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Systemic Gaps in Circular Plastics: A Role-Specific Assessment of Quality and Traceability Barriers in Australia

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Abstract

The effective adoption of quality assurance and traceability systems is increasingly recognised as a critical enabler of circular economy (CE) outcomes in the plastics sector. This study examines the factors that influence the implementation of such systems within Australia's recycled plastics industry, with a focus on how these factors vary by company size, supply chain role, and adoption of CE strategy. Recycled plastics are defined here as post-consumer or post-industrial polymers that have been reprocessed for reintegration into manufacturing applications. A mixed-methods survey was conducted with 65 stakeholders across the Australian plastics value chain, comprising recyclers, compounders, converters, and end-users. Respondents assessed a structured set of regulatory, technical, economic, and systemic factors, identifying whether each currently operates as an enabler or barrier in their organisational context. The analysis employed a comparative framework adapted from a 2022 European study, enabling a cross-regional interpretation of patterns and a comparison between CE-aligned and non-CE firms. The results show that firms with CE strategies report greater alignment with innovation-oriented enablers such as digital traceability, standardisation, and closed-loop models. However, these firms also express heightened sensitivity to systemic weaknesses, particularly in areas such as infrastructure limitations, inconsistent material quality, and data fragmentation. Small- and medium-sized enterprises (SMEs) highlighted compliance costs and operational uncertainty as primary barriers, while larger firms frequently cited frustration with regulatory inconsistency and infrastructure underperformance. These findings underscore the need for differentiated policy mechanisms that account for sectoral and organisational disparities in capacity, scale, and readiness for traceability. The study also cautions against the direct transfer of European circular economy models into the Australian context without consideration of local structural, regulatory, and geographic complexities.

Keywords: circular economy; Australia; recycling; plastic; quality; traceability

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1. Introduction

The global shift toward a circular economy has emphasised the need to close material loops and reduce reliance on virgin resources, particularly in plastic production and consumption [1]. As one of the most visible and problematic waste streams, plastics have drawn significant policy, industry, and public attention, driving efforts to improve recycling outcomes, promote the uptake of recycled content, and enhance traceability across supply chains [2]. In Australia, these challenges are particularly acute due to the country's geographical isolation, fragmented regulatory landscape, and limited domestic reprocessing capacity [3–5]. At the same time, growing momentum from state and federal initiatives, including mandatory recycled content targets, industry-led stewardship programmes, and extended producer responsibility schemes, has created a complex and dynamic environment in which businesses are being asked to do more with recycled materials, often without the operational clarity or infrastructure needed to support these ambitions.

While the technical feasibility of recycling plastics has improved considerably over the past decade, widespread adoption of high-quality recycled materials remains constrained by persistent challenges. These include contamination of input streams, inconsistent material quality, limited access to reliable traceability systems, and a lack of harmonised standards. Moreover, the capacity of businesses to engage with recycled content varies significantly depending on their size, sector, supply chain role, and level of engagement with circular economy principles. Despite a growing body of literature on plastic recycling and circularity, there is limited empirical evidence on how these factors shape business behaviour and investment decisions in Australia's recycled plastic value chain [6–8].

Existing studies tend to focus either on macro-level policy analysis or isolated technological innovations, leaving a gap in understanding firms' operational and organisational requirements when attempting to incorporate recycled plastic into their value chains [9,10]. While many international models, such as those implemented in the United Kingdom, The Netherlands, and Germany, have advanced mechanisms for tracking recycled content and ensuring material quality [11], their transferability to the Australian context remains limited due to profound structural, geographic, and regulatory differences [3]. These European systems are typically embedded in more mature and centralised market structures, underpinned by stronger policy coordination and enforcement capacity. In contrast, Australia's federal-state divide introduces significant regulatory heterogeneity, while its geographic isolation and dispersed infrastructure challenge system-wide standardisation and implementation. This raises questions about the assumption that policy frameworks can be transposed wholesale across national contexts without accounting for institutional fit. This study seeks to address this gap by examining the lived realities of Australian businesses involved in the plastic value chain, from raw material suppliers and recyclers to converters, compounders, and end-users. In this way, it aims to provide a grounded understanding of the barriers and enablers influencing the quality of recycled plastics and the systems needed to ensure traceability across diverse market applications.

This study focuses on both post-consumer and post-industrial recycled plastics, including commonly reprocessed streams such as flexible and rigid packaging, film, and industrial scrap. These materials represent the dominant input types in Australia's recycling sector and are especially affected by issues of quality variability, contamination, and downstream verification. Several European nations have developed advanced, system-wide mechanisms to improve traceability and material quality. For example, the United Kingdom's Plastic Pact integrates recycled content targets with product design guidelines and reporting requirements. At the same time, Germany's Dual System (Der Grüne Punkt) uses extended producer responsibility (EPR) to enforce packaging traceability and recycling quotas. In contrast, Australia's regulatory environment remains fragmented across states and sectors, with limited national coordination and voluntary participation in initiatives involving recycled content.

Drawing on industry survey data and comparing emerging patterns with European experiences, this research contributes to a more granular and actionable understanding of the institutional, technical, and relational conditions required to scale up recycled content in Australia. It offers a practical lens through which to assess the alignment between policy expectations and business capacity while identifying where targeted interventions or collaborative mechanisms could enhance the functionality and integrity of recycled plastic markets.

This study investigates the critical enablers and barriers shaping quality and traceability practices in Australia's recycled plastic value chain, focusing on how these factors vary according to company size and adopting circular economy (CE) strategies. By adopting a value chain perspective, the research aims to uncover the specific business requirements that influence the uptake of recycled plastics, providing both strategic insight and practical implications for advancing circularity in the sector. The core research question guiding this study is: What are the key enablers and barriers influencing quality and traceability practices in Australia's recycled plastic value chain, and how do these vary by company size and CE strategy adoption? In addressing this question, the study explores the broader business and operational conditions that facilitate or hinder the integration of recycled plastics into mainstream applications. These include technological capabilities, regulatory clarity, material availability, certification systems, and information-sharing mechanisms, each of which plays a distinct role in determining the reliability and scalability of recycled content in various market segments.

The research examines how these challenges and enablers are experienced differently by organisations based on their role in the supply chain, their degree of vertical integration, and whether they operate under a circular economy framework. Special attention is given to identifying how operational needs and strategic priorities translate into actionable requirements, such as investment in sorting technologies, establishing traceability systems, or the demand for harmonised material standards. These insights are grounded in survey data collected from Australian stakeholders across multiple sectors, including manufacturing, recycling, product conversion, and service provision. An important dimension of the study is its comparative ambition. In order to situate Australia's experience within a broader international context, the findings are discussed alongside recent literature and data from leading European countries such as the United Kingdom, the Netherlands, and Germany. These regions have made significant advances in the governance and technical implementation of quality and traceability frameworks for recycled plastics. By contrasting local findings with European benchmarks, the study highlights structural differences and potential areas of convergence, offering a critical perspective on Australia's positioning in the global circular plastics agenda. This research contributes a novel analytical angle by combining value chain mapping, CE strategy profiling, and practical business needs assessment within a single framework. Integrating role-based segmentation and within-role comparison further adds depth to the analysis, allowing the study to move beyond surface-level policy commentary to engage with the real-world constraints and innovations driving or impeding circularity at the firm level. Ultimately, the study provides evidence-based recommendations to policymakers, industry leaders, and supply chain actors seeking to scale up the use of recycled plastic in an economically viable and environmentally credible manner.

2. Method

This study employs a mixed-methods survey design to investigate the enablers and barriers influencing the uptake of recycled plastics in Australia. It specifically emphasises how practices related to quality assurance and traceability vary by company size and adoption of a circular economy (CE) strategy. By integrating quantitative and qualitative data, the research provides a comprehensive view of stakeholder perceptions, organisational capacities, and value chain dynamics shaping the use of recycled plastic across the Australian market.

The survey instrument was structured into two main sections. The first collected background and demographic information, including the respondent's role in the value chain, business model, years of operation, company size (approximated through processing volumes), market applications, and engagement in CE strategies. The second section was designed to identify perceived enablers and barriers to adopting recycled plastics. This was achieved by presenting participants with statements across four thematic domains, regulatory and policy, economic, technical, and systemic, and asking them to rate whether each factor currently operates as an enabler, a barrier, or neither within their organisational context.

The regulatory and policy factors included perceived alignment of regulations, financial stimulation and incentives, minimum recycled content requirements, public awareness initiatives, and enforcement of existing waste legislation. Economic factors covered recycling costs, the price competitiveness of recycled plastic, volatility in material prices, demand from existing or new markets, investment needs (in infrastructure or research and development), and factors affecting financial predictability such as long-term contracts and economies of scale. Technical factors addressed material-related issues, including contamination of waste streams, design for recyclability, innovation in materials and recycling technologies, inconsistency or uncertainty in material quality, and data availability (such as polymer composition or processing compatibility). Systemic factors included the presence of a systems perspective within organisations, closed-loop recycling models, standardisation of recycling processes and product designs, infrastructure capacity, and the use of data, digital technologies, or traceability systems.

Participants were also allowed to expand on their responses through open-text fields, sharing insights on the benefits and limitations of current practices, describing their investment intentions or plans, and suggesting specific improvements to traceability or quality systems. The survey combined multiple-choice, Likert-scale, and open-ended questions to support structured statistical analysis and deeper thematic exploration.

The survey was developed based on a review of previous research on traceability in plastic waste systems [7,12] and aligned with international standards such as ISO 22095 [13], which guides chain of custody. To enable meaningful international comparison, the factor analysis applied in this study was adapted from the methodology developed by van der Vegt, Velzing [11], which previously assessed circular economy practices to increase the integration of recycled plastic into material feedstock supply chain in The Netherlands, the United Kingdom, and Germany. By aligning the structure of our survey data with that study, we ensured methodological consistency across regions. This alignment allowed for a systematic cross-regional analysis between Australia and leading European contexts, facilitating a direct comparison of how businesses perceive and respond to enablers and barriers in quality assurance and traceability. However, it is important to note a key methodological distinction: van der Vegt, Velzing [11] employed open-ended qualitative interviews, recording only those factors that were spontaneously mentioned by participants, which were then coded thematically. In contrast, our study evaluated each factor presented, regardless of their supply chain role, using a structured response format. This contrasts with the thematic coding approach used in van der Vegt, Velzing [11], where a factor was only recorded when spontaneously mentioned during interviews. As such, our data allows for the calculation of mean scores, relative comparisons, and subgroup analyses, providing a more systematic and statistically robust assessment of perceived enablers and barriers across the Australian plastic value chain. The comparative framework was designed not only to identify best practices and shared challenges but also to explore how divergent regulatory settings, market maturity, and infrastructure availability influence the implementation and effectiveness of circular economy measures. Before launch, the survey was pilot tested with five industry stakeholders, including plastic converters, recyclers, and a policy advisor, to refine language and ensure contextual relevance. Data were collected via the Qualtrics platform between July 2023 and February 2024. Ethical approval was obtained from the Curtin University Human Research Ethics Committee (HRE2023-0315).

