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From Industrial Waste to Resource Recovery: A Review of Circular Economy Governance

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Abstract. Industrial waste is increasingly viewed not only as an environmental burden but also as a potential source of materials that can be recovered and returned to productive use. This shift reflects the growing importance of circular economy principles in industrial and environmental governance. This article reviews how industrial waste can be transformed into recoverable resources through governance mechanisms that support waste prevention, reuse, recycling, and material recovery. A structured literature review was conducted using peer-reviewed studies, policy documents, and institutional publications related to industrial waste, resource recovery, circular economy, environmental governance, and industrial sustainability. The review shows that successful resource recovery depends on more than technological capability. Regulatory clarity, institutional coordination, economic incentives, corporate commitment, market demand for secondary materials, and collaboration among stakeholders strongly influence the transition from disposal-oriented waste management toward more circular practices. The literature also identifies several barriers, including fragmented regulations, limited recycling infrastructure, uncertain markets for recovered materials, weak enforcement, and differences in industrial capacity. These challenges indicate that circular economy governance requires an integrated approach in which environmental regulation, economic instruments, technological innovation, and corporate responsibility operate together. This review concludes that industrial waste governance should increasingly prioritize resource recovery and material circulation rather than relying mainly on disposal. Strengthening policy coherence, institutional capacity, and cooperation between government and industry is essential to support a more effective transition toward circular industrial systems.

Keywords: industrial waste; resource recovery; circular economy; environmental governance; industrial sustainability

Abstrak. Limbah industri semakin dipandang tidak hanya sebagai beban lingkungan, tetapi juga sebagai sumber material yang masih dapat dipulihkan dan dimanfaatkan kembali dalam kegiatan produksi. Perubahan cara pandang ini sejalan dengan semakin pentingnya prinsip ekonomi sirkular dalam tata kelola industri dan lingkungan. Artikel ini mengulas bagaimana limbah industri dapat diubah menjadi sumber daya yang dapat dimanfaatkan kembali melalui mekanisme tata kelola yang mendukung pencegahan limbah, penggunaan kembali, daur ulang, dan pemulihan material. Kajian dilakukan melalui tinjauan literatur terstruktur terhadap artikel ilmiah, dokumen kebijakan, dan publikasi institusi yang membahas limbah industri, pemulihan sumber daya, ekonomi sirkular, tata kelola lingkungan, dan keberlanjutan industri. Hasil kajian menunjukkan bahwa keberhasilan pemulihan sumber daya tidak

hanya bergantung pada kemampuan teknologi. Kejelasan regulasi, koordinasi kelembagaan, insentif ekonomi, komitmen perusahaan, permintaan pasar terhadap material sekunder, dan kerja sama antarpemangku kepentingan turut menentukan peralihan dari pengelolaan limbah yang berorientasi pada pembuangan menuju praktik yang lebih sirkular. Literatur juga menunjukkan beberapa hambatan, seperti regulasi yang belum terintegrasi, keterbatasan infrastruktur daur ulang, ketidakpastian pasar bagi material hasil pemulihan, lemahnya penegakan, dan perbedaan kapasitas industri. Kondisi tersebut menunjukkan bahwa tata kelola ekonomi sirkular membutuhkan pendekatan terpadu yang menggabungkan regulasi lingkungan, instrumen ekonomi, inovasi teknologi, dan tanggung jawab perusahaan. Kajian ini menyimpulkan bahwa tata kelola limbah industri perlu semakin diarahkan pada pemulihan sumber daya dan sirkulasi material, bukan hanya pada pembuangan. Penguatan konsistensi kebijakan, kapasitas kelembagaan, serta kerja sama pemerintah dan industri menjadi penting untuk mendukung transisi menuju sistem industri yang lebih sirkular.
Kata Kunci: limbah industri; pemulihan sumber daya; ekonomi sirkular; tata kelola lingkungan; keberlanjutan industri

1. Introduction

Industrial production has traditionally followed a linear pattern in which raw materials are extracted, processed into products, consumed, and eventually discarded as waste. This model has supported industrial growth for decades, but it has also contributed to increasing material consumption, waste generation, and pressure on natural resources. The circular economy has emerged as an alternative approach that seeks to retain the value of products and materials for as long as possible through reduction, reuse, recycling, recovery, and other strategies that reduce dependence on virgin resources. Recent conceptual work shows that circular economy thinking has developed beyond waste management alone and increasingly emphasizes systemic changes in production, consumption, business models, and resource use (Kirchherr et al., 2023).

