrier ranked third in the systematic review and is also the only economic barrier that can be directly impacted without requiring other barriers to be immediately addressed. Similarly, continuing and implementing new policies that enable Australian products to compete with imported products would have beneficial effects throughout the whole supply chain.
2. Harmonise state legislation and standards for waste management and products containing non-virgin material across Australia and raise awareness, to prevent industry and community confusion, and also open up wider markets for sale. The complexity of circular economy and risk of businesses committing to a circular economy can be minimised by removing this barrier. This will be a difficult change to implement, as legislation and standards are currently decided in each state due to party priorities, availability of infrastructure and business, and reflect the preceding iterative progress that each state has made.
3. Implement testing and certification of products containing non-virgin material, recovered material, or repaired products to provide greater incentive for businesses through recognition, and create improved consumer and inter-business trust. This testing and certification should be highly transparent and harmonised across Australia for the same reasons as the above. This could be implemented in conjunction with revised standards and regulations.
4. Improve data availability of product or building material composition at EOL. This change would reduce the amounts of 'unknown' waste, health and safety concerns, and allow for dissemination of targeted educational material for collection and sorting and EOL treatment. This could be achieved by either regulatory change to business sharing of BOM (e.g. a maintenance version of the BOM, disassembly based BOM or elemental composition BOM), more restrictive standards or improved labelling or identification of materials. Research to further develop sensor technology and identification could help to develop this data without requiring changes to regulations. Preferably, this technology will be able to identify material composition of comingled or composite material to enable adoption in material recovery facilities.
5. Recognise that change takes time and plan iterative progressions towards a circular economy rather than assume a 'black' (linear) and 'white' (circular) scenario. This would allow for smaller improvements made over time, to allow for education of stakeholders, new standards, business procurement and practice change, consumer behaviour change, and development of infrastructure. This can help to address the problems of the current limited market for material and high transport costs created by distance between collection and processing.

4.2. Limitations

A limitation of this study is that the included studies that consulted consumers or businesses may not be true representations of barriers from these stakeholders as within each paper they have been interpreted and analysed by researchers and therefore could be subject to bias. For potentially more accurate representations from these stakeholders, industry or government reports should be used (grey literature). This systematic review has purposely focused on a higher-level view of circular economy in Australia, and consequently the search terms were limited to "circular economy" and "supply chain" and did not include other circular economy related words such as "product reuse", "waste prevention" and "recycling". Due to this decision, it is possible that other relevant papers to this systematic review may not have been included in this systematic review. However, this systematic review included 74 papers in the past 6 years, which is still a considerable number for a country the population size of Australia. Despite the intention of this systematic review to analyse a broad range of products and materials, approximately 25 % of all papers included in this systematic review were focused on C&D waste and this is likely to have skewed the barrier frequency towards C&D waste barriers.

5. Conclusion

In summary, this systematic review contributes to the understanding of the circular economy progress to date in Australia and highlights key areas for improvement. There were 21 barriers to an Australian circular economy identified in this systematic review, assigned to 8 life cycle stages. The most frequently occurring barriers included: current standards and regulations, the high cost of transport, lack of government incentive, missing or inaccurate data, and businesses not prioritising the changes needed for circular economy. Whilst these barriers have been assigned to a specific life cycle stage, it is clear that most barriers are highly connected and overcoming one barrier is often dependent on one or more other barriers. This illustrates the complexity of barriers across circular economy but also, actions to address a single barrier will likely have a positive impact on other barriers.

Implementing the 5 recommendations would help to address the identified barriers and help Australia to progress towards a circular economy, but they also include varying degrees of risk if implemented without careful consideration. Therefore, research should focus on these key areas to guide how to plan and deliver on the 5 recommendations in a way that balances economic, environmental and social benefits. At the same time, research to develop databases and understand the relationships between success of circular economy strategies and regional and government differences needs to be focused. This information is required to support these decisions being recommended in different locations and material supply chains. The recommendations made in this review are relevant to other countries with similar barriers to Australia and could be used in future global comparisons for circular economy barriers. These future global comparisons should consider the characteristics of each country, such as the economic profile and population characteristics discussed in this paper, when comparing circular economy progress.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Paulomi (Polly) Burey reports financial support was provided by Australian Government Department of Education. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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