A purposive sampling strategy was adopted to target stakeholders directly engaged in the recycled plastic value chain, including raw material suppliers, plastic compounders, converters, end-user manufacturers, waste processors, and supporting organisations such as testing labs, technology providers, consulting firms, and universities. Invitations were distributed through direct email outreach, industry associations, and professional networks, supplemented by snowball sampling via word-of-mouth referrals. A total of 548 invitations were sent. Respondents were eligible if they operated in Australia and had at least one year of experience in the field. After excluding incomplete responses and those from outside Australia, 65 valid responses were retained for analysis. The final sample comprised a diverse set of roles, including recyclers, compounders, converters, end users, and service providers, allowing for role-based segmentation and comparative subgroup analysis. This targeted approach prioritised depth and relevance of responses over statistical generalisability for this exploratory survey.

The final sample included stakeholders representing plastic converters (20.16%), end-user manufacturers (8.06%), compounders (8.87%), waste processors (21.77%), raw material suppliers (10.48%), and service/support organisations (30.65%). Some respondents reported involvement across multiple roles in the value chain, reflecting the integrative nature of several business models within the sector. This approach reflects calls for disaggregated stakeholder analysis in circular plastics, such as those made by Ramanathan, Sadhasivam [14].

The study applied quantitative and qualitative analysis to derive a nuanced understanding of value chain dynamics. Quantitative data were used to identify trends, compare responses across subgroups (e.g., with or without CE strategies), and test for statistical differences using *t*-tests, effect size calculations (Cohen's d), and frequency analysis. Qualitative responses were thematically analysed to uncover contextual factors, stakeholder motivations, and emergent patterns not captured through fixed-choice items. Integrating both methods enhanced the interpretive power of the findings and allowed for triangulation between statistical patterns and narrative insights.

The study focused specifically on the perspectives of industry actors, recognising that producers, recyclers, and supply chain intermediaries play a central role in implementing traceability systems. However, the survey did not extend to other stakeholder groups such as consumers, government bodies, or NGOs due to time and budget limitations. Future research should incorporate these perspectives to gain a comprehensive understanding of the full scope of support and influence available for advancing traceability in plastic recycling. As noted by Stewart and Niero [15], most collaborations in this space are business-focused despite the important role that consumers and other societal actors play in driving circularity. This point is further supported by Ruokamo, Räisänen [16], who found that most surveyed consumers viewed recycled plastic positively when making purchasing decisions. The anonymised dataset is available upon request following Curtin University's research ethics guidelines. This study contributes novel empirical evidence on business-level conditions required to enhance the adoption of recycled plastic in Australia, offering policy-relevant insights into how traceability and quality assurance practices can be better aligned with circular economy goals.

Descriptive statistics provide an overview of how respondents answered key questions, helping identify data patterns. The mean and standard deviation were used to summarise stakeholder responses. The mean reflects the average score on survey items, while the standard deviation indicates the extent to which responses varied around that average [17]. A low standard deviation shows that participants largely agreed on a particular issue, whereas a higher value indicates more diverse opinions [18]. These measures help quantify stakeholder views and allow comparisons across different groups within the industry. The inclusion of correlation coefficients would not be useful, as the survey responses were primarily ordinal (binary coding of enabler/barrier, followed by average aggregation), which limits the appropriateness of traditional parametric correlation analysis. Instead, the study emphasises comparative group-level trends and qualitative pattern interpretation. Future studies with continuous or Likert-scale data structures could explore these relationships using formal correlation or regression techniques.

3. Results

The factor analysis conducted on the survey results provides a quantitative assessment of the enablers and barriers associated with quality and traceability in the context of circular economy practices. Tables derived from the analysis present a graded evaluation where factors are weighted based on their perceived impact, with positive scores indicating enabling influences and negative or lower scores representing barriers. This approach allows for identifying specific drivers that promote the adoption of quality and traceability systems, as well as obstacles that hinder their implementation. Aggregated mean scores reflect the average perception across stakeholder groups. The scoring approach enables comparison across organisational roles and circular economy strategy adoption status, but should be read as indicative rather than absolute, given the perceptual and categorical nature of the data. By coding the factors as enabler (1) or barrier (−1), the analysis highlights the relative significance of various components across regulatory, economic, technical, and systemic dimensions such as Mandal, Mondal [19] highlighted into their methodology. For example, “standardisation of recycling processes” and “closed-loop recycling systems” consistently emerge as strong enablers, with high positive scores reflecting their critical role in advancing circularity. Conversely, “costs of recycling” and “fluctuating costs” appear as significant barriers, with negative or low scores indicating their potential to deter progress in achieving quality and traceability objectives also relate as barriers to circular adoption in Badhotiya, Avikal [20] study. The results underscore the variability of these influences across different company sizes and whether a circular economy strategy is in place, SMEs often encounter distinct obstacles, necessitating tailored strategies for circular economy integration, as emphasised by Olipp, Woschank [21]. Large companies with CE strategies report higher enabler scores, particularly in systemic factors such as “technology, data, and traceability”, suggesting that these firms are better positioned to leverage innovative tools for circular practices. On the other hand, small and medium enterprises without CE strategies often identify barriers like “inconsistent material quality” and “investment costs for capital and infrastructure”, reflecting resource constraints and operational challenges [22]. This nuanced grading of factors as enablers or barriers provides a framework for understanding the diverse experiences of organisations in integrating quality and traceability measures. The analysis emphasises the need for tailored approaches to address the unique challenges faced by different stakeholders while leveraging the most impactful enablers to drive progress toward a circular economy.

The regulatory factor (Table 1) examines the impact of company size and circular economy (CE) strategy on five regulatory and policy factors: alignment of regulations, financial stimulation, minimum recycled content requirements, public awareness, and enforcement of waste legislation. These regulatory levers are widely recognised as critical to supporting CE adoption and closing the loop on material use [23]. For small companies without a CE strategy, the mean scores for alignment of regulations and minimum recycled content requirement are 0.143. In contrast, financial stimulation, public awareness, and enforcement of waste legislation score higher at 0.429, with standard deviations indicating substantial variability across all factors. This aligns with previous research indicating that financial incentives and regulatory enforcement are particularly important for smaller enterprises that lack internal resources to pursue circular initiatives [24]. Medium-sized companies without a CE strategy display a unique pattern, with a mean score of 1 for minimum recycled content requirement and public awareness but −1 for alignment of regulations and 0 for enforcement of waste legislation, highlighting polarising responses and significant variability in some areas. This pattern reflects broader observations that medium-sized firms often struggle with inconsistent regulatory environments and lack of targeted support [25]. Large companies without a CE strategy show higher mean scores for alignment of regulations (0.4) and enforcement of waste legislation (0.8), though variability remains high for most factors. With a CE strategy, small companies show an increase in mean scores for most factors, notably public awareness (0.6) and minimum recycled content requirements (0.52), accompanied by reduced variability compared to their no-CE counterparts. As previously noted, public campaigns and mandatory content targets are effective tools to trigger CE action, especially when aligned with industry awareness and expectations [26]. Medium companies with a CE strategy demonstrate moderate engagement across all factors, with scores generally lower than their no-CE strategy counterparts, suggesting less pronounced differences due to CE adoption. Large companies with a CE strategy bring mean scores of 0.5 for minimum recycled content requirement and generally lower scores for the other factors, indicating limited engagement despite the adoption of CE principles, with variability remaining consistent across most factors. The data reveal how company size and CE strategy adoption interact with regulatory and policy factor engagement, showing distinct variability and engagement levels across the factors examined.

Table 1. Regulatory and policy factors (higher scores indicate that the factor is perceived an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

			Alignment of Regulations	Financial Stimulation	Minimum Recycled Content Requirement	Public Awareness	Enforcement of Waste Legislation
Without CE strategy	Small	Mean	0.14	0.42	0.14	0.42	0.42
		stdev	0.90	0.78	0.90	0.78	0.78
	Medium	Mean	−1.00	0.50	1.00	1.00	0.00
		stdev	0.00	1.00	0.00	0.00	1.15
	Large	Mean	0.40	0.40	0.00	0.00	0.80
		stdev	0.89	0.89	1.00	1.00	0.44
With CE strategy	Small	Mean	0.00	0.36	0.52	0.60	0.44
		stdev	1.00	0.95	0.87	0.81	0.87
	Medium	Mean	0.43	0.06	0.31	0.18	0.31
		stdev	0.89	0.99	0.94	0.98	0.94
	Large	Mean	0.00	0.25	0.50	0.00	0.00
		stdev	0.92	0.88	0.75	0.92	0.92
	[11]		−1	1	1	1	−1

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Given the methodological asymmetry between this study and the European reference study, which relies on qualitative coding of spontaneous mentions, the comparative insights should be treated cautiously. Our structured factor-rating approach enables broader participation and consistency but may also increase the visibility of factors that may not have emerged spontaneously in a qualitative setting. As such, the cross-regional comparison highlights general directional trends in perception rather than offering a score-to-score equivalence. The comparison with van der Vegt, Velzing [11], these findings show that regulatory perceptions vary by company size and CE strategy. While their study labels alignment and enforcement as barriers, medium firms without a CE strategy echo this view. In contrast, large and CE-oriented firms report more positive or moderate views, underscoring the need for context-specific policy design.

The comparative analysis of stakeholder perceptions across the plastics supply chain reveals that the presence or absence of a circular economy (CE) strategy does more than shift attitudes toward policy; it fundamentally reshapes how regulation is interpreted as an enabling or barrier (Table 2). The divergence reflects not merely varying organisational philosophies but a proxy for underlying structural, institutional, and perhaps even market-based asymmetries.