Within this transition, industrial waste occupies an important position. Materials that are considered waste in one production process may still contain economic or functional value that can be recovered, processed, or used as inputs elsewhere. Resource recovery therefore changes the way industrial waste is understood. Instead of being treated exclusively as material that must be disposed of, waste can become part of a secondary resource flow when appropriate technical, economic, and institutional conditions are available. Singh and Ordoñez (2016) demonstrate that resource recovery can create new material pathways by transforming discarded products and materials into resources for further use. Although their study focuses on post-consumer waste, the principle is equally relevant to industrial systems where residues, by-products, and secondary materials may retain significant value.

This perspective is closely related to industrial symbiosis. In an industrial symbiosis arrangement, materials, energy, water, or by-products generated by one organization can be used by another, reducing the need for virgin resources while preventing potentially useful materials from becoming waste. Neves et al. (2020), in a comprehensive review of industrial symbiosis, show that these relationships can contribute to resource savings, economic benefits, environmental performance, and more efficient material use. Industrial symbiosis therefore provides one practical pathway through which circular economy principles can move from general policy goals toward operational resource exchange between firms.

However, converting industrial waste into resources is not simply a technical matter. Even when a waste stream can technically be recycled or reused, recovery may remain limited when regulations are unclear, secondary-material markets are weak, information about available waste streams is incomplete, infrastructure is inadequate, or firms have little economic incentive to cooperate. Salmenperä et al. (2021) found that progress toward circularity in waste management is strongly influenced by institutional, economic, socio-cultural, and informational factors. Their findings highlight the importance of governance conditions that determine whether potentially recoverable materials actually return to productive use.

Governance becomes particularly important because circular economy transition involves actors operating at different levels. Governments establish waste classifications, environmental standards, recycling requirements, incentives, and market rules. Industries make decisions about production processes, waste prevention, technology, and investment. Waste-management and recycling companies provide collection, treatment, and recovery services, while consumers and downstream industries influence demand for recycled and secondary materials. These actors do not necessarily have the same priorities. Effective circular economy governance therefore requires mechanisms capable of aligning environmental objectives with economic incentives, technological possibilities, and organizational interests.

Policy design has consequently become a central issue in circular economy research. Hartley et al. (2020), examining expectations surrounding European Union circular economy policies, found that stakeholders regarded regulatory approaches as necessary but also emphasized the importance of economic instruments, information, infrastructure, and coordination. This suggests that circular transition cannot be

achieved through a single policy instrument. Waste regulation may prevent harmful disposal, but resource recovery also requires policies that make reuse, recycling, and secondary material utilization technically feasible and economically attractive.

More recent evidence supports this broader policy perspective. Losa (2025), in a systematic review of circular economy public policies, identifies a growing range of policy instruments intended to support circularity across production and consumption systems. These include regulatory instruments, economic mechanisms, information-based measures, and collaborative approaches. The increasing diversity of policy tools reflects a recognition that circular economy transition is not achieved merely by increasing recycling rates. It requires changes in how resources are produced, exchanged, valued, and retained within economic systems.

At the firm level, the transition also faces organizational and market barriers. Hina et al. (2022) identify a broad set of drivers and barriers affecting circular economy business models, including regulatory support, technological capability, market demand, organizational culture, financial resources, collaboration, and stakeholder pressure. These factors are highly relevant to industrial waste recovery because firms may recognize the environmental value of recovering materials while still being reluctant to invest when the financial return is uncertain or when demand for secondary materials is unstable.

This tension illustrates an important distinction between waste management and resource governance. Conventional waste management often begins after waste has already been generated and concentrates on collection, treatment, recycling, or disposal. Circular economy governance seeks to intervene earlier by questioning how materials enter production systems, how long they remain useful, whether waste can be prevented, and how residual materials can be returned to productive cycles. Ghisellini et al. (2016) describe circular economy transition as requiring a broader reorganization of economic and production systems rather than simply improving end-of-pipe waste management.

Resource recovery should therefore not be understood as an unlimited justification for producing waste. Recycling and recovery are important, but they occur after material has already entered the waste stream. A more circular approach gives priority to preventing unnecessary material use, reducing waste generation, extending product and material life, and then recovering resources when waste cannot reasonably

be avoided. This hierarchy is important because a policy system that focuses mainly on downstream recovery may improve recycling while leaving inefficient production and excessive material consumption largely unchanged.