Table 2. Regulatory and policy factors with stakeholder position within the supply chain (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

			Alignment of Regulations	Financial Stimulation	Minimum Recycled Content Requirement	Public Awareness	Enforcement of Waste Legislation
Without CE strategy	Conversion	Mean	−0.25	0.25	0.75	0.75	0.25
		Stdev	0.96	0.96	0.50	0.50	0.96
	End user	Mean	−1.00	1.00	1.00	1.00	−1.00
		Stdev	0.00	0.00	0.00	0.00	0.00
	Raw Material Importer	Mean	1.00	1.00	0.00	0.00	1.00
		Stdev	0.00	0.00	1.41	1.41	0.00
	Service	Mean	−0.11	0.33	0.11	0.33	0.56
		Stdev	0.93	0.87	0.93	0.87	0.73
With CE strategy	Conversion	Mean	0.50	0.25	0.50	1.00	0.75
		Stdev	0.93	1.04	0.93	0.00	0.71
	End user	Mean	1.00	1.00	0.33	1.00	1.00
		Stdev	0.00	0.00	1.15	0.00	0.00
	Raw Material Importer	Mean	−0.25	0.25	0.25	−0.25	0.75
		Stdev	0.96	0.96	0.96	0.96	0.50
	Waste processor	Mean	−0.13	−0.38	−0.38	−0.13	−0.38
		Stdev	0.99	0.92	0.92	0.99	0.92
	Service	Mean	−0.12	0.29	0.65	0.18	0.24
		Stdev	0.99	0.99	0.79	1.01	0.97

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Among stakeholders without a CE strategy, the inconsistent and often conflicting views on regulatory instruments suggest a reactive posture where regulation is perceived as externally imposed rather than internally aligned with business models [27]. For example, the conversion group's slight negative valuation of alignment of regulations (mean = −0.25) combined with its positive reception of content mandates and public awareness efforts (both mean = 0.75) exposes a selective approval dynamic. This group appears more open to consumer-facing or production-related incentives but remains sceptical of overarching regulatory coordination, potentially signalling frustration with policy fragmentation or administrative uncertainty as discussed by Ghisellini, Cialani [28]. Similarly, the unanimous negative perception of enforcement (mean = −1.00) by end users in this group may reflect more profound compliance fatigue or a lack of clarity in enforcement criteria, rather than resistance to regulation itself. Interestingly, raw material importers without CE strategies present a reverse profile: strongly supportive of alignment, financial stimulation, and enforcement (all with means = 1.00), but neutral or noncommittal toward recycled content requirements and public awareness. This could indicate a group that benefits from regulatory clarity and top-down policy measures but is insufficiently integrated into downstream consumer or product responsibility frameworks. Service providers, meanwhile, overlap neutrality and inconsistency, suggesting either a lack of intense engagement with regulatory instruments or a highly variable operational environment that makes generalisation difficult [29].

By contrast, stakeholders with CE strategies demonstrate more favourable perceptions overall and greater internal coherence in how regulation is interpreted. This trend is most striking among end users, who uniformly rated all policy dimensions positively (mean = 1.00 in nearly all cases). Such consensus reflects alignment between policy goals and organisational commitments [30], but it may also conceal a form of response bias or social desirability if sustainability narratives are strategically emphasised [31]. The conversion group within CE actors also markedly improved perception, shifting from a negative to a clearly positive view of regulatory alignment (mean = 0.50), suggesting that internal CE strategies may buffer perceived regulatory burdens or reframe them as enablers of competitiveness or innovation [32]. However, a CE strategy is not universally associated with positive attitudes. Waste processors, only present within the CE cohort, exhibited consistently negative views across all policy areas, suggesting that while ostensibly designed to promote circularity, regulatory frameworks may fail to account for the practical constraints faced by this group, such as low margins, high compliance costs, or insufficient infrastructure support [33,34]. Their high standard deviations further indicate intra-group disagreement, which may reflect differences in size, technological capability, or geographic policy exposure. Raw material importers with CE strategies also shifted toward a more cautious stance, with negative mean scores for aligning regulations and public awareness. This reversal from their favourable profile raises the possibility that engagement with CE discourses exposes systemic misalignments between upstream responsibilities and downstream expectations [35].

These findings problematise the assumption that CE adoption uniformly harmonises stakeholder perspectives. Instead, they highlight that CE strategies can amplify awareness of regulatory gaps, generate new tensions, or reframe existing burdens. The data suggest that regulation is not a neutral framework but a negotiated field, where its interpretation depends on organisational maturity, position within the value chain, and the tangible incentives or constraints it imposes [36]. Accordingly, policymakers should resist the urge to treat CE actors as a homogenous constituency. Regulatory design must be more attuned to sector-specific realities, particularly for those at operational block points like waste processing and materials handling. Policy coherence, especially in aligning mandates with infrastructure capacity and enforcement mechanisms, appears essential not only for compliance but for legitimacy. Without such alignment, the circular economy risks becoming more performative than transformative, endorsed rhetorically by some but structurally resisted by others [37].

The economic factor (Table 3) provides insights into how economic factors related to recycling differ across company sizes and the adoption of a circular economy (CE) strategy. For small companies without a CE strategy, the mean scores reflect negative perceptions of most economic factors, such as costs of recycling (−0.71) and fluctuating costs (−0.57). These findings are consistent with recent work showing that small firms are particularly vulnerable to variability in recycling costs, due to limited access to capital and inconsistent input quality [38]. In contrast, positive mean scores for new markets and applications (0.43) and long-term contracts for investment security (0.57) suggest selective optimism, an effect noted by Bening, Pruess [39] who found that some segments of the value chain embrace innovation where downstream demand and predictable offtake are assured. Standard deviations for these factors indicate moderate variability, reflecting diverse experiences within this group. Medium companies without a CE strategy show strong negative mean scores for factors like costs of recycling and price competitiveness of recyclate (−1 each) but positive scores for new markets and applications (0.5) and growing demand from existing markets (0.5), with higher standard deviations highlighting significant disparities in experiences. The results echo the fragmented access to market benefits identified by Grafström and Aasma [40], where middle-scale actors often struggle to overcome initial investment hurdles and compete with virgin material pricing structures. Large companies without a CE strategy report similar trend, with consistently negative mean scores for costs and fluctuating prices but slightly more optimism for new markets and economies of scale (both 0.4), albeit with high variability. With a CE strategy, small companies show modest improvements in their mean scores across several factors, such as new markets and applications (0.4) and long-term contracts (0.64). However, they maintain negative scores for costs of recycling (−0.76) and price competitiveness of recyclate (−0.44), which suggests that even proactive CE adoption does not insulate smaller players from systemic economic challenges [38]. The standard deviations remain relatively high, indicating ongoing variability in perceptions. Medium companies with a CE strategy exhibit more pronounced negativity in costs of recycling (−0.94) and fluctuating costs (−0.81), with slight optimism for growing demand (0.44), reflecting mixed experiences influenced by CE adoption. Large companies with a CE strategy maintain negative scores across most factors, such as costs of recycling (−0.75) and price competitiveness (−0.75), but show moderate positivity for investment in recycling methods (0.5) and growing demand (0.5), with moderate variability. These results suggest that while CE strategies improve certain areas, challenges persist in addressing economic factors across company sizes. The comparison with van der Vegt, Velzing [11] reveals partial alignment and clear divergences in how economic factors are perceived across firm sizes and CE strategy.

The perception data on economic factors (Table 4) reveal entrenched structural scepticism toward the financial viability of circularity, even among those who have adopted a CE strategy. Despite framing economic conditions as potential enablers of circular transformation, the stakeholder responses primarily depict economic variables as persistent barriers, particularly cost-related ones, underscoring the unresolved friction between environmental ambition and commercial pragmatism. Even when technically feasible, the economic viability of plastic sorting remains low, as confirmed by Lim, Ahn [41]. This aligns with our findings that, for downstream actors, cost-based barriers are not just deterrents, they are immovable constraints that make circular engagement appear economically irrational.

Table 3. Economic factors (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

			Costs of Recycling	Price Competitiveness of Recyclate	Fluctuating Costs	New Markets and Applications	Increased Prices for Consumers	Cost for Research and Development	Investment in Other Recycling Methods (Chemical Recycling, . . .)	Economies of Scale for New Investments	Investment Costs for Capital and Infrastructure	Supplier Transaction Costs	Long-Term Contracts for More Security of Investments	Growing Demand from Existing Markets
Without CE strategy	Small	Mean	−0.71	−0.14	−0.57	0.42	−0.71	−0.14	0.57	0.28	−0.28	−0.28	0.57	0.57
		stdev	0.48	0.90	0.53	0.78	0.48	0.90	0.53	0.75	0.75	0.75	0.53	0.53
	Medium	Mean	−1.00	−1.00	−0.50	0.50	0.00	−0.50	1.00	0.00	−1.00	−1.00	1.00	0.50
		stdev	0.00	0.00	1.00	1.00	1.15	1.00	0.00	1.15	0.00	0.00	0.00	1.00
	Large	Mean	−0.80	−0.80	−0.80	0.40	−0.80	−0.40	0.40	−0.40	−0.40	−0.80	0.00	0.40
		stdev	0.44	0.44	0.44	0.89	0.44	0.89	0.89	0.89	0.89	0.44	1.00	0.89
With CE strategy	Small	Mean	−0.76	−0.44	−0.68	0.40	−0.52	−0.48	0.44	0.20	−0.60	−0.56	0.64	0.76
		stdev	0.66	0.87	0.69	0.91	0.82	0.82	0.87	0.95	0.76	0.76	0.75	0.59
	Medium	Mean	−0.93	−0.56	−0.81	0.25	−0.81	−0.93	−0.18	−0.31	−0.56	−0.68	0.43	0.43
		stdev	0.25	0.81	0.54	0.93	0.54	0.25	0.98	0.94	0.81	0.70	0.89	0.89
	large	Mean	−0.75	−0.75	−0.75	0.25	−0.50	−0.75	0.50	0.25	−0.75	−0.75	0.25	0.50
		stdev	0.46	0.46	0.46	0.88	0.75	0.46	0.75	0.88	0.46	0.46	0.88	0.75
	[11]		−1	0	−1	1	−1	−1	−1	−1	−1	−1	1	−1

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Across both groups, entities with and without a CE strategy, costs associated with recycling, fluctuating expenses, and price competitiveness of recyclates are uniformly perceived as barriers. Conversion stakeholders, for example, consistently rate the cost of recycling and fluctuating costs (−0.75 with low standard deviations), regardless of CE engagement. This indicates a shared perception of risk and a degree of consensus that these are structural rather than transitional hurdles. The end user group is even more severe. In both CE and non-CE contexts, they assign scores of (−1.00) to all primary cost categories, a unanimous rejection of the current economic conditions underpinning circular supply chains. The absence of standard deviation further reinforces the strength and uniformity of this perception. Such responses suggest that, for downstream actors, cost-based barriers are not just deterrents, they are immovable constraints that make circular engagement appear economically irrational [42]. This aligns with Larrain, Van Passel [43], who show that fluctuating costs and marginal profitability, especially in closed-loop systems, undermine recycling viability.

Table 4. Economic factors with stakeholder position within the supply chain (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier.

			Costs of Recycling	**Price Competitiveness of Recyclate**	**Fluctuating Costs**	**New markets and Applications**	**Increased Prices for Consumers**	**Cost for Research and Development**	**Investment in Other Recycling Methods (Chemical Recycling, . . .)**	**Economies of Scale for New Investments**	**Investment Costs for Capital and Infrastructure**	**Supplier Transaction Costs**	**Long-Term Contracts for More Security of Investments**	**Growing Demand from Existing Markets**
Without CE strategy	Conversion	Mean	−0.75	−0.25	−0.75	0.75	0.25	−0.75	0.75	0.25	−0.75	−0.75	0.75	0.25
		stdev	0.50	0.96	0.50	0.50	0.96	0.50	0.50	0.96	0.50	0.50	0.50	0.96
	End user	Mean	−1.00	−1.00	−1.00	−1.00	−1.00	−1.00	1.00	−1.00	−1.00	−1.00	1.00	1.00
		stdev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Raw Material Importer	Mean	−1.00	−1.00	−1.00	1.00	−1.00	−1.00	0.00	0.00	0.00	−1.00	0.00	1.00
		stdev	0.00	0.00	0.00	0.00	0.00	0.00	1.41	1.41	1.41	0.00	1.41	0.00
	Service	Mean	−0.78	−0.56	−0.44	0.33	−0.78	0.11	0.67	0.00	−0.44	−0.44	0.44	0.44
		stdev	0.44	0.73	0.73	0.87	0.44	0.93	0.50	0.87	0.73	0.73	0.73	0.73
With CE strategy	Conversion	Mean	−0.75	−0.50	−0.75	0.50	−1.00	−1.00	0.50	0.25	−0.50	−1.00	0.75	0.75
		stdev	0.71	0.93	0.71	0.93	0.00	0.00	0.93	1.04	0.93	0.00	0.71	0.71
	End user	Mean	−1.00	−1.00	−1.00	0.33	−0.33	−0.33	1.00	0.33	0.33	−0.33	0.33	1.00
		stdev	0.00	0.00	0.00	1.15	1.15	1.15	0.00	1.15	1.15	1.15	1.15	0.00
	Raw Material Importer	Mean	−0.75	−0.75	−0.75	0.25	−0.25	−0.75	0.75	0.25	−0.25	−0.75	0.75	0.75
		stdev	0.50	0.50	0.50	0.96	0.96	0.50	0.50	0.96	0.96	0.50	0.50	0.50
	Service	Mean	−0.63	0.13	−0.38	−0.13	−0.38	−0.38	−0.13	−0.38	−0.88	−0.13	0.38	0.13
		stdev	0.74	0.99	0.92	0.99	0.92	0.92	0.99	0.92	0.35	0.99	0.92	0.99

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group. Differences in scores between small, medium, and large firms suggest variation in how capacity and constraints are perceived. Small firms often rated systemic factors, such as market access and closed-loop opportunities, more positively, possibly due to their greater agility, lower overhead costs, or targeted niches. In contrast, larger firms, despite having more resources, frequently expressed frustration with infrastructure gaps and policy fragmentation, which may hinder their ability to implement traceability systems at scale.

Interestingly, adopting a CE strategy does not substantially improve these economic perceptions for most actors. While one might expect CE-engaged organisations to view cost-related investments favourably, perhaps due to longer planning horizons or better-integrated value models, the data suggest otherwise. For example, converters with CE strategies still rate investment costs and capital infrastructure negatively (−0.50), and costs for research and development even more harshly (−1.00), mirroring the non-CE group. This suggests that even proactive adopters of circular practices may feel unsupported or under-capitalised within the current policy and market environment [38], raising concerns about the scalability of CE practices without targeted financial mechanisms or subsidies. However, a different narrative emerges when the analysis shifts to dynamic or forward-looking indicators, such as the emergence of new markets, investment in chemical recycling, or growing demand from existing markets. These are among the few categories where enabler perceptions surface, and CE-engaged stakeholders almost exclusively hold them. For example, end users and raw material importers with CE strategies score chemical recycling and market demand positively (1.00 and 0.75, respectively). These responses hint at latent optimism: while current costs are unsustainable, specific innovations and market signals are perceived as holding long-term promise [43]. However, this optimism remains unevenly distributed. Service providers, for instance, exhibit far less enthusiasm even in

CE groups, with most of their mean scores clustering around neutrality or mild negativity, and high standard deviations suggest uncertainty rather than conviction, an issue also observed by Bening, Pruess [39] in their analysis of fragmented value chain expectations.

One of the most notable fault lines is visible in the interpretation of long-term investment structures. CE-aligned end users and converters generally rate long-term contracts and economies of scale favourably (0.75 and 0.25–0.75), while non-CE stakeholders offer mixed to negative evaluations. This signals a possible maturation divide: entities with CE strategies may be better positioned to engage in capital planning and long-term procurement, while others remain trapped in short-term financial logic [44]. Nonetheless, even among CE entities, the uneven appreciation of supplier transaction costs and infrastructure investment suggests that foundational market and logistical bottlenecks continue to erode confidence [45]. The strikingly negative and unanimous responses from non-CE end users across all economic categories should also raise flags. This group rejects existing economic conditions and appears to lack exposure to or belief in emerging opportunities. Such detachment implies that current CE communication, support, and financial incentives fail to reach or convince key stakeholders [44]. Even the most ambitious upstream reforms or innovations are unlikely to translate into systemic change if downstream actors remain disengaged.

Ultimately, this table highlights a persistent disjuncture: while the circular economy narrative promotes value recovery, material reinvestment, and long-term economic resilience, many respondents, particularly those without CE strategies, perceive the transition as prohibitively expensive, financially unstable, and structurally under-supported. Even among CE adopters, optimism is fragile and primarily confined to a subset of factors, often tied to emergent markets or technologies that are not yet mainstreamed. For circularity to take hold across the supply chain, policy intervention must go beyond technical guidance and actively de-risk economic participation through targeted investment support, market incentives, and procurement guarantees responsive to each stakeholder group's unique cost structures [46].

The technical factor (Table 5) provides a detailed breakdown of how technical factors influence recycling practices, varying by company size and the adoption of circular economy (CE) strategies. For small companies without a CE strategy, mean scores indicate negative perceptions of contamination of waste streams (−0.71) and unknown material quality (−0.71), issues widely recognised as limited factors due to poor sorting and inconsistent inputs [47]. In contrast, new material innovation (0.57), new technologies for recycling (0.57), and design for recyclability (0.57) receive higher positive scores, reflecting selective optimism in technological advancements [9]. High standard deviations, such as for material separation (0.76) and availability of material data/information (0.76), suggest diverse experiences and opinions among these companies. Medium companies without a CE strategy report more polarised views, with strong negative scores for contamination (−1) and unknown material quality (−1), contrasting with high positive scores for new material innovation (1) and design for recyclability (1), indicating an apparent dichotomy in their perspectives. Large companies without a CE strategy exhibit similar trends, with negative mean scores for contamination (−0.8) and unknown quality (−0.8) but positive scores for new technologies (0.8) and application possibilities (0.8), paired with moderate variability (standard deviation: 0.45–0.89). When adopting a CE strategy, small companies show improvement in several factors, such as material separation (0.8), new technologies (0.96), and design for recyclability (0.84), reflecting an increased focus on leveraging technology for recycling. However, contamination (−0.84) and unknown quality (−0.84) remain significant concerns, with variability remaining high across many factors. Medium companies with a CE strategy present similar pattern, with strong positive scores for new technologies (0.94) and application possibilities (0.81), alongside persistent challenges with contamination (−0.81) and unknown quality (−0.94). Standard deviations indicate considerable variability, particularly regarding material data/information (0.99). Large companies with a CE strategy generally report improvements in scores for most factors, including new technologies (0.75) and material separation (0.5), while contamination (−0.75) and unknown quality (−0.75) remain critical issues. Large companies' variability is lower than smaller ones, reflecting more consistent practices and experiences. These results highlight that while CE strategies drive improvements in several technical factors, challenges such as contamination and unknown material quality persist across all company sizes. Adopting advanced technologies and enhanced material separation capabilities is key to addressing these challenges [9].

The reported perceptions of technical factors across stakeholder groups (Table 6) expose an unambiguous paradox at the heart of the circular plastics transition: while innovation and technological advancement are frequently framed as key enablers of circularity, the very stakeholders responsible for deploying and scaling these innovations often remain constrained by unresolved legacy issues, particularly around quality, compatibility, and data transparency [31].

Among stakeholders without a circular economy (CE) strategy, the technical landscape appears split between optimism about future-oriented capabilities and frustration with existing systemic flaws. For example, converters and end users enthusiastically rate new material innovation, new recycling technologies, and design for recyclability as strong enablers (means around 0.75–1.00), suggesting receptiveness to technical solutions that could enhance processing efficiency or product functionality. Nevertheless, these same groups simultaneously perceive contamination of waste streams, inconsistent and unknown material quality, and the complexity introduced by multi-material combinations as significant barriers (mean values as low as −0.75 to −1.00). The contradiction here is striking: the promise of technical innovation is acknowledged, but unresolved quality and data issues consistently undermine it. This dissonance suggests that while technological capacity is improving, systemic bottlenecks, such as the lack of standardised inputs and reliable traceability, continue to erode confidence in the circular model's practical viability. Stakeholders highlighted the absence of standardised quality models to support recyclate uptake, a gap addressed conceptually by Golkaram, Mehta [48], who proposed a quantitative model linking material properties to product functionality through a unified quality indicator.

The presence of a CE strategy slightly modifies but does not fully resolve this contradiction. There is increased uniformity among CE-engaged stakeholders in viewing technical levers like recyclability design, separation, and new technologies as enablers. Converters with CE strategies, for instance, give perfect scores to recyclability, sorting, and new technologies (1.00), indicating an advanced stage of internal alignment with circular production principles. However, they still rate core quality factors, like contamination, unknown material properties, and data availability, as barriers (−1.00 to −0.25), even though these issues are precisely the technical pillars upon which closed-loop systems depend. The implication here is sobering: even firms with internalised CE goals and implemented enabling practices are not insulated from wider systemic dysfunctions. This suggests that technological preparedness within an individual firm or sector cannot compensate for value chain-level incoherence, particularly when data infrastructure and upstream consistency remain weak, a finding consistent with Lisiecki, Damgaard [49] who demonstrate that CE initiatives do not automatically result in improved circularity without structural system alignment.