The governance of secondary materials creates an additional challenge. Industrial residues do not automatically become marketable resources simply because they have potential value. Their reuse may depend on quality standards, consistency of supply, contamination levels, technical specifications, transportation costs, regulatory classification, and the willingness of another industry to accept them. When regulations continue to classify recoverable materials primarily as waste, firms may face administrative burdens or legal uncertainty that discourage exchange. Conversely, overly permissive rules may create environmental risks if hazardous or contaminated materials are transferred under the label of resource recovery. Circular economy governance therefore needs to balance the facilitation of material circulation with safeguards for environmental and public interests.

Industrial symbiosis illustrates this balance particularly well. Neves et al. (2020) show that successful industrial symbiosis depends not only on physical proximity or the availability of compatible waste streams but also on trust, information exchange, economic benefits, regulation, and cooperation among participating organizations. Industrial waste recovery is therefore partly a coordination problem. One firm may possess a potentially useful residue while another requires a substitute material, but an exchange will occur only when both parties can identify the opportunity, establish technical compatibility, manage regulatory requirements, and agree on acceptable costs and responsibilities.

Digital information and reliable waste data are also increasingly relevant. Salmenperä et al. (2021) emphasize the importance of accessible and accurate waste information in enabling circular solutions. Better information on the quantity, quality, location, and timing of industrial waste streams can help identify opportunities for recycling and industrial symbiosis. However, information sharing may also face commercial confidentiality concerns and inconsistent data standards. Governance mechanisms are therefore required not only to collect waste data but also to make them useful for decision-making while maintaining appropriate protections for industrial information.

Another significant challenge is the difference in capacity between firms and regions. Large companies may have sufficient capital, environmental management systems, technical staff, and supply-chain influence to invest in circular technologies or develop partnerships for resource recovery. Smaller firms may face greater financial and technical constraints. Likewise, regions with established recycling infrastructure and markets for secondary materials may be able to develop circular industrial systems more rapidly than areas where waste collection, processing facilities, or market networks remain limited. These differences suggest that uniform policy requirements may not produce uniform outcomes.

The literature also demonstrates that circular economy implementation frequently encounters institutional and market barriers even in jurisdictions where circularity has become an explicit policy objective. Research on circular economy barriers repeatedly identifies technological, market, institutional, cultural, and organizational constraints as obstacles to implementation (Hina et al., 2022; Salmenperä et al., 2021). The persistence of these barriers indicates that the transition from waste disposal to resource recovery cannot be assumed to occur naturally as recycling technologies improve. It requires deliberate governance arrangements that shape incentives, responsibilities, information flows, and cooperation.

Despite the growing literature on circular economy, industrial symbiosis, recycling, and resource recovery, these topics are often examined from different disciplinary perspectives. Technical research tends to concentrate on processes for recovering materials or energy from particular waste streams. Business research examines circular business models and firm-level barriers, while policy studies focus on regulatory instruments and national circular economy strategies. Industrial symbiosis research examines inter-firm material exchanges but does not always connect these exchanges to broader questions of environmental governance. Recent reviews of public circular economy policies likewise show a rapidly expanding policy literature, but the relationship between governance arrangements and the practical transformation of industrial waste into secondary resources remains an important area for synthesis (Losa, 2025).

This gap is particularly relevant because the success of resource recovery ultimately depends on interactions across these different levels. Technology determines whether a material can be recovered; markets influence whether recovery is

economically viable; firms determine whether circular practices are adopted; and governance determines the regulatory and institutional conditions within which these decisions occur. Treating these elements separately can therefore provide only a partial explanation of why some industrial waste streams return to production while others continue to be discarded.

Accordingly, this article reviews the transition from industrial waste to resource recovery through the perspective of circular economy governance. It examines how regulatory frameworks, economic incentives, institutional coordination, industrial symbiosis, corporate capability, secondary-material markets, and information systems influence the recovery and circulation of industrial resources. Particular attention is given to the barriers that prevent technically recoverable waste from returning to productive use and to the governance mechanisms that can support more effective material circulation. By integrating waste management, resource recovery, and governance perspectives, the review seeks to clarify how industrial waste policy can move beyond disposal and conventional recycling toward a more coordinated and genuinely circular use of resources.

2. Method

2.1 Review Design

This study employed a structured integrative literature review to examine how industrial waste can be redirected toward resource recovery through circular economy governance. An integrative approach was selected because the topic brings together literature from environmental governance, waste management, industrial ecology, circular economy, industrial symbiosis, resource recovery, and public policy. This approach allows studies with different disciplinary perspectives to be compared within a common analytical framework while maintaining a clear focus on governance and policy rather than on individual waste-treatment technologies alone (Torraco, 2016; Snyder, 2019).

The review was guided by four questions: how industrial waste is positioned within circular economy systems; what governance mechanisms support the transition from waste disposal to resource recovery; what barriers limit the reuse, recycling, and circulation of industrial materials; and what policy conditions can strengthen resource recovery across industrial systems.

2.2 Literature Search Strategy

The literature search was conducted using combinations of keywords related to industrial waste, resource recovery, and circular economy governance. The main search terms included *industrial waste*, *resource recovery*, *waste valorization*, *circular economy*, *industrial symbiosis*, *secondary raw materials*, *waste governance*, *environmental governance*, *circular economy policy*, *waste regulation*, *recycling policy*, *resource efficiency*, *industrial sustainability*, and *material recovery*.

These terms were combined where appropriate, including "industrial waste AND circular economy," "industrial waste AND resource recovery," "waste valorization AND governance," "industrial symbiosis AND policy," "secondary materials AND regulation," and "circular economy AND environmental governance."

Relevant studies were identified through Google Scholar and direct searches of journal and publisher platforms. Priority was given to peer-reviewed journal articles published between 2016 and August 2026 to capture recent developments in circular economy policy, industrial resource recovery, waste governance, and industrial symbiosis. Earlier studies were retained when they provided an important conceptual foundation for understanding circular economy or resource recovery.

In addition to scholarly literature, selected institutional and policy documents were considered when they directly addressed circular economy strategies, waste hierarchy, resource efficiency, industrial waste regulation, or secondary-material governance.

2.3 Inclusion and Exclusion Criteria

Sources were included when they addressed at least one of the following areas: (1) industrial waste management within a circular economy context; (2) resource recovery, reuse, recycling, or waste valorization; (3) industrial symbiosis and inter-firm material exchange; (4) regulatory or policy instruments supporting circularity; (5) economic incentives and secondary-material markets; (6) organizational or institutional barriers to circular economy implementation; or (7) environmental governance related to industrial material flows.

Technical studies were included only when their findings contributed to understanding the broader governance, policy, economic, or implementation conditions of resource recovery. Studies concerned exclusively with laboratory-scale recovery

processes, material characterization, or treatment efficiency without meaningful implications for circular economy governance were excluded.

Publications were also excluded when they lacked sufficient bibliographic information, could not be traced to a credible journal or institutional source, or were not directly relevant to the transition from industrial waste management toward resource circulation.

2.4 Data Extraction

Information from the selected literature was extracted according to a common analytical framework. For each source, attention was given to the type of industrial waste or material flow discussed, the form of recovery or circular practice examined, the governance mechanism involved, the policy instrument applied, the actors participating in the process, the barriers identified, and the main environmental or economic implications.

The review also recorded whether circular practices were driven primarily by regulation, economic incentives, market opportunities, corporate strategies, technological capability, inter-firm collaboration, or a combination of these factors. Particular attention was given to the conditions that allowed industrial residues to move from a waste-management system into a secondary-resource market or another production process.

2.5 Thematic Analysis

The literature was organized into six main themes. The first examined the shift from conventional waste management toward resource recovery and circularity. The second focused on regulatory and policy instruments used to promote waste prevention, recycling, reuse, and material recovery. The third addressed industrial symbiosis and collaboration between firms as mechanisms for circulating materials.

The fourth theme examined economic incentives and markets for secondary materials. The fifth focused on corporate capability, technological readiness, information availability, and organizational commitment. The sixth examined institutional coordination and the wider governance arrangements needed to support circular industrial systems.

The analysis emphasized the relationships among these themes rather than treating them as independent factors. For example, technically recoverable waste may remain unused when regulatory classification restricts its transfer, when no market exists for the recovered material, or when industries lack information about potential users. Likewise, economic incentives may have limited impact when infrastructure or institutional coordination is weak.

2.6 Evidence Synthesis

A narrative thematic synthesis was used to compare findings across different industrial and policy settings. The review did not attempt to calculate a pooled quantitative effect because the selected studies differed considerably in industry type, material stream, geographical context, policy framework, and circular economy practice.