Table 5. Technical factors (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

			Contamination of Waste Streams	New Material Innovation	New Technologies for Recycling	Material Separation (Sorting)	Design for Recyclability	Inconsistent Material Quality	Unknown Material Quality	Availability of Material Data/Information	Combination of Polymer Type and Used Production Process	Use of Materials with Better Properties than Required	Application Possibilities	Additional Testing
Without CE strategy	Small	Mean	−0.71	0.57	0.57	0.28	0.57	−0.43	−0.71	0.28	0.28	0.57	0.57	0.28
		stdev	0.49	0.53	0.53	0.75	0.53	0.79	0.49	0.75	0.75	0.53	0.53	0.75
	Medium	Mean	−1.00	1.00	1.00	0.50	1.00	−1.00	−1.00	0.50	0.00	0.50	0.50	0.00
		stdev	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.15	1.00	1.00	1.15
	Large	Mean	−0.80	0.80	0.80	0.40	0.80	−0.80	−0.80	0.00	−0.40	0.40	0.80	0.40
		stdev	0.45	0.45	0.45	0.89	0.45	0.45	0.45	1.00	0.89	0.89	0.45	0.89
With CE strategy	Small	Mean	−0.84	0.52	0.96	0.80	0.84	−0.76	−0.84	−0.28	−0.40	0.48	0.52	0.44
		stdev	0.55	0.82	0.20	0.58	0.47	0.66	0.55	0.94	0.91	0.77	0.77	0.82
	Medium	Mean	−0.81	0.69	0.94	0.69	0.69	−0.81	−0.94	0.06	−0.19	0.19	0.81	0.43
		stdev	0.54	0.70	0.25	0.70	0.70	0.54	0.25	0.99	0.98	0.98	0.54	0.89
	large	Mean	−0.75	0.00	0.75	0.50	0.50	−0.75	−0.75	−0.25	−0.25	0.25	0.25	0.00
		stdev	0.46	0.92	0.46	0.75	0.75	0.46	0.46	0.89	0.89	0.89	0.89	0.92
[11]			−1	−1	1	1	1	−1	−1	1	−1	−1	−1	−1

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Table 6. Technical factors with stakeholder position within the supply chain (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

			Contamination of Waste Streams	New Material Innovation	New Technologies for Recycling	Material Separation (Sorting)	Design for Recyclability	Inconsistent Material Quality	Unknown Material Quality	Availability of Material Data/Information	Combination of Polymer Type and Used Production Process	Use of Materials with Better Properties than Required	Application Possibilities	Additional Testing
Without CE strategy	C.	Mean	−0.75	0.75	0.75	−0.25	0.75	−0.75	−0.75	0.25	−0.25	0.75	0.25	−0.25
		stdev	0.50	0.50	0.50	0.96	0.50	0.50	0.50	0.96	0.96	0.50	0.96	0.96
	E-U	Mean	−1.00	1.00	1.00	1.00	1.00	−1.00	−1.00	1.00	1.00	1.00	1.00	1.00
		stdev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	RM	Mean	−1.00	1.00	1.00	0.00	1.00	−1.00	−1.00	0.00	0.00	1.00	1.00	0.00
		stdev	0.00	0.00	0.00	1.41	0.00	0.00	0.00	1.41	1.41	0.00	0.00	1.41
	S.	Mean	−0.78	0.67	0.67	0.67	0.67	−0.56	−0.78	0.22	0.00	0.22	0.67	0.44
		stdev	0.44	0.50	0.50	0.50	0.50	0.73	0.44	0.83	0.87	0.83	0.50	0.73
With CE strategy	C.	Mean	−1.00	0.25	1.00	1.00	1.00	−1.00	−1.00	−0.25	−0.25	0.63	1.00	0.75
		stdev	0.00	1.04	0.00	0.00	0.00	0.00	0.00	1.04	1.04	0.74	0.00	0.71
	E-U	Mean	−1.00	1.00	1.00	1.00	1.00	−1.00	−1.00	−0.33	0.33	0.33	0.33	0.33
		stdev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	1.15	1.15	1.15	1.15

Table 6. *Cont.*

		Contamination of Waste Streams	New Material Innovation	New Technologies for Recycling	Material Separation (Sorting)	Design for Recyclability	Inconsistent Material Quality	Unknown Material Quality	Availability of Material Data/Information	Combination of Polymer Type and Used Production Process	Use of Materials with Better Properties than Required	Application Possibilities	Additional Testing
RM	Mean	−0.75	0.75	0.75	0.75	0.75	−0.75	−0.75	−0.25	−0.25	0.25	0.25	0.25
	stdev	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.96	0.96	0.96	0.96	0.96
S.	Mean	−0.63	0.63	0.88	0.63	0.38	−0.38	−0.63	−0.13	−0.63	0.38	0.63	0.13
	stdev	0.74	0.74	0.35	0.74	0.92	0.92	0.74	0.99	0.74	0.92	0.74	0.99

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group. **Note:** C. for Converter, E-U for End-users, S. for Service, and RM for Raw material importer stakeholders.

End users in both CE and non-CE groups present an unusual profile: they report uniformly positive views on forward-facing technical opportunities (innovation, recyclability, new applications) while holding the most severe and consistent negative views on material quality and contamination (-1.00). The zero-standard deviation across these responses' points to a profound and non-negotiable consensus. From a systems perspective, this signals that end users may be the most dependent on and yet least empowered to resolve technical barriers, as they rely on the reliability and predictability of upstream material quality but lack visibility or influence over those production stages.

Raw material importers reflect another complex picture. Despite their central role in feedstock management, their responses indicate a constrained or cautious perspective. Even in CE-aligned contexts, they negatively rate quality-related variables (contamination, unknown material properties). At the same time, their perception of enabling factors such as sorting, innovation, and application possibilities remains modest and more variable than that of other stakeholders. This cautious optimism may reflect exposure to real-time market failures, such as contaminated imports or mismatches between claimed and actual recyclability. This could explain their persistent scepticism about technical maturity within the system.

The most revealing patterns emerge in the responses from service providers. CE and non-CE groups within this stakeholder class exhibit highly fragmented perceptions across almost all variables, with standard deviations consistently high, such as for the availability of material data/information (stdev = 0.83 for non-CE; 0.99 for CE), combination of polymer type and production process (stdev = 0.87 non-CE; 0.74 CE), and additional testing (stdev = 0.73 non-CE; 0.99 CE). This intra-group inconsistency likely reflects the diversity of roles service providers play, from logistics to testing to consultancy, and their uneven exposure to the technical challenges along the supply chain. The fluctuating perceptions, especially for data-related variables, polymer/process combinations, and additional testing, suggest that while some service providers may be actively involved in solving these issues, others remain peripheral or disconnected from the heart of the technical transformation.

This collective dataset clarifies that the technical enablers of circularity are largely present, recognised, and even valued, but persistent system-level flaws are holding them back. Most notably, contamination, unknown material characteristics, and poor information availability remain cross-cutting barriers, especially pronounced among those who have invested in CE strategies and, thus, have greater exposure to circular system design. The technical promise of circularity is not in question; it is consistently rated high across both CE and non-CE actors regarding innovation, recyclability, and application potential. However, unless the structural issues around material integrity, traceability, and standardisation are resolved across the entire supply chain, these innovations are unlikely to scale effectively or yield the systemic change required. This gap between innovation readiness and infrastructure maturity should concern policymakers, industry coalitions, and standardisation bodies. Without coordinated technical governance and investment in traceable quality assurance mechanisms, the circular economy will continue to operate in a fragmented and inefficient manner, technically possible, but operationally fragile.

Table 7 presents the systemic factors influencing recycling practices, categorised by company size and the adoption of circular economy (CE) strategies. For small companies without a CE strategy, mean scores indicate moderate engagement with systemic factors such as closed-loop recycling (0.57) and reliable streams of material (0.43). However, infrastructure capacity (-0.29) is perceived negatively, reflecting challenges in ensuring adequate recycling capabilities. High variability in factors such as matchmaking platforms (0.53) and standardisation of recycling processes (0.75) suggests inconsistency in practices and perceptions within this group. Medium companies without CE strategies exhibit mixed patterns, with high scores for closed-loop recycling (1) and reliable material streams (1), indicating strong alignment with systemic recycling principles. Negative scores for infrastructure capacity (−1) highlight significant gaps in addressing logistical and infrastructural barriers. Large companies without CE strategies display uniformly positive scores across most factors, including closed-loop recycling (0.8) and standardisation of recycling processes (0.4) but also show moderate variability, as reflected in standard deviations of 0.45 to 0.89. When CE strategies are adopted, small companies demonstrate notable improvements, particularly in factors such as reliable streams of material (0.8), standardisation for recyclate quality (0.8), and technology, data, and traceability (0.84). Infrastructure capacity remains a challenge (−0.16), with variability remaining high for this factor (standard deviation: 0.90). Medium companies with CE strategies show more balanced improvements, with positive scores across reliable streams of material (0.81), matchmaking platforms (0.44), and increased recycling capacity (0.69). However, infrastructure capacity presents challenges (−0.19), highlighting ongoing logistical barriers. Large companies with CE strategies report reduced engagement across several systemic factors, with negative scores for infrastructure capacity (−0.75) and matchmaking platforms (0). Variability for large companies remains relatively consistent, with standard deviations ranging from 0.46 to 0.92. These results suggest that while CE strategies improve systemic factor alignment for small and medium companies, persistent issues with infrastructure capacity remain across all company sizes. Despite their resources, large companies appear to deprioritise certain systemic factors, possibly due to their established systems or reduced perceived need for specific improvements.

Assessing systemic factors across the plastics supply chain reveals deep structural fragmentation in how stakeholders understand and engage with the institutional foundations of circularity (Table 8). While technological readiness or economic incentives may receive greater attention in circular economy discourse, the data here point to systemic alignment, or the lack thereof, as the decisive condition that enables or constrains transition. Stakeholder responses show that perceptions of enablers are inconsistent and often contingent on whether the actor has internalised a CE strategy. However, the dissonance between upstream and downstream actors is even more telling about where systemic shortcomings lie.

Among stakeholders without a CE strategy, we see sharp contrasts between groups that perceive systems-level elements as clear enablers (end users, raw material importers) and those for whom these factors remain ambiguous or actively obstructive (conversion and service). For instance, end users consistently rate all factors, apart from infrastructure capacity, standardisation of recycling processes, and traceability, as strong enablers, with perfect scores (mean = 1.00) and no variation. This may reflect a reliance on top-down narratives about circularity success and the assumption that systemic functionality exists or will be delivered externally. However, their simultaneous and unanimous rating of infrastructure capacity and traceability as barriers (mean = −1.00) introduces a contradiction: downstream actors assume the system works until it concerns core dependencies over which they have limited control. This suggests that user confidence in circular systems may be more aspirational than operational, buoyed by high-level support but undermined by weak backend functionality.

Table 7. Systemic factor (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

		Indicator	Systems Perspective	Closed-Loop Recycling	Matchmaking Platform	Infrastructure Capacity (Actual)	Standardisation of Recycling Processes	Increased Recycling Capacity	Lack of Reliable Stream of Material	Standardisation for (Quality of) Recyclate	Standardisation of Product Designs	Technology, Data and Traceability
Without CE strategy	Small	Mean	0.28	0.57	0.43	−0.28	0.28	0.57	0.43	0.57	0.57	0.57
		stdev	0.75	0.53	0.53	0.75	0.75	0.53	0.79	0.53	0.53	0.53
	Medium	Mean	0.00	1.00	0.50	−1.00	0.50	1.00	1.00	1.00	0.50	1.00
		stdev	1.15	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00
	Large	Mean	0.80	0.80	0.80	0.00	0.40	0.80	0.80	0.80	0.40	0.80
		stdev	0.45	0.45	0.45	1.00	0.89	0.45	0.45	0.45	0.89	0.45
With CE strategy	Small	Mean	0.52	0.60	0.68	−0.16	0.32	0.68	0.80	0.80	0.60	0.84
		stdev	0.77	0.71	0.63	0.90	0.85	0.69	0.50	0.50	0.71	0.37
	Medium	Mean	0.12	0.44	0.44	−0.19	0.31	0.69	0.81	0.56	0.44	0.56
		stdev	0.96	0.89	0.89	0.98	0.95	0.70	0.54	0.81	0.89	0.81
	large	Mean	−0.12	0.50	0.00	−0.75	0.00	0.25	0.25	0.00	0.25	0.25
		stdev	0.83	0.75	0.75	0.46	0.92	0.89	0.89	0.92	0.89	0.89
	[11]		1	1	1	−1	1	1	−1	1	1	1

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Table 8. Systemic factor with stakeholder position within the supply chain (higher scores indicate that the factor is perceived as an enabler, whereas lower or negative scores suggest it is viewed as a barrier).

		Indicator	Systems Perspective	Closed-Loop Recycling	Matchmaking Platform	Infrastructure Capacity (Actual)	Standardisation of Recycling Processes	Increased Recycling Capacity	Lack of Reliable Stream of Material	Standardisation for (Quality of) Recyclate	Standardisation of Product Designs	Technology, Data and Traceability
Without CE strategy	Conversion	Mean	−0.25	0.75	0.25	−0.25	0.75	0.75	0.75	0.75	0.75	0.75
		stdev	0.96	0.50	0.96	0.96	0.50	0.50	0.50	0.50	0.50	0.50
	End user	Mean	1.00	1.00	1.00	−1.00	−1.00	1.00	1.00	1.00	−1.00	1.00
		stdev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Raw Material Importer	Mean	1.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	1.00
		stdev	0.00	0.00	0.00	1.41	1.41	0.00	0.00	0.00	1.41	0.00
	Service	Mean	0.44	0.67	0.56	−0.44	0.44	0.67	0.56	0.67	0.67	0.67
		stdev	0.73	0.50	0.53	0.73	0.73	0.50	0.73	0.50	0.50	0.50
With CE strategy	Conversion	Mean	0.00	0.75	0.50	−0.25	0.50	0.50	0.75	0.50	0.50	0.75
		stdev	1.07	0.71	0.93	1.04	0.93	0.93	0.71	0.93	0.93	0.71
	End user	Mean	0.67	1.00	1.00	−1.00	1.00	1.00	1.00	1.00	1.00	1.00
		stdev	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Raw Material Importer	Mean	−0.25	0.75	0.25	0.25	0.75	0.75	0.75	0.75	0.75	0.75
		stdev	0.96	0.50	0.96	0.96	0.50	0.50	0.50	0.50	0.50	0.50
	Service	Mean	0.38	−0.13	0.13	−0.63	−0.63	0.13	0.38	−0.13	0.13	0.13
		stdev	0.92	0.99	0.99	0.74	0.74	0.99	0.92	0.99	0.99	0.99

Note: Scores are based on respondent perceptions of each factor as an enabler (coded as +1) or a barrier (coded as −1). Higher average values indicate the factor is more frequently viewed as enabling circularity or traceability, while negative averages suggest it is perceived as a barrier. Standard deviations reflect variation in perceived impact within each group.

Converters, despite being production-centric actors with visibility into both upstream inputs and downstream markets, offer more cautious assessments. While they view specific system levers, such as standardisation and closed-loop recycling, as enabling (means between 0.25 and 0.75), they remain sceptical about infrastructure and systems integration (means around -0.25), reflecting exposure to operational bottlenecks that others may overlook. Their split perceptions point to a system in transition: functional in parts but lacking integration or predictability. The relatively high standard deviation in key areas (e.g., matchmaking platforms, infrastructure capacity) suggests divergent experiences within the group, possibly influenced by firm size, location, or product type. Raw material importers without a CE strategy display a contradictory profile. They assign strong enabling scores to almost all standardisation and systems categories (mean = 1.00), but flatline at zero for infrastructure and traceability-related indicators, with large standard deviations (1.41). This suggests that while the principles of circularity are supported at a conceptual level, there is significant uncertainty about whether system-level infrastructure is delivering on those expectations. Such a profile may reflect risk aversion or hedging behaviours, supporting CE in theory but hesitating to scale engagement due to practical unpredictability. Service providers show middling support across the board, with moderate positivity toward closed-loop systems and standardisation, but low confidence in infrastructure and traceability (means around -0.44), and moderate to high standard deviation across most variables. This reflects their role as intermediaries or facilitators, partially embedded in systemic flows, but rarely in control of them. Their perceptions hint at fragmented exposure and the absence of a coherent, system-wide interface that enables reliable coordination across actors.

The outlook shifts among stakeholders with a CE strategy, but not in a uniformly positive direction. One might expect CE-aligned actors to perceive systemic factors as more enabling, but the data suggest partial optimism tempered by ongoing frustration.

The end user group with a CE strategy stands out for its complete confidence in nearly every systemic factor. It assigns maximum positive scores (mean = 1.00) to all variables except the systems perspective (mean = 0.67) and infrastructure capacity (mean = -1.00), where once again the contradiction re-emerges: firm belief in the promise of systemic circularity, paired with a critical view of actual infrastructural readiness. The lack of variation (standard deviation = 0.00) further suggests that these are entrenched beliefs rather than tentative evaluations. These users appear ideologically committed to CE but are materially constrained by infrastructural deficits and informational opacity, which prevent them from exercising agency despite strategic alignment. Converters and raw material importers with CE strategies report mixed to moderately positive perceptions, particularly in standardisation areas (means between 0.50 and 0.75). Their support appears grounded in operational realities, favouring institutional mechanisms that create consistency, but their persistent doubts about infrastructure, traceability, and systems integration (means at or below zero) reflect ongoing friction between internal efforts and external coordination failures. In other words, CE strategy adoption improves alignment but cannot overcome the broader system's fragmentation without collective support. The service group with CE strategies is perhaps the most disillusioned. Their responses are low and scattered across nearly all systemic factors, with a notable shift toward negative or neutral scores (means range from -0.63 to 0.38). This suggests that increased engagement with CE has not led to a stronger sense of systemic coherence; it may have heightened their awareness of coordination failures and institutional gaps. Their low scores in infrastructure, standardisation, and systems perspective may reflect their proximity to friction points and their dependence on underdeveloped integration mechanisms.

What emerges from this analysis is not a simple binary between CE and non-CE actors, but a deeper pattern: belief in system-level enablers is highly correlated with distance from operational bottlenecks. Downstream actors (end users) are more optimistic, likely because they do not bear the cost of systemic breakdowns directly. Upstream and intermediary actors, particularly converters and service providers, are more critical because their success depends on system-level consistency, which is presently lacking. The infrastructure gap and traceability deficit are the most consistently cited barriers across all groups, regardless of CE commitment, underscoring that the weakest links in the system are widely recognised but structurally unresolved. Stakeholders consistently identified infrastructure as a bottleneck, echoing the findings of Lisiecki, Damgaard [49] that systemic capacity constraints limit the impact of CE. If circular economy policies are to succeed, they must address these systemic bottlenecks not just through rhetoric, but through governance structures, data harmonisation platforms, and investment in scalable infrastructure. Without these foundations, stakeholder alignment will remain aspirational and fractured, and even committed CE actors will find themselves navigating systems that are too fragmented to sustain meaningful circularity at scale.

4. Discussion

The survey findings reveal several notable differences in how quality and traceability enablers and barriers are perceived across company sizes, circular economy (CE) strategy adoption, and stakeholder roles within the supply chain. Contrary to the assumption that larger firms are better positioned to implement circular practices, the results show that both larger and medium companies reported more barriers than smaller entities, particularly infrastructure limitations, system complexity, and regulatory inconsistency. In contrast, small enterprises consistently highlight cost constraints and technical uncertainties, particularly regarding material quality and contamination, as key challenges. This aligns with findings that SMEs face both 'hard' (infrastructure, cost) and 'soft' (knowledge, coordination) barriers when adopting circular practices [50]. SMEs often face different motivational and capability challenges compared to larger firms, as confirmed by Sohal and De Vass [51]. Even when they express optimism toward new technologies or market opportunities. Adopting a CE strategy correlates with a more favourable view of enablers, particularly in innovation, new markets, and systems integration. However, CE-aligned firms are not immune to systemic challenges. They often report heightened awareness of data availability gaps, traceability shortcomings, and regulatory fragmentation, suggesting that deeper engagement with CE principles may amplify visibility into system-level failures rather than resolve them. This variation reflects findings from regional systems such as Emilia-Romagna, where decentralised governance shapes traceability success [52]. This phenomenon is especially evident among large firms and waste processors with CE strategies, who score infrastructure and traceability factors more negatively than expected, indicating the persistence of operational bottlenecks despite strategic alignment. Differences across stakeholder types further deepen this complexity. End users tend to support CE principles and rate most enablers highly. However, they uniformly flag infrastructure and traceability as critical barriers, likely reflecting their downstream reliance on upstream coordination and transparency. Converters and compounders are more cautious, acknowledging technical innovation while reporting concerns about feedstock reliability and regulatory clarity. Raw material suppliers and service providers show more mixed or neutral responses, often due to their diverse roles and exposure levels across the value chain. These distinctions underscore that perceptions of enablers and barriers are not merely a function of ideology or policy awareness but are deeply shaped by firm size, CE maturity, and the material realities of each stakeholder's operational position within the circular plastics ecosystem.

A striking paradox emerging from the findings is the simultaneous optimism around innovation and persistent frustration with quality-related bottlenecks. Across both CE and non-CE stakeholders, there is strong agreement that new recycling technologies, advanced material innovations, and improved sorting methods are potential enablers of circularity. These responses suggest that businesses are often aware of and receptive to technical solutions that promise efficiency gains, product performance improvements, or expanded applications for recyclates. However, this optimism is sharply undercut by the persistent and widespread perception that contamination, inconsistent material quality, and lack of data transparency remain significant barriers. Even among CE-adopting firms, which one might expect to be better prepared to implement these technologies, challenges such as the lack of reliable material specifications and traceability mechanisms consistently score as impediments. This tension between technological readiness and systemic immaturity reflects what Hahladakis and Iacovidou [6] describe as the dual challenge of quality assurance and product compatibility in post-consumer plastic streams, where innovations alone cannot compensate for upstream deficiencies in material segregation or standardisation. The contradiction is particularly acute among end users and converters, who rate forward-facing technical capabilities, such as design for recyclability and new applications, while concurrently expressing severe dissatisfaction with the quality and reliability of input materials. This aligns with Eriksen, Christiansen [53], who found that while specific polymers like Polyethylene terephthalate (PET) can be effectively recycled under controlled conditions, other plastics such as polyethylene (PE) and polypropylene (PP) pose significant difficulties due to their heterogeneous properties and susceptibility to degradation. As these findings demonstrate, the technological promise of circularity often clashes with real-world material inconsistencies, limiting the effective scaling of innovation. Furthermore, the issue is compounded by the lack of harmonised information and traceability standards, as Gall, Wiener [7] noted, who emphasise the critical role of transparent data infrastructure in supporting high-quality recycling outcomes. This paradox reveals an important insight: while firms may be technologically capable, or at least willing, to adopt innovative solutions, their efforts are hampered by a lack of system-level coherence. The absence of reliable material data, insufficient feedstock standardisation, and fragmented regulatory support contribute to innovation becoming aspirational rather than transformative. It also points to a fundamental flaw in circular economy implementation: the assumption that technological advancement alone can drive change without corresponding governance, quality control, and market integration. Addressing this gap requires not only investment in technology but also institutional commitment to standardised material classification, traceability frameworks such as ISO 22095 [13], and coordinated infrastructure development that ensures consistency across the supply chain. Without resolving these foundational quality barriers, the technical enablers identified in the survey risk remaining underutilised, ultimately undermining the viability of circular strategies.