Instead, the synthesis focused on recurring governance patterns, enabling conditions, implementation barriers, and differences between disposal-oriented and resource-oriented approaches. The findings were interpreted through three interconnected levels: waste prevention and recovery at the firm level, material exchange and market development across industrial networks, and regulatory and institutional governance at the policy level.

This structure made it possible to examine resource recovery not simply as a technological process but as the outcome of interactions among regulation, markets, organizations, infrastructure, information, and collaboration. The resulting synthesis was used to identify governance conditions that can support a more effective transition from industrial waste disposal toward circular material use.

3. Result and Discussion

3.1 From Waste Disposal to Resource Recovery

The reviewed literature shows a clear shift in the way industrial waste is understood within circular economy thinking. In a conventional linear system, waste generally appears at the end of production and is managed through treatment, recycling, or disposal. A circular approach changes this perspective by asking whether waste can be prevented, whether materials can remain in use for longer periods, and whether residues from one process can become inputs for another. Resource recovery

therefore represents more than an improvement in waste treatment; it reflects a broader change in how industries value and manage material flows.

Ghisellini et al. (2016) describe the circular economy as a system-level approach intended to reduce dependence on virgin resources and minimize waste through repeated circulation of materials. More recent work by Kirchherr et al. (2023) similarly shows that contemporary definitions of the circular economy increasingly emphasize systemic transformation rather than recycling alone. This distinction is important because an industrial system can achieve relatively high recycling rates while still consuming large amounts of virgin material and generating substantial waste. Circularity therefore requires attention to material use before waste is generated as well as to recovery after it enters the waste stream.

The literature also indicates that the concept of "waste" is partly determined by economic, regulatory, and organizational conditions. A residue with potentially useful properties may continue to be discarded when no viable user, market, or regulatory pathway exists. Conversely, the same material may become economically valuable when another industry can use it as a secondary input. Singh and Ordoñez (2016) illustrate this transition by showing how discarded materials can be redirected into new productive applications when technical characteristics and user requirements are matched.

This suggests that the transition from waste to resource can be represented as a governance process rather than as a purely technological conversion:

Industrial residue → identification of resource potential → technical validation → regulatory acceptance → market or industrial user → productive reuse

Failure at any stage may return the material to the conventional waste-management pathway. A material may be technically reusable, for example, but still be disposed of because transport costs are high, regulations classify it restrictively, or no reliable buyer exists.

3.2 Waste Prevention Should Precede Resource Recovery

Although resource recovery is central to the circular economy, the literature does not support treating recovery as the first or only solution to industrial waste. Circular economy principles generally place greater emphasis on preventing waste and maintaining material value before relying on recycling or recovery. This is important

because recovery processes themselves can require energy, additional materials, transportation, and processing infrastructure.

The distinction between waste prevention and waste recovery has important policy implications. A policy framework that mainly rewards recycling may increase the quantity of materials recovered without necessarily encouraging industries to redesign inefficient production processes. In contrast, policies that encourage cleaner production, material efficiency, product redesign, reuse, and longer material life can reduce the amount of waste requiring downstream treatment.

Kirchherr et al. (2023) show that circular economy thinking increasingly moves beyond the narrower interpretation of "reduce, reuse, recycle" toward broader structural changes in production and consumption. Ghisellini et al. (2016) likewise emphasize that genuine circularity requires changes across production systems rather than simply better end-of-pipe management.

For industrial governance, this means that resource recovery should be placed within a hierarchy. The preferred sequence is to avoid unnecessary material use, reduce waste generation, reuse materials where possible, and recover resources from unavoidable residual streams. Disposal remains necessary for some materials, particularly when contamination, safety, or technical limitations prevent responsible recovery, but it should increasingly become the final rather than the dominant option.

3.3 Industrial Symbiosis as a Pathway for Resource Circulation

Industrial symbiosis emerges from the literature as one of the clearest mechanisms for turning industrial residues into productive resources. It involves collaboration between organizations in which waste, by-products, energy, water, or other resources from one activity are used by another. This creates the possibility of reducing both waste disposal and demand for virgin materials.

Neves et al. (2020) show that industrial symbiosis can generate environmental and economic benefits through resource exchange, but successful implementation depends on several conditions. Compatible material flows must be available, participating firms need information about potential exchanges, transportation and processing costs must remain reasonable, and organizations must be willing to cooperate over time.