While alignment with circular economy (CE) principles enhances organisational awareness and prioritisation of circular practices, it does not automatically overcome the structural barriers embedded in Australia's recycled plastics value chain. CE-adopting firms in this study reported greater interest in innovation, new markets, and system integration. However, persistent challenges, such as inadequate infrastructure, inconsistent material quality, and high compliance costs, remain widespread, even among those most aligned with CE strategies. This reflects a gap between strategic intent and operational reality, as internal commitment alone cannot resolve external system weaknesses. As Gall, Wiener [7] and van der Vegt, Velzing [11] suggest, progress depends on coordinated interventions supporting quality, traceability, and investment beyond the firm level. In the Australian context, however, such coordination is still limited. Inter-firm collaboration and government-supported learning mechanisms across company sizes remain underdeveloped, with many circular practices concentrated in a small number of specialised firms. This raises concerns that, rather than enabling system-wide engagement, circularity is driven by market niches, while bureaucratic complexity and uneven regulatory enforcement continue to hamper widespread implementation. These findings also highlight the limits of transferring policy models from high-capacity European contexts to Australia. Silva, Stocker [54] argue that Australia's early leadership in zero waste policy, such as Canberra's "No Waste by 2010" program, ultimately faltered due to a narrow framing of the term around landfill diversion rather than full-cycle material strategies. Their discourse analysis shows that policy keywords like "zero waste" and "sustainable materials management" significantly shape public interpretation and institutional pathways. In the Australian context, such framing often lacked alignment with upstream production systems and policy integration, leading to disjointed governance and implementation shortfalls. The authors advocate for transitioning toward a more life-cycle-oriented framing, such as SMM, that better captures the circular economy's systems-level ambitions and reduces reliance on narrowly defined waste metrics. This aligns with broader challenges in global plastic governance, where EPR schemes face design and enforcement inconsistencies [55]. King and Locock [56] reinforce this concern by showing that, although Australia has made recent policy advances, it still ranks only 15th globally in CE-related plastics research and 21st on a per capita basis. Their review found a disproportionate focus on end-of-life interventions, particularly recycling and system-level analysis, while early-stage strategies such as design and production remain under-researched. Most studies overlook resin specificity and use category, limiting practical translation. These findings suggest that without targeted, polymer-specific, and use-phase interventions, circular economy policy in Australia risks repeating the same generalisations that have hindered global CE implementation. Ref. [57] confirm that Australia's lack of specific end-of-life (ELV) regulation results in lower material circularity outcomes than the EU and Japan. Using MCI and PCI indicators, their study shows that even aggressive recycling improvements yield marginal gains. In contrast, upstream strategies, such as increasing recycled feedstock use, product reuse, and vehicle utility, deliver significantly greater circularity improvements. This underscores that in Australia's regulatory context, policy impact depends less on mandating recycling targets and more on enabling systemic design, production, and market-level reforms. While European systems benefit from stronger infrastructure and governance alignment, Australia's fragmented policy environment and uneven capacity undermine the direct applicability of such frameworks. Without adapting policies to local conditions, efforts to scale CE risk reinforce existing barriers rather than dismantle them. This calls for context-specific policy tools that address Australia's distinct institutional and infrastructural realities. This aligns with Arbolino, Boffardi [58] who found that while policy convergence in the EU is partly driven by learning and emulation, successful adoption also depends heavily on domestic structural factors such as institutional quality, political orientation, and R&D investment. Their findings emphasise that convergence is not merely a function of policy mimicry but of alignment between governance readiness and the complexity of the circular transition. For Australia, this implies that importing CE policy frameworks must be mediated by a truthful assessment of local governance, infrastructure disparities, and stakeholder capacities to avoid policy misfit and implementation failure. These insights are also echoed by Dąbrowski, Varjú [59], who argue that transferring circular economy solutions across differentiated regions requires more than policy emulation; it necessitates a process of translation that considers cultural, legal, and infrastructural differences. Their study, based on living lab experiments between Amsterdam and Naples, reveals how place-specific constraints such as land use regulations, socio-cultural norms, and governance structures shape what can be realistically adapted. The authors emphasise the importance of collaborative adaptation platforms, like living labs, as mechanisms to enable mutual learning, stakeholder engagement, and co-designed solution development. In the Australian context, where federal-state fragmentation and uneven CE maturity persist, these findings reinforce the need for reflexive, locally grounded adaptation rather than top-down policy importation.

The study identifies three interrelated barriers that consistently hinder the adoption of quality and traceability systems in Australia's recycled plastics sector: infrastructure gaps, data limitations, and economic constraints. It is important to note that the economic findings in this study are based on stakeholder perceptions rather than verified or audited cost data. While this approach provides valuable insights into how actors experience financial barriers, it does not offer quantitative cost assessments. To inform robust policy development, future studies should consider incorporating cost audits or lifecycle costing methodologies to triangulate perceived economic challenges with actual expenditure data. Inadequate sorting and reprocessing infrastructure, especially in regional areas, undermines efforts to ensure material quality and implement traceability. These findings reinforce earlier observations by Eriksen, Christiansen [53], who emphasised the role of decentralised and underfunded infrastructure as a significant bottleneck in scaling high-quality recycling systems. The inability to process mixed or contaminated plastic streams consistently undermines attempts to implement traceability protocols and meet quality benchmarks. Even among CE-oriented firms, access to reliable and standardised material data, such as polymer composition and processing history, remains insufficient, limiting confidence in recyclate performance. These issues are compounded by the absence of harmonised standards like ISO 22095 [13], which would enable consistent classification and chain-of-custody verification. Economically, high recycling costs, price volatility, and the cost gap between virgin and recycled plastics continue to deter investment, especially for small and medium enterprises. Even technically viable solutions struggle to gain traction without systemic financial incentives and coordinated infrastructure and data reforms. Addressing these barriers requires integrated, sector-wide strategies rather than isolated interventions.

The study reveals that many perceived enablers of quality and traceability, such as closed-loop recycling, standardisation, and digital tracking, remain more aspirational than operational. Stakeholders, especially CE-adopting firms, strongly support these tools, but their enthusiasm often reflects future expectations rather than current practice. Despite recognising traceability as essential, respondents report persistent barriers, including poor data quality, limited interoperability, and lack of standard enforcement. This tension suggests a disconnect between strategic ambition and systemic readiness, mirroring concerns Gerasimidou, Martin [12] and Stewart and Niero [15] about the overstatement of implementation capacity in sustainability narratives. Optimism toward mechanisms like long-term contracts or design-for-recyclability also appears premature, as market volatility, procurement uncertainty, and fragmented standards obstruct progress. These findings reinforce the need to distinguish between rhetorical support for circularity and the structural conditions required to realise it at scale.

This study affirms and extends the framework of van der Vegt, Velzing [11] by applying it to the Australian context through a more systematic, mixed-methods approach. Like the original study, it identifies persistent cost, material quality, and traceability barriers. However, this research offers greater granularity by analysing variations across firm size, CE engagement, and supply chain roles. A key divergence lies in the perception of systemic and innovation-related enablers: while van der Vegt, Velzing [11] presented them as uniformly positive, Australian stakeholders, especially CE-aligned firms, express cautious optimism tempered by frustration over infrastructure gaps, data fragmentation, and regional disparities. This reflects the argument of Gall, Wiener [7] that enabling conditions must be underpinned by policy and institutional alignment. The study also highlights how the CE strategy influences regulatory interpretation. Unlike van der Vegt, Velzing [11], who classified policies by stakeholder consensus, this research shows that CE-aligned firms tend to frame regulation more constructively, even when incomplete mechanisms suggest that strategic orientation shapes both perception and engagement with policy frameworks.

This study offers a novel, data-driven contribution to the circular economy literature by providing a role-specific analysis of barriers and enablers to quality and traceability in the recycled plastics sector. Unlike prior studies such as van der Vegt, Velzing [11], which relied on qualitative interviews, this research uses a structured survey with statistical measures to capture variation across company size, supply chain role, and CE strategy adoption. This disaggregation reveals significant differences in how firms experience circularity; end users, for example, align with CE goals but still report critical weaknesses in infrastructure and traceability. At the same time, waste processors and service providers show more fragmented perceptions due to operational bottlenecks. These findings address a key gap that Gall, Wiener [7] identified and provide actionable policy design insights. Crucially, the same enabler, such as digital traceability, may be seen as a strategic asset by large CE-aligned firms but a compliance burden for smaller ones. Recognising such disparities is essential for designing differentiated support mechanisms and aligning policy ambition with operational capacity. This role-based, quantified approach advances the field's methodological rigour. It reinforces recent calls, such as those in ISO 59020 [60], for performance frameworks that reflect the complexity of circular transition across value chains.

The findings challenge the effectiveness of one-size-fits-all policy tools for circular economy implementation. Barriers and enablers, particularly about quality and traceability, vary significantly by company size, CE strategy, and supply chain role. While CE-aligned end users support regulatory goals, they still cite infrastructure and traceability as persistent barriers. Conversely, service providers and waste processors often view the same policies as burdensome due to high compliance costs and limited infrastructure access. These differences reflect structural asymmetries in circular governance, as Gall, Wiener [7] described, where uniform requirements fail to account for diverse capacities and constraints. Smaller firms, for instance, are more sensitive to investment risks, while larger firms, though better resourced, struggle with system-wide coordination. Even CE-aligned organisations report heightened awareness of unresolved issues like data harmonisation and feedstock quality. Fedotkina, Gorbashko [61] show that progress in Russia's circular economy relied on stakeholders' differentiated roles aligned with their capacities and positions in the value chain. Their framework identifies roles such as generator, processor, educator, and funder, and illustrates how large firms like Gazprom focused on infrastructure and public engagement, while SMEs led on reverse logistics. This supports van der Vegt, Velzing [11] and Stewart and Niero [15], who argue that internal commitment alone is insufficient without external policy and market alignment. The results underscore the need for differentiated policy instruments, tailored to specific stakeholder profiles, to ensure equitable participation and functional circular systems. Policy may reinforce existing disparities without such nuance and leave circularity unrealised in practice. These findings align with recent research by Ababio, Lu [62], who argue that circular outcomes in the construction sector depend on aligning stakeholder roles with context-specific collaborative capabilities. Using a MoSCoW prioritisation framework, they demonstrate that not all capabilities are equally critical at each stage of the circular procurement process. What is essential for end-of-life recovery may be only desirable during early design. This logic applies to plastics recycling: end-users require confidence in traceability and data integrity, while recyclers prioritise infrastructure access and quality control mechanisms. Therefore, policies must match interventions, such as funding, data platforms, or capacity-building, to each actor group's operational realities and influence levels. A nuanced strategy of this nature avoids the pitfalls of generic mandates and promotes more inclusive, feasible circular transitions. This is resonated by Mies and Gold [32], who argue that current circular economy practices often sideline the social dimension, particularly actor-specific concerns such as worker protection, local community involvement, and consumer empowerment. Through a systems-based causal mapping of stakeholders, they demonstrate that leverage points such as education, participation, and inclusive governance must be tailored to each group's roles, capacities, and social vulnerabilities. Their analysis reinforces the need to move beyond narrow job-creation metrics or generic CSR narratives toward a normative, equity-centred approach to circularity. In the Australian context, where informal roles in recycling, community cohesion, and public trust are unevenly developed, uniform CE interventions risk deepening social inequalities unless explicitly designed with actor differentiation in mind. In response to the broader call for integrating policy-relevant tools into circular economy research, we acknowledge that life cycle assessment (LCA) has long been considered a valuable decision-support framework in the waste and resource management domain. However, as [63] point out, while LCA is effective in quantifying environmental trade-offs, it has limitations in addressing institutional readiness, system interoperability, and social acceptance, dimensions that are central to enabling traceability and quality in plastics circularity. Our findings reinforce this point by highlighting how perceived enablers, such as standardisation and certification, often interact with context-specific barriers that are not fully captured by environmental metrics alone. Similarly, digitalisation has emerged as a prominent theme in CE discourse, primarily through technologies such as blockchain and the Internet of Things (IoT). While some literature, including [64], has mapped digitalisation trends within CE research, empirical evidence of how such technologies function in traceability systems remains scarce. To illustrate practical deployment, we instead refer to [65], which documents a real-world pilot in Japan where blockchain was used to enhance traceability in recycled plastics. This example illustrates the potential of digital infrastructure to support interoperability, transparency, and accountability in complex supply chains, functions that several respondents in our study identified as critical yet underdeveloped in the Australian context.

The study highlights the urgent need for coordinated, system-level investment to address the persistent barriers to quality and traceability in Australia's recycled plastics sector. While CE-aligned firms are willing to adopt advanced tools, their efforts are hampered by infrastructure deficits, fragmented data systems, and insufficient economic support. These challenges are unevenly distributed across the value chain, exposing significant disparities in resources and capabilities. A uniform investment approach is, therefore, inadequate. Instead, tailored strategies are needed: SMEs require targeted financial support and shared infrastructure access, while larger firms benefit from investments in high-capacity processing and interoperable data platforms. These findings align with Gall, Wiener [7] and Hahladakis and Iacovidou [6], who stress the importance of institutional coordination and harmonised standards to scale circular solutions. Without integrated investment in infrastructure, traceability systems, and procurement mechanisms, guided by frameworks like ISO 59020 [60], efforts risk becoming fragmented and ineffective. To illustrate this need, Table 9 presents a policy-action matrix outlining differentiated responses to key barrier domains across major stakeholder groups. A shift from isolated interventions to a coherent, actor-sensitive investment model is essential to make circularity both feasible and equitable at scale. Further support for differentiated strategies comes from Eiselein and Langenus [66], who demonstrate that thriving circular economy transitions hinge on fostering principles, such as transparency, inclusivity, complementarity, and pragmatism, and clearly defined yet adaptive stakeholder roles. Drawing from three

Belgian socio-circular hubs, they show that distributive roles like coordinators and match-makers must enable equitable participation, primarily where resource asymmetries exist between large firms and smaller actors like civil society organisations. Their application of the Quintuple Helix Model (QHM), which is a multi-stakeholder governance framework that emphasises collaboration across five key spheres—academia, industry, government, civil society, and the natural environment—reinforces the need for systems-level thinking, where stakeholder capacities, motivations, and power positions are dynamically assessed and rebalanced. Providing a practical framework for the actor-sensitive investment and governance models urgently needed in Australia's fragmented CE context.

Table 9. Policy-Action Matrix for Addressing Barriers to Quality and Traceability in the Australian Recycled Plastics Value Chain.

Barrier Domain	SMEs Without CE Strategy	Large CE-Aligned Firms	Waste Processors	End-Users
Infrastructure gaps	Subsidised access to shared sorting/reprocessing facilities	Investment in high-capacity processing aligned with national standards	Public co-investment in regional processing infrastructure	Improved access to verified recyclate through certified suppliers
Data and traceability limitations	Low-cost digital traceability tools and training	Interoperable data platforms and policy incentives for data sharing	Clear data classification standards and interoperable reporting systems	Mandatory product labelling and origin tracking standards
Economic constraints	Targeted grants or tax credits to offset compliance costs	Support for long-term procurement and public–private partnerships	Risk-sharing models to stabilise input cost variability	Green procurement incentives favouring recycled-content products

We acknowledge that the relatively low response rate introduces potential for non-response bias. Due to the anonymity and sectoral diversity of the respondent pool, formal testing for non-response bias was not feasible. However, the motivated sampling approach and triangulation with existing literature helped mitigate this limitation. Furthermore, subgroup analysis by CE strategy adoption and the organisational role provided internal comparative validity across respondent types. But the major limitation is still around the sample size, which restricts the ability to draw statistically significant conclusions. Increasing the number of participants would enhance the reliability of the survey results and enable more nuanced comparisons between different company sizes, industries, and CE adoption levels. Additionally, including multiple respondents from within the same company, encompassing both decision-makers and operational staff, would provide a more comprehensive perspective on company-wide perceptions and practices related to quality and traceability. This approach would also allow for internal variability analysis, offering insights into how strategic and operational viewpoints align or diverge within organisations. Expanding the survey to other countries where circular economy strategies are more established could provide valuable comparative insights. Countries with advanced circular practices may reveal trends, benchmarks, and best practices that could inform policy and industry approaches in regions where CE adoption is still emerging. By addressing these limitations, the survey's capacity to develop meaningful indicators and draw actionable insights from the data would be significantly strengthened, ultimately contributing to a more global understanding of quality and traceability in recycled plastic systems. This study focused on industry-facing actors, such as recyclers, compounders, converters, and end users, who are directly responsible for implementing quality and traceability systems within the recycled plastics value chain. While this focus aligns with the study's operational scope, it excludes perspectives from other critical stakeholders such as consumers, NGOs, and regulatory authorities. Their absence limits the systemic breadth of the analysis, particularly in terms of behavioural drivers, governance dynamics, and broader public accountability.

We acknowledge this as a limitation and recommend that future research expand the stakeholder base to capture a more holistic view of traceability ecosystem interactions.

A further limitation of this study is its reliance on self-reported perceptions regarding cost and economic feasibility. While these perceptions are meaningful in shaping organisational behaviour, they do not substitute for audited cost data. Future research should seek to validate these findings through financial analysis or case-based cost audits to strengthen the evidence base for economic policy design in circular plastics systems.

This survey, conducted in 2024, reflects more recent developments and trends, which likely account for the observed differences. Since the van der Vegt, Velzing [11] study was performed before 2022, it does not capture the most current advancements and shifts in regulatory policies, market demand, and technological innovations. In the intervening years, there may have been significant policy changes and increased enforcement of waste legislation in Australia, leading to a more substantial alignment with regulatory frameworks. Moreover, the growing demand from existing markets and the introduction of new material innovations in recent years might have enhanced the perceived enablers in Australia. Advances in additional testing methods, application possibilities, and using materials with better properties have also likely contributed to this shift. Furthermore, improvements in the reliability of material streams have reinforced the effectiveness of circular economy practices in Australia. These factors collectively highlight the dynamic nature of the field and underscore the importance of considering the timing of data collection when interpreting survey results. Additionally, European stakeholders' perceptions may have shifted with progress over the criteria identified as different in our analysis. Today's follow-up survey of the same European stakeholders could highlight these changes and provide valuable insights as a future research study. This would help understand how recent advancements and policy implementations have influenced stakeholders' perceptions and practices in both regions. The data collection period for this study (July 2023 to February 2024) preceded several significant policy developments in Australia, including proposed updates to packaging design standards and national traceability frameworks. As such, some policy shifts underway during 2024–25 are not directly reflected in our analysis. While this limitation may hinder the capture of the most up-to-date regulatory context, the findings remain highly relevant, as they document structural barriers and institutional fragmentation that persist even amid increased policy momentum. The study, thus, captures a transitional phase in which system readiness may lag behind emerging regulatory ambition.

5. Conclusions

This study provides a differentiated and empirically grounded assessment of the enablers and barriers shaping the adoption of quality and traceability practices in Australia's recycled plastics sector. By incorporating a role-specific, statistically structured analysis across various company sizes and degrees of circular economy (CE) engagement, the research reveals that while CE strategies enhance internal alignment with circular goals, they do not consistently resolve structural constraints such as cost burdens, infrastructural limitations, and traceability fragmentation. The persistent challenges surrounding data interoperability, inconsistent material quality, and the high cost of recycled plastics suggest that an immature enabling environment is undermining firms' technical and organisational readiness.

The findings highlight critical fault lines in the current circular transition: innovation is widely supported in principle but hampered in practice by systemic gaps in material standardisation, policy coherence, and market incentives. Notably, while smaller firms often cite cost and compliance challenges, they also report relatively greater optimism and adaptability in specific domains, such as process innovation and market responsiveness. In contrast, larger firms, despite possessing greater resources, tend to report more profound frustration with systemic barriers, particularly concerning infrastructure capacity and policy fragmentation. These differences suggest that enabling factors and obstacles manifest differently depending on organisational size and supply chain role. End users, converters, waste processors, and service providers exhibit different exposure levels to these barriers, demonstrating that a one-size-fits-all policy or investment model is unlikely to succeed. Instead, the results call for differentiated and role-sensitive policy frameworks, targeted financial mechanisms, and coordinated system-level investments that address the unique constraints faced by each actor across the value chain.

Moreover, the study builds on and extends existing international frameworks, by providing updated, region-specific evidence from the Australian context and by offering a quantitative lens that exposes internal contradictions between strategic ambition and operational capacity. It reinforces the urgent need for harmonised traceability protocols, interoperable data systems, and infrastructure upgrades to transform circularity from aspiration to viable practice.

What emerges from this research is a clear call for more nuanced and actor-specific policy design. The data show that even firms with circular economy strategies, while conceptually aligned with sustainability goals, remain hindered by persistent barriers such as poor infrastructure, data fragmentation, and economic uncertainty. This matters because current policy frameworks are often applied uniformly across sectors and company types, assuming a level playing field that does not exist. One-size-fits-all approaches overlook the varied capacity, exposure, and role-based challenges that shape how circularity is implemented in practice. To address this, policy interventions must move toward differentiated and role-sensitive mechanisms. Small- and medium-sized enterprises require targeted financial support to overcome upfront investment barriers and compliance costs. Larger firms, while more equipped, need interoperable traceability and material classification systems to operate across fragmented supply chains. All actors would benefit from coordinated infrastructure investment and enforcement mechanisms that match policy ambition with practical feasibility. Without this layered and collaborative approach, circular economy strategies will remain aspirational, and policy efforts risk reinforcing rather than resolving systemic inequalities in the recycled plastics sector.

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