These requirements explain why industrial symbiosis does not necessarily emerge automatically even when firms are located close to one another. A company producing a useful residue may not know which organization could use it. A potential user may be concerned about variations in quality or supply. Firms may also be reluctant to share information about production processes because of commercial confidentiality. Regulatory uncertainty can further discourage exchanges if companies are unsure whether a material legally remains "waste" or can be treated as a secondary resource.

The governance challenge is therefore to reduce the transaction costs associated with finding, evaluating, and maintaining industrial exchanges. Public authorities, industrial-estate managers, business associations, and digital platforms can potentially act as intermediaries by improving information about available material streams and facilitating relationships between firms.

Industrial symbiosis also demonstrates that circular economy governance extends beyond individual companies. A single firm may improve internal recycling, but a broader circular industrial system requires connections among firms. The unit of governance therefore shifts from an individual facility toward networks of producers, recyclers, processors, logistics providers, and secondary-material users.

3.4 Regulatory Frameworks Can Enable or Restrict Circularity

Regulation has a dual role in industrial waste governance. It protects environmental and public interests by controlling potentially harmful waste, but it can also shape whether materials can move from waste-management systems into legitimate secondary-resource markets.

This creates an important regulatory tension. If rules are too restrictive, materials with demonstrated resource value may face lengthy administrative procedures that make recovery economically unattractive. If regulation is too permissive, hazardous or contaminated waste may be circulated under the label of reuse or recycling, creating environmental and health risks.

Effective circular economy governance therefore requires a clear distinction between legitimate resource recovery and practices that merely shift the location of waste. Regulatory frameworks need criteria for material quality, environmental safety, traceability, and responsibility. Where appropriate, clear conditions for determining

when a material ceases to be waste can reduce legal uncertainty and support legitimate secondary-material markets.

Hartley et al. (2020) found that stakeholders involved in European circular economy policy considered regulatory instruments necessary but insufficient by themselves. Infrastructure, economic incentives, information, and coordination were also regarded as important. More recent synthesis by Losa (2025) likewise shows that circular economy policies increasingly rely on combinations of regulatory, economic, informational, and collaborative instruments.

The evidence therefore suggests that the central policy question is not whether regulation should be reduced or strengthened in general. Rather, regulation should become more adaptive and coherent: strict enough to prevent environmentally harmful practices, but sufficiently clear to allow safe and economically viable material circulation.

3.5 Economic Incentives and the Market for Secondary Materials

A technically recoverable material does not automatically become an economically viable resource. The reviewed literature repeatedly identifies market conditions as an important barrier to circular economy implementation. Recovered materials must compete with virgin materials on price, quality, availability, and consistency.

This creates a particular problem when virgin materials are inexpensive. Even if the environmental benefits of recycled or recovered materials are substantial, firms may have little commercial reason to use them when primary resources provide more predictable quality at a lower cost. Resource recovery can therefore remain dependent on policy intervention or market development.

Hina et al. (2022) identify financial resources, market demand, regulation, stakeholder pressure, technological capability, and organizational factors as important influences on circular business-model adoption. Their findings suggest that firms are more likely to adopt circular practices when environmental benefits are accompanied by a credible economic case.

Policy instruments can influence this calculation in several ways. Disposal charges can increase the cost of sending recoverable materials to landfill or other final treatment. Financial incentives can lower investment costs for recycling and recovery technologies. Public procurement can create demand for products containing secondary

materials. Requirements for recycled content can strengthen markets, while taxes or charges associated with virgin-resource use may improve the competitiveness of recovered alternatives.

However, economic instruments need careful design. Subsidizing recovery without adequate environmental criteria may encourage low-value processing that produces little genuine circularity. Likewise, excessively high disposal costs without sufficient recycling infrastructure may encourage illegal disposal rather than resource recovery. Economic instruments therefore work best when they are aligned with environmental regulation and supported by viable recovery infrastructure.

3.6 Information and Traceability as Governance Infrastructure

Information emerged as another recurring condition for successful resource circulation. Industrial waste streams are highly diverse in composition, volume, frequency, contamination, and potential application. Without reliable information on these characteristics, firms cannot easily assess whether a waste stream can serve as a substitute material.

Salmenperä et al. (2021) identify information availability among the factors that can enable or constrain circular waste management. In industrial settings, useful information may include the type of material generated, quantity, chemical or physical characteristics, location, generation schedule, current treatment method, and conditions under which the material could be transferred.

Digital systems can potentially improve this situation by connecting producers of residual materials with potential users. Such systems can reduce search costs and help identify opportunities for industrial symbiosis. Nevertheless, the usefulness of digital platforms depends on data quality. A marketplace containing incomplete or unreliable information about material composition provides limited value to industrial users who must meet technical specifications.

Traceability is equally important from a regulatory perspective. When materials move across multiple firms, authorities need to understand their origin, composition, destination, and final use. Greater circulation should therefore be accompanied by systems capable of distinguishing legitimate recovery from uncontrolled waste transfer.

This reveals an important feature of circular economy governance: information itself becomes infrastructure. Material circulation depends not only on physical facilities

such as recycling plants and transport networks but also on reliable systems for sharing and verifying information.

3.7 Corporate Capability and Organizational Commitment

The literature also shows that circular transition ultimately requires decisions at firm level. Regulations and markets create external conditions, but companies determine whether investments in waste reduction, resource recovery, redesign, or industrial collaboration actually occur.

Hina et al. (2022) show that organizational culture, management commitment, knowledge, financial capability, and technological readiness influence adoption of circular business models. These factors help explain why firms operating under the same regulatory framework may display different levels of circularity.

Large industrial firms may be able to invest in specialized recovery equipment, environmental management teams, and supply-chain partnerships. Smaller firms may face more significant barriers related to capital, expertise, available space, or minimum economic scale. Circular economy policy therefore needs to recognize differences in organizational capacity rather than assuming that all industries can respond to regulation in the same way.

Management commitment is particularly important because resource recovery often requires cooperation across departments. Production teams may need to modify processes to maintain the quality of residual materials. Environmental staff may need to ensure regulatory compliance. Procurement units may need to accept secondary materials, while financial managers assess investment and operational costs.

Circularity therefore cannot remain solely the responsibility of waste-management personnel. It needs to become part of production strategy and organizational decision-making.

3.8 Institutional Coordination and the Problem of Fragmented Governance

Circular economy policies frequently cross traditional administrative boundaries. Waste regulation may be managed by environmental authorities, industrial development by another ministry or agency, resource efficiency through energy or industry policy, and recycling markets through economic or trade regulation. Fragmentation between these policy areas can create inconsistent signals for industries.

For example, environmental regulation may encourage waste reduction while procurement rules provide no preference for recycled materials. Industrial policy may promote new production capacity while waste infrastructure receives limited investment. Recycling targets may increase, but product or material standards may still discourage the use of secondary resources.

The literature reviewed by Losa (2025) illustrates the expanding range of policy instruments associated with circular economy transition. Their diversity creates opportunities for more comprehensive governance, but it also creates a coordination challenge. Circularity depends on whether instruments reinforce one another rather than operate as separate initiatives.

Institutional coordination is therefore required horizontally across government agencies and vertically between national and local authorities. It is also needed between public institutions and industrial actors because regulators may not always understand the technical characteristics of particular waste streams, while firms may not fully understand environmental or public-policy considerations.

Governance arrangements that encourage structured communication can help identify barriers before they prevent circular practices. Nevertheless, collaboration should not remove regulatory accountability. Government retains responsibility for establishing environmental safeguards and ensuring that economic interests do not undermine pollution prevention.

3.9 Main Barriers to Industrial Resource Recovery

The synthesis indicates that barriers to resource recovery can be grouped into several interconnected categories.

Table 1. Main Governance Factors Affecting Industrial Resource Recovery

Dimension	**Enabling conditions**	**Common barriers**	**Governance implication**
Regulation	Clear waste and secondary-material rules	Legal uncertainty and fragmented requirements	Establish predictable criteria for safe resource circulation
Technology	Reliable recovery and processing	High investment costs and technical	Support innovation and appropriate technology

	systems	limitations	adoption
Market	Stable demand for recovered materials	Low virgin-material prices and uncertain demand	Develop markets and purchasing incentives for secondary materials
Information	Reliable material-flow and quality data	Limited information and confidentiality concerns	Improve data systems, traceability, and exchange platforms
Infrastructure	Accessible collection, sorting, processing, and logistics	Inadequate recovery facilities	Align circular economy targets with infrastructure investment
Organization	Management commitment and technical competence	Limited knowledge, capital, or organizational support	Strengthen firm-level capacity and circular management practices
Collaboration	Trust and long-term relationships between firms	Coordination and transaction costs	Facilitate industrial symbiosis and intermediary institutions
Institutions	Coordinated policy and enforcement	Fragmented responsibilities	Improve cross-agency and public–private coordination

The table demonstrates why industrial resource recovery cannot be increased through a single intervention. Technology may exist, but weak demand can prevent investment. Strong markets may exist, but unclear regulation can restrict material movement. Regulations may promote recycling, but inadequate processing infrastructure can make compliance difficult.

The barriers are therefore cumulative. When several occur together, the likelihood that waste will return to productive use declines considerably. Circular economy governance needs to address these interconnected constraints rather than treating each one in isolation.

3.10 From Waste Governance to Resource Governance

The most important conceptual finding of this review is that circular economy transition requires a movement from waste governance toward resource governance. Waste governance generally concentrates on what happens after material becomes waste: collection, transportation, treatment, recovery, or disposal. Resource governance follows the material earlier and for longer, asking how it is extracted, used, retained, exchanged, recovered, and returned to production.

This does not mean that conventional waste regulation becomes unnecessary. Hazardous materials still require strict controls, and some residues will remain unsuitable for reuse. Instead, waste regulation becomes one component of a broader system that also includes resource efficiency, industrial innovation, market development, product standards, information systems, and inter-firm cooperation.

3.11 Implications for Circular Economy Policy

The findings suggest several directions for policy development. First, governments need clear regulatory criteria that distinguish waste requiring strict control from secondary resources that can circulate safely. Second, policy should prioritize waste prevention and resource efficiency rather than treating recycling volumes as the sole measure of circular progress. Third, resource recovery infrastructure needs to develop alongside regulatory targets. Industries cannot respond effectively to circular economy requirements where collection, sorting, processing, or secondary-material markets are absent.

Fourth, economic incentives should be aligned with environmental goals so that recovery becomes competitive without encouraging environmentally weak forms of recycling. Fifth, information systems should improve knowledge about material flows and potential industrial exchanges while maintaining traceability. Finally, policy should strengthen collaboration across industries and institutions without weakening public regulatory responsibility.

The review therefore indicates that circular economy governance works best as a policy mix rather than as a single regulation. Regulatory standards protect environmental quality; economic instruments influence commercial decisions; information systems make resource opportunities visible; infrastructure enables material movement; and organizational capability determines whether firms can respond.

Overall, the transition from industrial waste to resource recovery is not primarily limited by the absence of technical solutions. Technologies for recycling, reuse, and material recovery continue to improve, but their practical adoption depends on the wider governance environment. The central challenge is to create conditions in which avoiding waste, retaining material value, and using secondary resources become technically feasible, economically reasonable, and institutionally supported.

The literature therefore supports a circular economy model in which industrial waste is not automatically considered a resource, but neither is it automatically assumed to have reached the end of its useful life. Its future depends on material quality, environmental safety, technology, market conditions, regulation, and collaboration. Effective circular economy governance is the mechanism that brings these elements together and determines whether industrial residues ultimately return to productive use or continue toward disposal.

4. Conclusion

This review shows that the transition from industrial waste to resource recovery depends on more than the availability of recycling and recovery technologies. Circular economy governance requires a combination of clear regulation, institutional coordination, market development, information systems, corporate capability, and collaboration among industrial actors. Industrial residues can only become useful secondary resources when their technical quality, environmental safety, regulatory status, economic value, and potential users are considered together.

The findings also indicate that resource recovery should not replace waste prevention as the main objective of circular industrial policy. A more effective circular approach begins by reducing unnecessary material use and waste generation, followed by reuse, internal circulation, industrial symbiosis, recycling, and recovery of unavoidable residual materials. Disposal should remain the final option for materials that cannot be safely or economically returned to productive use.

Another important conclusion is that industrial waste governance needs to move toward broader resource governance. This requires policy instruments that do not focus solely on waste treatment and disposal but also support secondary-material markets, industrial symbiosis, traceability, infrastructure, technological innovation, and information exchange. Government regulation remains essential to protect

environmental interests, but regulatory measures are more effective when they are supported by economic incentives, clear institutional responsibilities, and cooperation with industry.

Overall, circular economy governance should create conditions in which resource recovery becomes technically feasible, environmentally responsible, economically attractive, and legally clear. Strengthening policy coherence and coordination across environmental, industrial, and economic institutions is therefore essential to reduce dependence on virgin materials and increase the productive use of industrial residues. Future research should examine how these governance arrangements perform across different industrial sectors and regional contexts, particularly where infrastructure, market development, and institutional capacity remain uneven.

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